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Evaluating variability in rhythmic gymnastics: Analysis of split leap using the gold standard motion analysis system

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ABSTRACT

Recent research suggests that variability enhances motor control, learning, and adaptation by improving the system's response to environmental demands. It also develops the cognitive and executive functions of athletes. The purpose of the study is to evaluate the variability of the split leap in rhythmic gymnastics, performed with and without ribbon handling, analysing in which of the two techniques there is greater variability. The sample consists of six competitive gymnasts with an average age of 15.1 years (± 0.94). The acquisitions were carried out with the BTS Bioengineering integrated multifactorial optoelectronic system, using fifteen passive markers, six BTS Smart-DX cameras, two cameras for video support and seven BTS-6000 force platforms. The results show that the coefficient of variation (CV%) in trials performed with ribbon is higher than those without the apparatus. Cohen's Effect Size revealed a small effect size between trials with ribbon and those without. Despite being minimal, this difference emphasizes the presence of variability in jumps executed with ribbon in comparison to free body trials. In conclusion, this study explored both intrinsic (CV%) and extrinsic (task complexity, technical experience) factors of jump performance, highlighting the utility of gold standard motion analysis systems for researching executive variability in rhythmic gymnastics jumps.

Keywords: Performance analysis, Motor control, Training, Gymnasts, Skill acquisition, Multifactorial optoelectronic system.

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INTRODUCTION

The human body produces variable patterns and movements (Gray, 2021). Movement variability has always been defined as noise to be reduced or eliminated because it is associated with technical errors during the execution of a motor task (Seifert et al., 2013; Stergiou et al., 2013; Kudo & Ohtsuki, 2008). Many coaches, in fact, think that variability is a noise that intervenes in athletes' learning of a motor skill, producing different rhythms and modifying performances (Liu et al., 2006). Recently, however, thanks to the studies conducted by James, Newell et al., variability has assumed positive acceptance as it could provide the movement system with good adaptability and flexibility (Newell & James, 2008; Riley & Turvey, 2002; Newell & Slifkin, 1998) to cope with the demands of the surrounding environment. Therefore, variability represents a functional aspect for improving motor control and, consequently, learning and adaptation (Barbado et al., 2012; Manor et al., 2010). Adding perturbations to the system, in fact, as Davids et al. (2004) suggest, is useful for making signals deriving from the environment more visible. Furthermore, variability plays an important role in performance as it provides the necessary fluctuations that allow individuals to refine and adapt acquired movement patterns (Davids et al., 2003; Newell, 1985).

Variability in sports practice also affects the development of the athlete's cognitive and executive functions. Innovation, diversity and engagement, belonging to the construct of variability, are essential to make learning experiences meaningful, as described in the ecological approach to learning motor skills (Pesce et al., 2016).

The quantity and complexity of the variability depend on the health status of the performer, the degree of learning and the conditions in which the acquisitions are made (Winter, 1983).

Furthermore, the skill to be performed and the environment in which it is performed are also considered factors that influence performance variability (Malcata & Hopkins, 2014).

Even in high-level athletes there are variable movements, although, apparently, they seem to repeat the same actions to obtain the same result (Bernstein, 1967). This happens because, during the execution of a movement, the internal and external conditions of the body are never identical to the previous ones. In this regard, we talk about 'variability conditioned by the context' (Fitch, 2014), according to which body movements are conditioned by changing internal and external factors. For this reason, you will never have exactly same movement results.

In the literature, variability is also related to the complexity of the tasks to be performed and to motor learning. In this regard, according to Gentile's Multidimensional Classification System (2000), the movement of the body in space, associated with the manipulation of objects, is considered a complex and variable condition. Therefore, one of the principles of motor learning that interacts with the variability of practice is the complexity of the activity to be performed (Kaipa, 2016). Inserting a task constraint, in fact, influences both the variability and complexity of the motor task (Nohelova et al., 2021). The complexity of the task to be performed also significantly affects the variance of the individual's learning rates (Nembhard & Osothsilp, 2002).

Below are presented several studies from the scientific literature that investigate the variability in relation to the complexity of the motor task and the athletes' level of mastery of the task. In particular, reference is made to situational sports such as rugby, football and Australian football.

In rugby, Pearce et al. (2020) conducted a study to examine the relationship between the evasive skills to be used in the match and the degree of motor development of athletes. This study demonstrated that the type of evasive skill and its variability depend on the athletes' level of motor development.

McLaren et al. (2016) and Kempton et al. (2014) examined the variability in low, high, and very high speed running performance of rugby athletes. By calculating the coefficient of variation (CV%), greater variability emerged in high intensity activity. Furthermore, the data shows that the position of the players on the pitch influences the variability in their performances. Therefore, part of the inter- and intra-subject variability can be explained by the characteristics of the players and the tactical roles they play.

These results are also found in football and Australian football. In fact, in the study by Trewin et al. (2018), which examined the degree of variation in the run of 45 female players, and in the study of Kempton et al. (2015) found that CV% was lower in low-intensity activities and higher in sprints and during high-intensity activities. Therefore, the variability of movements increases as the speed of actions is increased.

Furthermore, as in the McLaren et al. (2016) study carried out with rugby players, these researches also show that the variation in speed was due to the role played by the athletes in the match.

Even the study conducted by Liu et al. (2016) explored the match-to-match variation of footballers by calculating CV% at different points in matches. The data revealed a difference in technical performance between the players of the stronger and less strong teams and that the variation in performance is influenced by the game context and the opponents. In line with the studies in the literature, these results underline how the variability in performance depends on the level of mastery of the movement by the athlete.

Other studies on variability have been carried out in artistic gymnastics. In particular, the research by Busquets et al. (2016) has highlighted how the inter-trial variability in bar swings, observed in young and novice gymnasts, was higher than the variability recorded in the same tests carried out by older and more experienced athletes. Therefore, also in this study the relationship between variability, gesture complexity and motor learning are underlined.

Bradshaw et al. (2010) evaluated the validity and reliability of inter-daily training of vaulting exercises using infrared timing systems and a contact mat. Through CV% the variability was measured during the run-up and at the time of contact with the board. For some technical elements performed, the contact times with the carpets showed high variability. This could be due to the touch of the board at different points before the flight, the return of energy generated by the take-off on the board and the flight path of the athletes. Variability, therefore, has a fundamental role in performance because it allows the expert gymnast to perform multiple attempts of the same skill but with different performance patterns especially in terms of muscle coordination, joint coupling and movement kinematics (Latash et al., 2002).

The present study examines the split leap in rhythmic gymnastics. This sport is characterized by elegance, fluidity, harmony, strength and dynamism, which are expressed in particular in jumps performance (Coppola et al., 2024).

Split leap is body difficulty (BD) that, as described in the 2022-2024 Code of Points (CoP), has a value of 0.30 points and involves a split in flight bringing the dominant leg forward and the non-dominant leg backwards, reaching an amplitude of at least 180°. This jump requires great qualities of speed, explosive strength, body control and coordination (Aparo et al., 1999).

The jump involves three fundamental phases: the run-up, the flight phase and the landing. The run-up can be carried out with a run or with the chassè step (Coppola et al., 2020). During the flight phase, the shape of the BD must be fixed and well defined and the elevation must allow the desired figure to be achieved (Di

Cagno et al., 2008). The landing phase is very important because, as underlined in the study conducted by Błażkiewicz et al. (2019), the hip and knee joints are the most vulnerable to injuries. Variability, in fact, is also useful in the prevention of injuries (Bartlett et al., 2007) because it allows to distribute on several joints the high and protracted forces over time (Nordin & Dufek, 2019). Reduced variability can lead to increased mechanical stress on the anatomical structures involved in the motor task, representing a predisposing factor to injuries (Barrett et al., 2008). Moreover, in the absence of adequate movement variability, adaptation is not promoted and, consequently, the continuous application of the load can lead to injury to the joints and tissues involved (James, 2004).

In scientific literature, variability research uses technologies such as GPS, triaxial accelerometers, gyroscopes, magnetometers, infrared timing systems and contact mats. However, there are no studies that deal with the variability of technical gestures in rhythmic gymnastics with the use of the integrated multifactorial optoelectronic system, considered the gold standard for motion analysis. In this regard, the study by Coppola et al. (2023) investigated the effectiveness of the integrated multifactorial optoelectronic system to analyse the dynamic and kinematic parameters of complex motor tasks such as the split leap performed with and without the ribbon.

Other studies on rhythmic gymnastics concern the kinematic parameters of the run-up phase of the jump performed with the simple run and the chassè step (Coppola et al., 2020); the take-off with one and two-feet (Polat, 2018) and with the glissade-step technique (Akkari-Ghazouani et al., 2022); the relationship between body composition, flexibility and explosive strength of the lower limbs in jumping performance (Aji-Putra et al. 2021) and the dynamic and kinematic parameters of jumps performed with and without apparatus (Mkaouer et al., 2012).

The aim of this study is to evaluate the executive variability (CV%) in the horizontal split of the split leap performed with and without ribbon, analysing in which of the two techniques there is greater variability. It is assumed that the trials performed with the ribbon have a greater variability due to the inclusion of the handling of the tool during the jump which makes the motor task more complex.

MATERIAL AND METHODS

Participants

Six top level gymnasts aged between 13 and 16 took part in this study. The average age is 15.1 years (± 0.94). The gymnasts were randomly selected from a group of top-level (N = 30) gymnasts who competed for at least two years.

The athletes compete in Gold and Silver competitions organized by the Italian Gymnastics Federation (FGI). Five out of six female athletes train three hours a day for five days a week, while one gymnast trains three times a week for two hours. Three gymnasts have more technical experience in handling the ribbon.

The gymnasts' parents signed an informed consent form, authorizing their participation in the study.

Instruments

The BTS Bioengineering integrated multifactorial optoelectronic system was used, which represents the gold standard for the motion analysis, consisting of six BTS Smart-DX cameras, three of which are placed anteriorly and three posteriorly to the acquisition volume; two cameras for video support; seven BTS-6000 force platforms and fifteen passive markers.

Survey

A survey was given to the athletes regarding the years of sporting experience, the hours and days of weekly training, the level of experience in using the ribbon in training and competition and based on previous experience, their considerations on the execution of the split leap with and without a ribbon and with the chosen handling (serpentine above and behind the head).

Procedures

The study was conducted at the Laboratory for innovative teaching methodologies and analysis of sports performance of the University of Salerno. The acquisitions were conducted within a week. A pilot investigation was carried out to verify the correct administration of the movement analysis protocol. This investigation was conducted in the same laboratory and with the same technologies and on a sample similar to that of the study.

Initially, the system was calibrated through the Axes, Platform and Wand sequences.

Subsequently, the following anthropometric measurements of the athletes were taken: the body weight; the height; the length of the legs, measuring the distance between the anterior superior iliac spine and the medial malleolus; the width of the pelvis with a pelvimeter, measuring the distance between the anterior superior iliac spines; the height of the pelvis, taking the measurement perpendicular to a ruler placed parallel to the table passing through the greater trochanter and the anterior superior iliac spine; the diameter of the knees, measuring the distance between the femoral condyles of the knee and the diameter of the ankles, measuring the distance between the medial and lateral malleoli (Vastola, 2018).

All the gymnasts carried out standardized neuromuscular activation with warm-up and joint mobility exercises of the lower limbs and the muscles involved in the realization of the motor task.

Then, fifteen passive markers were applied on the landmarks of the athletes' body following the Helen Hayes protocol. In particular, the markers were positioned on the sacrum, on the anterior-superior iliac spines, on the lateral epicondyles, on the lateral malleoli, on the heels and on the second metatarsal heads. In addition, four bars covered with a marker were used, two of which were positioned on the thighs in alignment with the greater trochanter of the femur and the markers on the epicondyles and two on the legs aligned with the markers on the epicondyles and those on the lateral malleoli (Kadaba et al., 1990).

The split leap, being a very fast motor task, resulted in high muscle vibrations. Consequently, it was necessary to pay attention to the positioning of the markers on the anatomical landmarks and, in some cases, it was useful to further block the markers by applying adhesive tape around them.

To identify the position of the markers with respect to the biomechanical model, static acquisitions were carried out in which the athletes were in orthostasis on the force platforms. The next step was the dynamic acquisition of the motor task. The athletes performed five trials of the free body split leap and then five trials of the same jump with the ribbon. The handling of the tool consisted of coils above and behind the head.

Analysis

The data were processed and analysed using SMARTtracker and SMARTanalyser software. Specifically, SMARTtracker was employed to track the jump trials, assigning names to each marker based on the reference biomechanical model (Helen Hayes protocol) and to identify the ground reaction force (GRF).

Instead, with the SMARTanalyser software, the split amplitude event ($^{\circ}$) was identified at the instant in which the two limbs were parallel to the ground.

A qualitative analysis was first carried out, viewing videos of the jumps and selecting the best performances based on the correct execution of the leap's technical movement.

Subsequently, with quantitative analysis, the coefficient of variation (CV%) for the maximum horizontal split was calculated in both free body and ribbon jumps. A statistical analysis of Cohen's Effect Size and a hypothesis test were carried out with MATLAB software. The normality of the distribution of the data of free body and ribbon trials was verified using the Shapiro-Wilk test. Subsequently, the t-test for independent samples was useful to verify whether the difference in the mean values of the tests with and without ribbon was statistically significant.

RESULTS

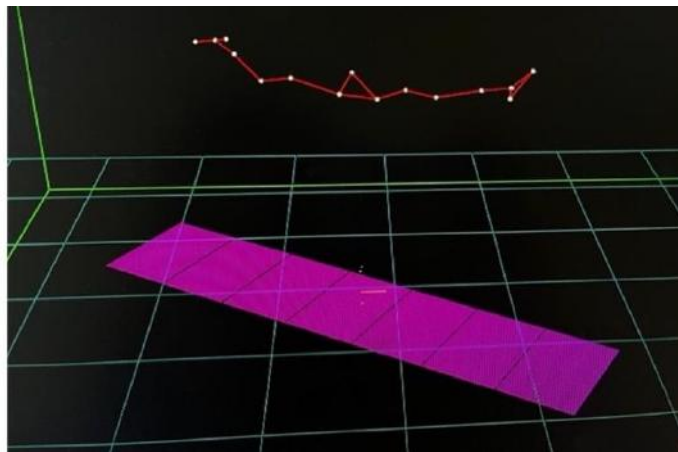


Figure 1. Representation of split leap with the SMARTtracker software.

Table 1. CV% of the horizontal split with and without ribbon.

CV of the horizontal split (%) without ribbon	0.521 ± 0.26
CV of the horizontal split (%) with ribbon	0.591 ± 0.25

Table 1 shows the coefficients of variation (CV%) of the horizontal split of the split leap (shown in Figure 1) performed with and without ribbon. In particular, the CV of the horizontal split without ribbon is 0.521 ± 0.26 , while the CV of the split with ribbon is 0.591 ± 0.25 .

Table 2. p -Value of the Shapiro-Wilk test.

p -value of Shapiro-Wilk test without ribbon	.842
p -value of Shapiro-Wilk test with ribbon	.167

Table 2 shows the p -values of the Shapiro-Wilk test. Regarding the trials carried out without ribbon, the p -value is .842, while the p -value of the trials with ribbon is .167.

The Cohen's Effect Size result is 0.3. Therefore, according to McGuigan's (2017) guidelines, the effect size is small.

The p -value of the t-test for independent samples is .674.

Table 3. CV% of horizontal split with ribbon for each gymnast.

	CV% of horizontal split with ribbon
Expert gymnasts in handling ribbon	
Gymnast 1	0.2
Gymnast 2	0.378
Gymnast 3	0.395
Less expert gymnasts in handling ribbon	
Gymnast 4	0.79
Gymnast 5	0.81
Gymnast 6	0.9

Table 3 shows, for expert and less expert gymnasts in handling the ribbon, the coefficients of variation (CV%) of the horizontal split of the split leap performed with the ribbon.

DISCUSSION

From the results obtained using the Shapiro-Wilk test, which verifies the normality of the data distribution, it emerges that both p -values (.842 for the trials without ribbon and .167 for those with ribbon) are greater than .05, therefore, the data were normally distributed. Subsequently, the t-test for independent samples was carried out to compare the jump trials data with and without apparatus. The result shows a p -value (.674) greater than .05, indicating no statistically significant evidence of a meaningful difference in the mean values of the jumps performed free body and with ribbon. This is probably due to the small sample size of the study which does not allow to draw conclusions representative of the entire population of gymnasts.

Significant findings relate to the coefficients of variation (CV%) and the value of Cohen's Effect Size. As regards the CV, it is higher in the jumping trials performed with ribbon (0.591 ± 0.25) compared to the free body ones (0.521 ± 0.26). Therefore, these results show how the introduction of a task constraint (handling the ribbon during the execution of the jump) influences the execution of the motor task, making it more complex and, consequently, also more variable (Nohelova et al., 2021; Kaipa, 2016; Gentile, 2000).

Furthermore, Cohen's Effect Size also shows a difference, although minimal, between the jump trials performed free body and with ribbon. In fact, although the size of the effect relating to the use of the apparatus (0.3) is small (McGuigan 2017), it indicates the presence of a difference between the two values. This reflects the starting hypothesis, i.e. that the jumps performed with the ribbon have greater variability due to the complexity of the motor task (split leap with the addition of handling the apparatus). These results are in line with the studies in scientific literature regarding the variability and complexity of the task (Nohelova et al., 2021; Kaipa, 2016; Nembhard & Osothsilp, 2002; Gentile, 2000).

A further finding of interest emerged from the comparison of the CV% of the horizontal split between the more and less experienced gymnasts using a ribbon. As shown in Table 3, a lower CV% was detected in the more experienced gymnasts compared to the less experienced counterparts (0.2, 0.378, 0.395 vs 0.79, 0.81, 0.9).

These results are fully consistent with other studies conducted in scientific literature on motor tasks of other sports activities that have investigated performance levels in relation to the variability, complexity of the task

and the experience of the athletes (Pearce et al., 2020; Trewin et al., 2018; Busquets et al., 2016; Liu et al., 2016; McLaren et al., 2016; Kempton et al., 2015; Kempton et al., 2014; Bradshaw et al., 2010).

CONCLUSIONS

Given the absence of specific studies on variability in rhythmic gymnastics, particularly concerning the split leap with and without apparatus, a direct comparison of data was not possible.

The integrated multifactorial optoelectronic system, considered the gold standard for motion analysis, has proved to be an effective technology for evaluating aspects relating to the variability of a motor task with high complexity and executive speed such as the split leap, with the addition of handling five meters ribbon. This system allowed to obtain more accurate and detailed quantitative results compared to traditional systems, such as GPS, triaxial accelerometers, gyroscopes and magnetometers, used in other research conducted in this field of study. The use of this technology enabled a comprehensive analysis, combining quantitative (integrated multifactorial optoelectronic system) and qualitative (video analysis) methods, obtaining consistent results on a qualitative-quantitative level.

In conclusion, although the results obtained are not representative of the population of gymnasts, due to the limited sample size, this study allowed to investigate simultaneously intrinsic (CV%) and extrinsic aspects (task complexity and technical experience) of sports performance of a jump in rhythmic gymnastics.

Finally, this study opens a reflection on the potential in the use of gold standard system for the motion analysis for research on executive variability in the jumping tasks in rhythmic gymnastics.

AUTHOR CONTRIBUTIONS

The article is the result of a collaborative work by all the authors. SC, CC and DA contributed to the preparation and research design, data collection, data analysis, result, interpretation, manuscript writing, supervision of the study, and review of the final version. RV is the scientific coordinator of the study. All authors have read and agreed to the final version of the manuscript and consent to its publication in JHSE.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

ETHICAL APPROVAL

These trials are conducted in accordance with ethical principles of the Declaration of Helsinki. Declaration of Helsinki Ethical Principles for Medical Research involving human subjects (WMA, 2013).

CONSENT TO PARTICIPATE

The gymnasts' parents signed an informed consent form, authorizing their participation in the study.

DATA AVAILABILITY STATEMENT

Data available on request.

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Perception of interpersonal relationships between students and sports coaches in Piura, Peru

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ABSTRACT

Background: In Peru, current laws require universities to integrate complementary sports services in order to obtain institutional licensing. However, the scarcity of information makes it difficult to understand behaviour among athletes and coaches. The objective of the study is to analyse the interpersonal behaviour between athletes and coaches at the Universidad Nacional de Frontera, Sullana, Peru, 2023. The study was a non-experimental, descriptive study based on a quantitative approach. A total of 85 athletes involved in one of the sports disciplines offered by the university participated. The valid and reliable Interpersonal Behaviour Perceptions (IBQ) scale (Cronbach's alpha = 0.913) was applied. The results reveal that football (31.8%), volleyball (30.6%) and basketball (18.8%) are the most practiced disciplines and are related to the gender of the participants ($p < .016$), whose ages range from 18 to 23 years. In addition, athletes value the support of coaches in decision-making but show neutrality in perceived empowerment. There is resistance towards pressure and discrepancies in emotional support and comfort from the coach. In conclusion, positive interpersonal behaviour is observed between athletes and coaches at the Universidad Nacional de Frontera, Sullana, Peru.

Keywords: Physical education, Interpersonal relations, Technician sporty, College athletes, Behaviour, Sports competition, IBQ.

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INTRODUCTION

Interpersonal relationships refer to the social and emotional interactions between individuals in a given environment and are guided by rules of social exchange that dictate how individuals are expected to treat each other (Rosso et al., 2010). Therefore, social relationships are fundamental; however, despite a growing interest in sport psychology on interpersonal coping, a lack of conceptual clarity and divergence in terminology hinder its progress (Eckardt & Tamminen, 2023).

On the other hand, Laios (2005) in his study highlights that ineffective communication is one of the main causes of conflict in professional and institutional sports. Since it affects the coach-athlete relationship (Pitney et al., 2023). Choi et al., (2020), likewise, inappropriate treatment by a coach could impede the development of athletes' athletic performance and psychological well-being.

However, this situation is aggravated by the lack of respect, which manifests itself between the coach-athlete pair through contempt, unfair criticism and unequal treatment (Cerrada & Gime, 2021). In terms of (House, 2022) conflicts of interest, such as the prioritization of outcomes over athletes' well-being, can generate tensions, as well as differences in vision and approach. Likewise, a lack of emotional support from the coach, especially during difficult times, can lead to a strained relationship (Aguinaga et al., 2023).

According to the National Survey of Social Relations (ENARES) published by the Instituto Nacional de Estadística e Informática- INEI (2020) in Peru both males and females between 12 and 17 years of age were victims of physical and psychological violence in 78.0%. These events took place at home and at school. Therefore, young people in these conditions who qualify as athletes in universities will have a suboptimal performance because they carry psychological problems from an early age. In terms of Rosalie & Vilca (2023) it is essential to generate plans and policies aligned with encouraging good efficient interpersonal relationships.

In that context, further research is required to better understand the problem of interpersonal relationships (Trolio et al., 2021). Simons & Bird, (2023), examined the theory of "*Inversion*" and concluded that it has the potential to provide a comprehensive framework for understanding interpersonal relationships in sport. According to Putranto (2023) good communication is fundamental to the quality of interactions between coach and athlete. However, there is still a lack of information, which makes it difficult to understand the behaviour between athletes and coaches.

Therefore, we consider that the present study is relevant because localized data can have a significant impact on decision-making based on localized gaps between interpersonal relationships between athletes and sports coaches. In terms of Pulido et al. (2022) these types of studies predict the style of support in the face of the needs of coaches and athletes. On the other hand, Cronin et al. (2022) asserts that the results of this type of analysis promote the development of vital skills in sport. Bissett et al. (2020) based on the results, coaches and athletes can be trained to optimize sports performance.

In short, the assessment of interpersonal relationships can help detect potential problems or conflicts before they escalate, and coaches have a key influence on the transmission of values and ethics to students. A positive relationship with the coach can increase students' sense of safety and security, which is especially crucial in youth sport, where the safety and well-being of participants are of utmost importance.

It is important to assess interpersonal relationships between coaches and athletes to detect problems or conflicts before they escalate, because coaches have a key influence in transmitting values and ethics to athletes. A positive relationship with the coach can increase the athletes' sense of security, which is crucial in youth sports to deal with stress, competitive pressure and other emotional challenges.

Therefore, the objective of this study was to identify the sports preferences of athletes according to age and gender, as well as to describe and relate the interpersonal behaviour of coaches and athletes at the Universidad Nacional de Frontera, Sullana, Peru.

METHODS

The study was descriptive and of non-experimental design.

Participants: The population consisted of 85 qualified student athletes belonging to various sports disciplines at the University. All of them resided in the Piura region and came from different academic cycles and professional careers of the 3 faculties of the University (Business Sciences and Tourism, Economic and Environmental Sciences, and Engineering in Food Industries and Biotechnology).

Measures: The Interpersonal Behaviour Questionnaire (IBQ) reported in a previous study Rocchi et al. (2017), was adapted to Spanish for use in this population. The questionnaire was valid and reliable (Cronbach's alpha = 0.913). The questionnaire scale was Likert, with the lowest score being 1 "Strongly Disagree" and the highest score being 5 "Strongly Agree". The questionnaire was adapted from a study.

Procedures: The study was conducted at the Universidad Nacional de Frontera, Peru for 9 months (March to November 2023). The investigators gave the athletes the questionnaire to voluntarily complete and to evaluate the informed consent of the study. Once the questionnaires were completed, the data were processed for analysis (Myers et al., 2022).

Analysis: A descriptive analysis of the variable was carried out and Spearman's correlation test was performed to analyse the relationship of the variable, for which Microsoft Excel 2019 spreadsheets and SPSS v27 software were used.

RESULTS

Out of a population of 85 athletes qualified in different sports disciplines of the National University of Frontera, the results indicate that the disciplines that practice the most are soccer (31.8%), volleyball (30.6%) and basketball (18.8%).

Table 1. Athletes by type of sport they practice.

	Sport	N	%
Sporting activity	Football	27	31.8
	Volleyball	26	30.6
	Karate	13	15.3
	Basketball	16	18.8
	Athletics	3	3.5
Total		85	100%

Table 2 shows that women show a more significant participation in volleyball (22.4%), football (16.5%) and football (12.9%). On the other hand, the male gender exhibits higher percentages in football (15.3%), basketball (12.9%) and volleyball (8.2%). In summary, it is observed that a higher proportion of women prefer volleyball and men prefer soccer, indicating a significant association between the gender of the participants ($p < .04$).

Table 2. Athletes by gender according to the type of sport they practice.

Gender	Type of sport you play in college						p-value
	Athletics	Basketball	Football	Karate	Volleyball	Total	
Female	1 (1.2%)	5 (5.9%)	14 (16.5%)	11 (12.9%)	19 (22.4%)	50 (58.8%)	.016
Male	2 (2.4%)	11(12.9%)	13(15.3%)	2(2.4%)	7(8.2%)	35 (41.2%)	
Total	3 (3.5%)	16 (18.8%)	27 (31.8%)	13 (15.3%)	26 (30.6%)	85 (100.0%)	

Table 3 provides information on sports preferences according to the age of the athletes. It should be noted that, between 18 and 19 years of age, the most practiced sport is soccer (17.6%), followed by volleyball (14.1%). In the 20-21 age group, soccer leads with 9.4%, followed by karate and volleyball, both with 5.9%. In the 22-23 age group, volleyball leads with 3.5%, followed by karate with 2.4%. From 23 years of age onwards, volleyball is the most practiced sport with 4.7%, followed by basketball. This shows that there is a constant tendency at all ages towards soccer as the most practiced sport, followed by volleyball compared to other sports disciplines.

Table 3. Sports preferences practiced by qualified university students.

Age	Athletics	Basketball	Football	Karate	Volleyball	Total	p-value
18-19 years	2 (2.4%)	6 (7.1%)	15 (17.6%)	3 (3.5%)	12 (14.1%)	38 (44.7%)	.603
20-21 years	1 (1.2%)	6 (7.1%)	8 (9.4%)	5 (5.9%)	5(5.9%)	25 (29.4%)	
22-23 years	0 (0.0%)	0 (0.0%)	1(1.2%)	2 (2.4%)	3 (3.5%)	6 (7.1%)	
23 years and over	0 (0.0%)	4 (4.7%)	3 (3.5%)	3 (3.5%)	6 (7.1%)	16(18.8%)	
Total	3 (3.5%)	16 (18.8%)	27 (31.8%)	13(15.3%)	26(30.6%)	85(100.0%)	

Regarding the interpersonal behaviour of the coaches from the perspective of the athletes, the following was evidenced:

A mean of 4.00 of athletes, agree with the statement "*coaches support the decisions I make by myself*" this means that coaches trust in the athletes' ability to make decisions and take responsibility for their own performance, tactics and competition strategies. A mean of 3.27 of the athletes consider that the coach encourages them to make their own decisions, i.e., they have a neutral position regarding the empowerment they receive to make their own decisions. Likewise, they have a neutral position regarding the support of the coach towards the decisions made by the athletes (mean of 3.06) and the freedom given by the coach to make their own decisions (3.00), respectively.

Likewise, the majority of athletes consider that they do not agree to receive pressure from the coach to do things their way (mean 1.87), the coach imposes his/her opinions (mean 1.81), pressures them to adopt certain behaviours (mean 1.76) or limits the athletes' choices (mean 1.54).

Regarding coaches' support of athletes' competencies, respondents showed a neutral position regarding their coaches' motivation to improve their skills (mean 3.09), providing valuable feedback to athletes (mean

3.15), recognizing athletes' ability to achieve their goals (mean 3.10), telling athletes that they can achieve things (mean 3.15).

Regarding reinforcement of athletes' competence, respondents strongly disagreed with the statement that the coach tells them they will probably fail (mean 1.19), sends them messages saying they are incompetent (mean 1.12), doubts athletes' ability to improve (mean 1.25) and doubts athletes' ability to overcome challenges (mean 1.45).

Regarding the relationship and support of coaches, athletes have a neutral position to the interest their coach has in what they do (mean 3.12), disagree with the statement "*the coach takes the time to get to know me*" (mean 2.88), "*the coach sincerely enjoys spending time with me*" (mean 2.72) and "*relates to me*" (mean 2.85).

In relation to frustration, they strongly disagree with the statement "*the coach does not comfort me when I feel bad*" (mean 1.52) among other aspects evidenced in Table 4.

Table 4. Application of the Interpersonal Behavioural Questionnaire (IBQ) in sport.

"My coach..."	Medium	SD
Autonomy-supportive (AS)		
Gives me the freedom to make my own choices.	3.00	0.83
Supports my decisions	3.06	0.69
Supports the choices that I make for myself	4.00	0.83
Encourages me to make my own decisions	3.27	0.71
Autonomy-thwarting (AT)		
Pressures me to do things their way.	1.87	1.24
Imposes their opinions on me.	1.81	1.21
Pressures me to adopt certain behaviours.	1.76	1.28
Limits my choices.	1.54	1.22
Competence-supportive (CS)		
Encourages me to improve my skills	3.09	0.78
Provides valuable feedback	3.15	0.84
Acknowledges my ability to achieve my goals	3.11	0.74
Tells me that I can accomplish things.	3.15	0.81
Competence-thwarting (CT)		
Points out that I will likely fail	1.19	1.26
Sends me the message that I am incompetent.	1.13	1.29
Doubts my capacity to improve.	1.26	1.29
Questions my ability to overcome challenges.	1.46	1.38
Relatedness-supportive (RS)		
Is interested in what I do.	3.13	0.75
Takes the time to get to know me	2.88	0.89
Honestly enjoy spending time with me	2.72	0.91
Relates to me.	2.86	0.80
Relatedness-thwarting (RT)		
Does not comfort me when I am feeling low.	1.53	1.28
Is distant when we spend time together.	1.54	1.27
Does not connect with me	1.59	1.28
Does not care about me.	1.42	1.2

Regarding the 6 dimensions of interpersonal behaviour of coaches in sport there is a positive and significant relationship ($Rho = 0.747^{**}$) between autonomy-thwarting and autonomy support, i.e., the greater the autonomy-thwarting the greater the autonomy support, this allows taking concrete actions to strengthen the autonomy of athletes, coaches are providing a type of support that helps athletes feel empowered and responsible for their own sport development. In addition, there is evidence of a positive and significant relationship between competence-supportive and autonomy support ($Rho = 0.729^{**}$), which are fundamental to cultivate an environment that fosters growth, excellence and well-being of athletes. It was also evidenced that the greater the competence-supportive, the greater the autonomy-thwarting ($Rho = 0.673^{**}$), this contributes to the development of more resilient athletes, capable of facing challenges and difficulties with determination and self-direction. Both aspects are fundamental for growth and long-term success in sport.

It was observed that the less autonomy support there is less competence-thwarting ($Rho = -0.088^{**}$), this is explained when athletes experience less autonomy support, that is, when they have less freedom to make decisions and less control over their own sport development, they may become more dependent on external direction, such as that of coaches or team expectations. In addition, if athletes feel they have no control over their training, tactics or personal goals, they are less likely to experience the satisfaction and commitment associated with intrinsic motivation. Furthermore, the results show that lower autonomy-thwarting results in lower competence-thwarting ($Rho = -0.095$), which can lead to a lack of alignment between coaches' training methods and athletes' individual needs, which in turn can negatively affect their development and competence in their sport discipline. When autonomy is reduced, opportunities for athletes to experiment, make mistakes and learn from their errors are also reduced. The relationship of the other dimensions is evident in Table 5.

Table 5. Correlation of the dimensions of interpersonal behaviour of coaches in sport.

	AS	AT	CS	CT	RS	RT
Autonomy Support (AS)	1					
Autonomy-thwarting (AT)	.747**	1				
Competence-supportive (CS)	.729**	.673**	1			
Competence-thwarting (CT)	-.088	-.095	.114	1		
Relatedness-supportive (RS)	-.305**	-.411**	-.080	.757**	1	
Relatedness-thwarting (RT)	-.336**	-.352**	-.182	.716**	.867**	1

Note: ** indicates a highly significant correlation at 1%.

DISCUSSION

The results of the study indicate a positive dynamic between athletes and coaches at the Universidad Nacional de Frontera, Sullana, Peru, as well as a high degree of interest on the part of the coaches in sports activities. This finding coincides with previous research that highlights the importance of the coach-athlete relationship for the development and performance in sport. Specifically, it supports the significant influence of the coach's leadership behaviours on the emotional experience of athletes during competition, as pointed out by González-García et al. (2021), Furthermore, it agrees with the relevance of effective coach-athlete communication, highlighted by (Davis et al., 2019), where the interest shown by coaches towards athletes' activities can be interpreted as an indicator of open and responsive communication. Finally, the results agree with the findings of Kim and Park (2020), who emphasize the importance of trust, friendship and constructive communication in the coach-athlete relationship, suggesting that the high level of interest shown by coaches can foster a positive work environment and facilitate both individual and collective development.

The data also reveal that the sports disciplines most commonly practiced by qualified college athletes are soccer (31.8%), volleyball (30.6%) and basketball (18.8%). However, the results of Paul et al. (2023), show a lower preference for soccer (6.9%), women's volleyball (3.5%) and baseball (3.5%), among other activities. On the other hand, Moreno-Quispe et al. (2020), found that 30% of the participants showed a preference for mountaineering, followed by 18.5% who preferred volleyball and 16.5% who opted for soccer. In an additional study, it was observed that during COVID-19 confinement, athletes presented a high level of physical activity, especially women from rural areas compared to urban areas Moreno-Quispe et al. (2021), results that differ slightly from ours. According to Tan et al. (2023), these discrepancies could be attributed mainly to individual differences in tastes and preferences.

When evaluating athletes' preferences according to gender in various sports activities, the data show that in greater proportion 27 (31.8%) of males prefer soccer and 26 (30.6%) of females prefer volleyball. These results compare with those of Paul et al. (2023), whose findings favour male athletes in most sports, including mixed sports. Possible reasons for this inequality in evaluation may be due to financial and promotional incentives, sex biases, and others. On the other hand Nuzzo (2023), points out that these differences occur because men are more motivated by challenge, competition and social recognition. Women have fewer competitive events and are more motivated by greater attractiveness, muscle "toning". Dakic et al. (2023), for women face unique challenges to participate.

Finally, it was found that in the ages evaluated (18-19 years, 20-21 years, 22-23 years and 23 and over), soccer is the most practiced sport, followed by volleyball in terms of proportion. These data compare with the results found by Hernández-Beltrán et al. (2024), who point out that in addition to tastes and preferences, the levels of physical condition of university athletes also play a role. On the other hand Lourenço et al. (2022), autonomous and psychological motivation also play an important role.

Despite these findings, our study has limitations because it focused exclusively on athletes from one university and residents of a single region. In addition, the information did not include details on the socioeconomic conditions of the participants, nor did it inquire about emotional aspects and health status.

CONCLUSIONS

The data show that interpersonal behaviour is positive between athletes and coaches of the Universidad Nacional de Frontera, Sullana, Peru, 2023. Soccer, volleyball and basketball are the most practiced sports among athletes at the Universidad Nacional de Frontera. There is a differentiated preference for sports between genders. Women show a stronger inclination towards volleyball, while men have a stronger affinity for soccer.

AUTHOR CONTRIBUTIONS

JWCC and LAMQ participated in project conceptualization, methodology, data curation and analysis, research, visualization, and writing of the manuscript. GFVA participated in data analysis, research, visualization, and writing of the manuscript. All authors approved the final version of the manuscript for publication.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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Effect of 10-week Isometric handgrip exercise at home on hemodynamic and psychological factors of sedentary hypertensive women during COVID-19: A randomized controlled trial

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ABSTRACT

Background and Objective: COVID-19 poses significant public health threats and impacts physical activity, particularly in hypertensive patients. The aim of this study is to examine the ten weeks of isometric handgrip exercise impact on hypertensive women during quarantine. **Methods:** thirty female volunteers with high blood pressure participated in this randomized controlled trial study. The isometric handgrip (IHG) exercise group performed the exercise for ten weeks (3 sessions per week, 4x2 min isometric contractions at 30% MVC, separated by 2 minutes rest) via video call at home, and the control group had no exercise program. The blood pressure (systolic, diastolic, and mean), heart rate, and myocardial oxygen consumption were measured before and after exercise program; DASS21 and quality of life (Sf-36) questionnaires were then completed by the participants. **Results:** Systolic, diastolic, and mean blood pressure showed a significant decrease (5 mmHg, 2 mmHg, respectively); quality of life and DASS21 scores showed a significant improvement after IHG exercise compared to the control ($p < .05$). **Conclusion:** IHG exercise activity at home is highly effective and useful for improving blood pressure and quality of life of hypertensive women, and it is also a treatment option to reduce stress, depression and anxiety due to COVID-19.

Keywords: Sport medicine, Blood pressure, Quality of life, Anxiety, Depression, Stress.

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INTRODUCTION

The current pandemic due to COVID-19, which is caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), appeared for the first time in late December 2019 in Wuhan, China; it has been currently described as the worst public health crisis in the world (Wang, Horby, Hayden, & Gao, 2020). Social distancing and home quarantine became mandatory to deal with the spread of COVID-19 because this virus has a high potential of infectivity, as well as death rate and prevalence (Organization, 2020). Many countries resorted to distance working, as well as closing schools, universities, sports halls, and public parks, and billions of people around the world were socially isolated by such measures (Rogers et al., 2020). These factors, namely obligatory restrictions during the COVID-19 pandemic, have created unique structural barriers to maintaining a physically active lifestyle, which on the one hand increased the prevalence of several chronic and underlying diseases, including Cardiovascular Diseases (CVD) and hypertension (Stockwell et al., 2021), and on the other hand, decreased the quality of life of patients and led to an increase in mental health disorders, depression and anxiety (De Sousa et al., 2021).

In this regard, recent epidemiological surveys reported that elderly people followed by those with underlying diseases, such as blood pressure, diabetes, and cardiovascular disorders are the most vulnerable this regard (Ma, Song, & Huang, 2021). These persons are more susceptible to COVID-19 so approximately 50% of them who were admitted to the hospital due to COVID-19 were afflicted with at least one underlying disease. In older persons and those with underlying diseases, the mortality rate is much higher than other patients (Wang et al., 2020).

Studies also showed that 24% of patients diagnosed with the severe spectrum of COVID-19 had hypertension as the underlying disease (Nasrollahzadeh Sabet et al., 2020; Schiffrin, Flack, Ito, Muntner, & Webb, 2020). This high rate has been attributed to the fact that SARS-CoV-2 binds and enters cells through angiotensin-converting enzyme 2 receptor (ACE2), which is abundantly found in alveolar cells, cardiac myocytes and vascular endothelial cells. Considering the high binding affinity of COVID-19 to ACE2, a large number of viruses infect these cells. The interaction of SARS-CoV-2 with ACE2 in endothelial cells raises the possibility that endothelial dysfunction, which commonly occurs in hypertension, is exacerbated through the effect of the virus. In other respect, COVID-19 also leads to cardiovascular complications by causing thrombosis in arteries and veins. Inflammation, activation of platelets, dysfunction and blockage of blood vessel are responsible for thrombosis in COVID-19. In fact, COVID-19 poses a serious risk to patients with high blood pressure (Nadar, Tayebjee, Stowasser, & Byrd, 2020; South, Diz, & Chappell, 2020).

Moreover, the emergence of COVID-19 and its resulting stress-anxiety are related to pathophysiology of hypertension, in such a way that the high sensitivity of sympathetic nervous system (SNS) increases the heart rate and blood pressure, which can escalate the severity of disease by compromising the immune system (Pfefferbaum & North, 2020). Hypertension by itself is a major challenge for the global health system and a main mortality factor of nearly 7,000,000 people in the world, the prevalence of which will increase by 60% by 2025. For prevention, control and non-drug treatment of high blood pressure, exercise is a good intervention that can reduce blood pressure (Millar, MacDonald, Bray, & McCartney, 2009; Shakoor, Salesi, Daryanoosh, & Izadpanah, 2020), and it is also an effective strategy to improve the positive changes in physiological process of the body and to ameliorate psychology as well as physical and mental health status of people during COVID-19 pandemic (De Sousa et al., 2021).

It seems that physical exercise at home is the best way to prevent COVID-19 contraction through the air and to deal with negative effects of quarantine, such as lack of physical activity, increase in mental disorders and

depression, reduced quality of life, and most importantly, to create long-term adherence to exercise (Ashworth, Chad, Harrison, Reeder, & Marshall, 2005; Qiu et al., 2020). In this respect, isometric handgrip exercises at home are safe, simple, applicable, and without risk for most people with clinical diseases, and (most importantly) require little equipment, space, and time, so that they can be practiced at any time and place with relatively inexpensive equipment. Despite the low volume of these exercises, they significantly reduce blood pressure and its related factors (Shakoor et al., 2020; TAYLOR et al., 2017). As a result, isometric handgrip exercise may be a safe alternative for sports activities in closed places and gyms during quarantine. These features of IHG exercise can be crucial for increasing motivation and self-efficacy, as well as keeping people physically active.

Physiologically, compared to aerobic exercises, isometric exercise is associated with a lower myocardial oxygen demand because of the slight increase in heart rate, as well as the increase of diastolic blood pressure (in contrast to aerobic exercise) and coronary blood flow. Besides, adding isometric exercises to dynamic aerobic exercise reduces ST-segment depression as well as occurrence of myocardial ischemia. Another sign of a proper and safe blood pressure response during isometric exercise is spontaneous breathing without using Valsalva maneuver (i.e., breathing under closed glottis pressure) (Cornelissen & Smart, 2013; Peters et al., 2006).

Considering the novelty of SARS-CoV-2, there has been no coherent scientific research on COVID-19, high blood pressure and exercise. As a result, the purpose of this research is to investigate the impact of 10-week exercise at home on blood pressure, quality of life and quality of sleep of hypertensive women during COVID-19 quarantine.

METHODS

Study design and trial registration

This study is a randomized controlled trial with parallel arms, which was conducted and reported in accordance with CONSORT guidelines for non-drug treatment (Boutron et al., 2008). The participants were recruited using information and documents registered in family doctor general health system (SIB) from Sa'adi Neighborhood of Shiraz. Sixty-five patients with high blood pressure were contacted by phone. Afterward, 30 participants were selected voluntarily considering inclusion and exclusion criteria and were randomly assigned to control and IHG exercise groups (15 participants in each group). Recruiting finished once the number of required volunteers was reached.

Initially, the participants were invited through social media to fill out an online questionnaire using Google Forms software. Therefore, before starting the program, all participants completed an informed consent form, namely voluntary participation that was sent to them online (using the Google Forms software; Mountain View, CA, USA).

Ethics approval

This study was approved by Ethics Committee of Sport Sciences Research Institute of Iran (No: IR.SSRC.REC.1402.027). All procedures followed national standards and the Declaration of Helsinki.

Sample size calculation

With reference to the paper by Taylor et al, (2017) Row 10 of Table 1 (Awake DBP), sample size was calculated 15 participants in each group (N = 30) using the following formula by considering $n_1 = 92.1$, $n_2 = 87.2$, $S_1 = 1.4$, $S_2 = 3.3$, $\alpha = 0.05$, $\beta = 0.2$, 80% power and 30% dropout:

$$n_1 = n_2 = \frac{(S_1^2 + S_2^2) \left(Z_{1-\frac{\alpha}{2}} + Z_{1-\beta} \right)^2}{(\bar{X}_1 - \bar{X}_2)^2}; \alpha = 0 / 05, \beta = 0 / 2$$

$$\bar{X}_1 = 92.1$$

$$\bar{X}_2 = 87.2$$

$$S_1^2 = 1.4$$

$$S_2^2 = 3.3$$

$$Z_{1-\frac{\alpha}{2}} = 1.96, Z_{1-\beta} = 0 / 84$$

Participants

Eligibility criteria

Thirty women with stage 1 hypertension and prehypertension (systolic blood pressure 138 ± 2 mmHg and diastolic blood pressure 89 ± 3 mmHg) and mean age of 36 ± 4 years (range: 30-45) whose data was registered in family doctor general health system (SIB) from Sa'adi Neighborhood of Shiraz were recruited in this study. Considering the participants' available records at their specialists, the required assessments for stage 1 hypertension and prehypertension were done online, and they were then recruited to the study.

Inclusion criteria

All participants were non-smokers, had no history of CVD (coronary artery disease, arrhythmia, heart failure), metabolic and renal diseases, did not consume drugs affecting blood pressure, had no cognitive and mental, neuromuscular or skeletal disorders (for performing exercise), had a sedentary lifestyle (≤ 150 minutes of aerobic exercise per week using International Physical Activity Questionnaire (Chtourou et al., 2020; Zhang, Zhang, Ma, & Di, 2020) and were not infected with COVID-19 over the last few months as well as during the exercise period.

Exclusion criteria

The exclusion criteria were as follows: not attending more than two sessions, concurrent participation in another clinical trial and having the following symptoms: chest pain, chills, diarrhea, dizziness, dry cough, eyes, and mouth, fatigue, fever $>37.9^\circ\text{C}$, headache, anorexia, loss of sense of smell (anosmia), muscle or body pain, congestion or runny nose, nausea or vomiting, shortness of breath, difficulty breathing, dyspnea, joint pain or sore throat before and during the study were the exclusion criteria. None of the participants reported flu-like symptoms over this period.

Randomization

The participants were randomized into one of two groups (three interventions and one control) using an online randomization system (randomizer.org) (see Figure 1). A member of the research team not involved in the selection of samples determined the randomization sequence using a computer program. The participants were notified of their group allocation using a sealed envelope.

This is a randomized controlled clinical trial with single-blind data analysis. Single blind method was used to reduce the bias or distortions related to the intervention and assessment of results.

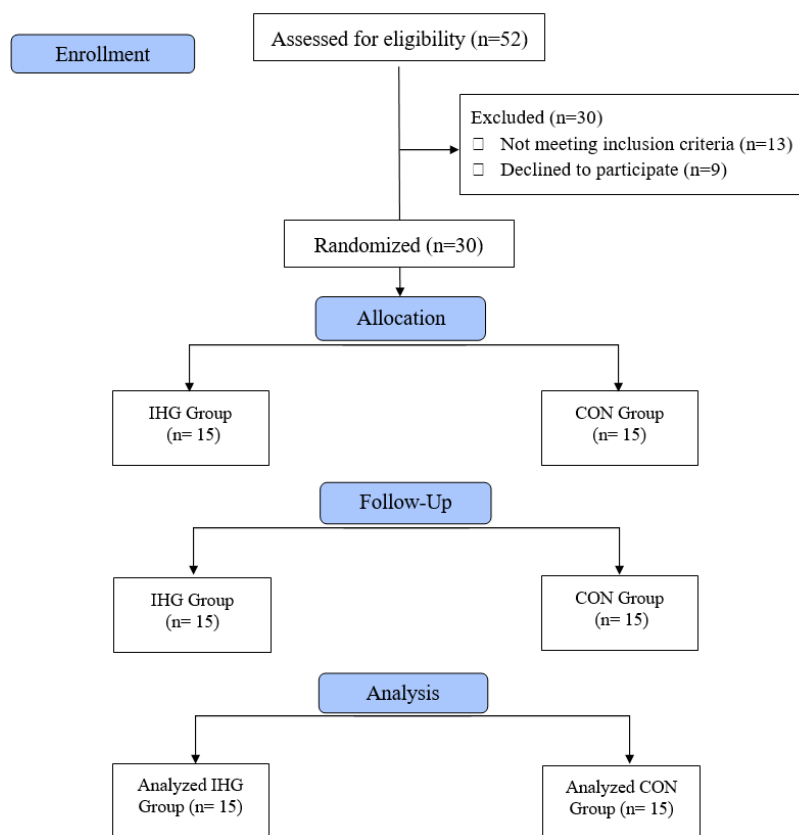


Figure 1. Flow chart of the randomized control trial.

Adherence strategies

After the volunteers presented their consent, they received notifications through SMS, e-mail and phone call to attend sessions. The volunteers could make round the clock contact with the coordinator of intervention and with researchers through e-mail or mobile phone.

Interventions

The participants were randomly assigned to control and exercise groups. The exercise group performed the exercise for 10 weeks (three sessions per week), during which the control group did not have sport activity.

IHG exercise group

The exercise group performed 30 sessions of physical activity using a digital isometric handgrip device (Saehan Grip, model DHD-3, made in South Korea) with the non-dominant hand unilaterally based on recommendations provided by American Heart Association (AHA) and American College of Sports Medicine (ACSM) (Cornelissen & Smart, 2013). The isometric handgrip protocol was performed as follows:

IHG: 4x2 min isometric contractions at 30% of Maximal Voluntary Contraction (MVC), separated by 2 minutes' rest, overall session with non-dominant hand unilaterally. The length of training session was 14 minutes, reaching 22 minutes with 5 minutes of warm-up and 3 minutes of cool down (Figure 2) (Thompson, Arena, Riebe, Pescatello, & American College of Sports, 2013; van Assche, Buys, de Jaeger, Coeckelberghs, & Cornelissen, 2017).

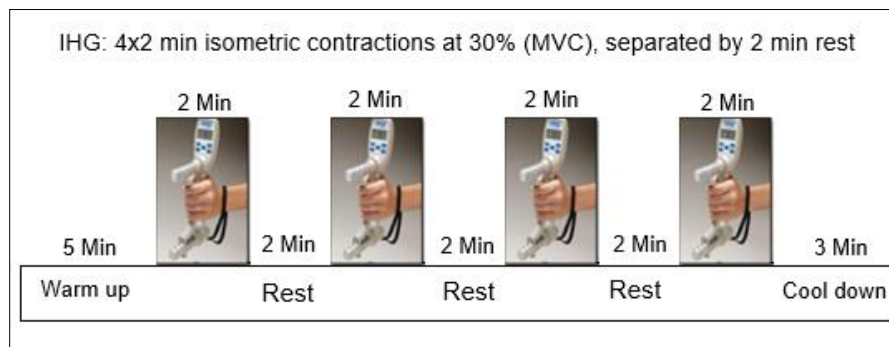


Figure 2. The handgrip exercise protocols.

The exercise intensity in these 10 weeks was 30% MVC. To comply with the principle of overload, the participants' MVC was measured online every two weeks, and they performed their exercise based on new values (TAYLOR et al., 2017; Thompson et al., 2013). Each participant did her training online under supervision of the researcher three times a week (every other day) between 8 and 11 AM, a period showing the greatest reduction in blood pressure (de Brito et al., 2015). All training programs were individualized and progressive. The Borg Rating of Perceived Exertion scale (RPE scale) was used to gauge intensity during exercise sessions. The RPE consists of a scale of 6 (no exertion at all) to 20 (maximal exertion) (Thompson et al., 2013) (Pescatello, Arena, Riebe, & Thompson, 2013) (Pescatello et al., 2013). All the patients were repeatedly informed about the progress of the study and its partial results during the follow-up period. In addition, the researchers maintained constant contact with the physicians responsible for each patient. At the end of the study, both physicians and patients received the final report along with the results.

Maximal Voluntary Contraction (MVC)

To measure MVC, the participants sat down on the chair of isometric handgrip device (Saehan Grip, model DHD-3, made in South Korea) with their non-dominant hand, the soles of their feet on the floor and knees at a 90-degree angle. In addition, the participants' elbow was in contact with the chair handle or the table, and they were informed of their performance by reading the values shown on the device during performance. Before performing each protocol, the participants applied their maximum force to the device by their non-dominant and training hand after warming up with low intensity using the handgrip device in three contractions without Valsalva maneuver, and the average force recorded in the device was considered their MVC.

Control group

During this time, the control group was encouraged to continue their normal daily routine, not participate in any other program and not have any special exercise. Their blood pressure was checked online every week just to adhere to the research Study.

Measurements or evaluation of outcomes

Primary and secondary outcome measures were evaluated according to American College of Sports Medicine guidelines for health-related physical assessment (Ware & Sherbourne, 1992). Initial and final assessment was done before the start of the first session and 48 hours after the last exercise session, respectively.

Before each assessment, the participants were asked to avoid consuming alcohol, tea, coffee, soft drinks or any food/beverage containing caffeine 6 hours before measurement, not to do strenuous activities 24 hours

before assessment, and to drink plenty of water. They were also encouraged to have enough rest and proper sleep (6-8 hours) the night before the evaluation. In addition, the participants were requested to record their activities for 24 hours after the experiment, including working hours, sleep schedule, meals, medication use, and any complications they considered to be important (e.g., stressful situations).

The primary outcome measure includes blood pressure (systole, diastole and average), Rate pressure product (RPP), Heart Rate (HR), and the secondary outcome variables were Quality of life and DASS-21 questionnaires.

Primary outcomes

Blood pressure measurement

An automated oscillometric cuff, namely Omron 705CP (Omron, Matsusaka, Matsusaka City, Japan), was fastened around the participants' left arm during the home visit and after 5 minutes of rest in a sitting position to measure systolic blood pressure (SBP) and diastolic blood pressure (DBP) according to the established guidelines (Dorans, Mills, Liu, & He, 2018).

All blood pressure measurements were repeated; the average of two values was recorded and used for analysis. If the values differed by 5 mmHg, a third measurement was done, and the two closest values were averaged.

Mean Arterial Pressure (MAP) was calculated as the sum of 2/3 DBP and 1/3 SBP.

$$\text{MAP} = 1/3 \text{ SBP} + 2/3 \text{ DBP}$$

Rate Pressure Product was also calculated by multiplying systolic blood pressure by heart rate.

$$\text{RPP} = \text{SBP} \times \text{HR}$$

Secondary outcomes

Using Google® Forms software, the questionnaires were distributed through an online platform to all participants who were interested in participating in the survey. These questionnaires were divided into three parts as follows:

The first part included age, disease history, weight and height to calculate BMI, physical activity history before and during the outbreak of COVID-19.

The second part was the quality-of-life questionnaire, and the third part was DASS21 questionnaire.

Anthropometrics

Weight (kg) and height (m) were measured using standard techniques. Body mass index (BMI) was calculated based on the following formula: $\text{BMI} = \text{height (m)}^2 / \text{weight (kg)}$.

Quality of life

SF-36, the short form of HRQOL, is an instrument to assess quality of life, which is widely used in general and mental health care (Aaronson et al., 1998; Ware & Sherbourne, 1992). SF-36 consists of 36 items, 35 of which are divided into 8 health concepts as follows:

1. Physical Functioning (PF) (questions = 3,4,5,6,7,8,9,10,11,12).
2. Bodily Pain (BP) (questions = 21,22).

3. Role limitations due to physical problems (RP) (questions = 13,14,15,16).
4. Role limitations due to emotional problems (RE) (questions = 17,18,19).
5. General Mental health (GM) (questions = 24,25,26,28,30).
6. Social functioning (SF) (questions = 20,32).
7. Vitality (energy and fatigue) (VT) (questions = 23,27,29,31).
8. General Health perceptions (GH) (questions = 1,2,34,35,36).

Another part deals with changes in health status. The response options are different for each item. For each of the eight domains, item scores were coded, summed and converted to a scale from 0 (worst possible health status as measured by the questionnaire) to 100 (best possible status).

In general, the questions and background concepts of the scale structure and summary measurements of SF-36 questionnaire are classified in three levels as follows (Aaronson et al., 1998; Ware & Sherbourne, 1992):

1. Questions.
2. Eight scales that are obtained from combining 2-10 questions.
3. Two summary measurements obtained by integrating the scales as follows:
 - Physical health (PH) = Physical function (PF) + physical limitation (RP) + physical pain (BP) + general health (GH).
 - Mental health (MH) = Social functioning (SF) + emotional problems (RE) + mental health (GM) + vitality (VT).

DASS-21

Depression Anxiety Stress Scale-21 (DASS-21) questionnaire was developed by Lovibond in 1995 and contains 21 questions based on four-point Likert scale with never, a few, sometimes and always options (Henry & Crawford, 2005).

The answers are scored according to the four-point Likert scale and pass through 0 points (did not apply to me at all); 1 (applied to me to some degree, or some of the time); 2 (applied to me to a considerable degree or a good part of time), and 3 (applied to me very much or most of the time).

Seven questions are related to depression (items: 3, 5, 10, 13, 16, 17 and 21), 7 questions examine anxiety (items 2, 4, 7, 9, 15, 19 and 20) and 7 other questions are concerned with stress level of patients (items 1, 6, 8, 11, 12, 14 and 18). The scoring ranges 0-3, with a score of 0 indicating the never option, 1 a little option, 2 sometimes option, and 3 always option. Because the short form questionnaire has 21 questions, each score is multiplied by two.

The DASS-21 scale scores are classified by summing the relevant items. Cutoff points for the anxiety subscale are as follows: normal (<7), mild (8–9), moderate (10–14), severe (15–19), and extremely severe (>20). For depression subscale, normal (<9), mild (10–13), moderate (14–20), severe (21–27), and extremely severe (>28). The cutoff points for the stress subscale are normal (<14), mild (15–18), moderate (19–25), severe (26–33), and extremely severe (>34) (Chew et al., 2020; Henry & Crawford, 2005).

Statistical analysis

Data were analyzed using SPSS software (version 23). Analysis of covariance (ANCOVA) was conducted to find the difference between post-test, and baseline variables as covariates. When applicable, Bonferroni post hoc tests were used to check the difference between the groups. Besides, paired t-test was employed to

compare within-group (pre- and post-test) differences. The effect size of each variable was tested using partial eta squared (η^2) values (small effect = 0.01, medium effect = 0.06, and large effect = 0.14). $\alpha = 0.05$ was considered significance level in this study. In addition, one-way analysis of variance was applied on baseline scores across groups.

RESULTS

Anthropometric and resting hemodynamic parameters (SBP, DBP, MBP, HR) of participants are shown in Table 1. With ANCOVA, no significant difference was observed between factors under study in the baseline state (Table 1). All participants (30 women) took part in the randomized controlled trial.

Table 1. Anthropometric variables of participants between groups (mean \pm SD).

Variables	IHG group (n = 15)	Control (n = 15)	p-value
Age (Years)	49.53 \pm 3.73	48.53 \pm 4.24	.49
weight (kg)	68.73 \pm 8.68	67.46 \pm 7.85	.74
height (cm)	166.86 \pm 5.06	167.66 \pm 5.60	.68
BMI (Kg/m ²)	28.66 \pm 6.68	29.85 \pm 10.18	.71
SBP (mmHg)	139.20 \pm 1.08	138.86 \pm 1.64	.51
DBP (mmHg)	89.26 \pm 1.62	88.40 \pm 3.77	.42
MAP (mmHg)	105.91 \pm 1.08	105.17 \pm 2.57	.35
Resting HR (bpm)	74.06 \pm 2.96	72.40 \pm 2.44	.10
RPP (mmHg x bpm)	10310.13 \pm 422.87	10052.13 \pm 302.19	.06

Note. IHG: Isometric Handgrip, BMI: Body Mass Index, SBP: Systolic Blood Pressure, DBP: Diastolic Blood Pressure, MAP: Mean Arterial Pressure, HR: Heart Rate, RPP: Rate pressure product.

Between group comparisons

Blood pressure

The results of the study show that there was significant difference between groups in the systolic blood pressure SBP ($f_{(1,27)} = 12.46$, $p = .002$, $\eta^2 = 0.31$), Diastolic Blood Pressure DBP ($f_{(1,27)} = 16.96$, $p = .001$, $\eta^2 = 0.38$), Mean Arterial Pressure MAP ($f_{(1,27)} = 41.75$, $p = .001$, $\eta^2 = 0.60$), RPP ($f_{(1,27)} = 43.84$, $p = .001$, $\eta^2 = 0.61$).

Quality of life (SF-36 Domains)

The results of the study show that there was significant difference between groups in the Physical Functioning (PF) ($f_{(1,27)} = 619.73$, $p = .001$, $\eta^2 = 0.95$). In addition, there was significant difference between groups in the Bodily Pain (BP) ($f_{(1,27)} = 95.57$, $p = .001$, $\eta^2 = 0.78$), Role limitations due to Physical problems (RP) ($f_{(1,27)} = 66.74$, $p = .001$, $\eta^2 = 0.71$), Role limitations due to Emotional problems (RE) ($f_{(1,27)} = 56.98$, $p = .001$, $\eta^2 = 0.67$), general Mental Health (GM) ($f_{(1,27)} = 243.55$, $p = .001$, $\eta^2 = 0.90$), Social functioning (SF) ($f_{(1,27)} = 143.07$, $p = .001$, $\eta^2 = 0.84$), Vitality (VT) ($f_{(1,27)} = 757.23$, $p = .001$, $\eta^2 = 0.96$), General Health perceptions (GH) ($f_{(1,27)} = 507.54$, $p = .001$, $\eta^2 = 0.94$), Total score of Quality of life ($f_{(1,27)} = 1160.661$, $p = .001$, $\eta^2 = 0.97$), Physical health (PH) ($f_{(1,27)} = 654.619$, $p = .001$, $\eta^2 = 0.96$) and Mental health (MH) ($f_{(1,27)} = 435.33$, $p = .001$, $\eta^2 = 0.94$).

DASS-21

The results of study show that there was significant difference between groups in Depression ($f_{(1,27)} = 29.33$, $p = .001$, $\eta^2 = 0.51$) and Anxiety ($f_{(1,27)} = 50.39$, $p = .001$, $\eta^2 = 0.65$). In addition, there was significant difference between groups in Stress ($f_{(1,27)} = 29.52$, $p = .001$, $\eta^2 = 0.52$). and in the Total score of the DASS-21 ($f_{(1,27)} = 101.03$, $p = .001$, $\eta^2 = 0.78$).

Within group comparisons

The paired t-test was employed to control intra-group changes (pre-test and post-test). The results of paired t-test were illustrated in the Blood Pressure Table 2, Quality of life (SF-36 Domains) Table 3 and DASS-21 Table 4.

Table 2. Comparison of the blood pressure variables within (paired t-test) exercise and control groups.

Variable	Group	Baseline	Post Test	Within group		
				t	p	
Blood Pressure	SBP (mmHg)	IHG	139.20 ± 1.08	134.40 ± 1.95	7.01	.001
		Control	138.86 ± 1.64	139.20 ± 4.67	0.26	.79
	DBP (mmHg)	IHG	89.26 ± 1.62	87.40 ± 1.35	4.40	.001
		Control	88.40 ± 3.77	89.66 ± 2.35	1.53	.14
	MAP (mmHg)	IHG	105.91 ± 1.08	103.06 ± 1.26	7.29	.001
		Control	105.17 ± 2.57	106.17 ± 2.03	1.88	.80
RPP (mmHg x bpm)	IHG	10310.13 ± 422.87	9614.40 ± 373.49	11.79	.001	
	Control	10052.13 ± 302.19	10189.53 ± 461.09	1.43	.17	

Note. SBP: systolic blood pressure, DBP: Diastolic blood pressure, MAP: Mean arterial pressure, RPP: rate pressure product.

Table 3. Comparison of the Quality of life (SF-36 Domains) variables within (paired t-test) exercise and control groups.

Variable	Group	Baseline	Post Test	Within group		
				t	p	
Quality of life (SF-36 Domains)	PF	IHG	21.67 ± 5.87	84.67 ± 9.15	27.03	.001
		Control	24.67 ± 9.15	12 ± 6.76	4.83	.09
	BP	IHG	31.33 ± 12.74	83.67 ± 14.84	14.13	.001
		Control	21.83 ± 11.93	20.83 ± 16.16	0.9	1
	RP	IHG	20 ± 16.90	71.67 ± 20.84	7.27	.001
		Control	23.33 ± 17.59	15 ± 18.42	2.09	.75
	RE	IHG	13.33 ± 21.08	80 ± 24.56	9.160	.001
		Control	17.78 ± 21.33	15.56 ± 21.33	0.26	.79
	GM	IHG	30.33 ± 9.15	84 ± 7.60	20.98	.001
		Control	25.33 ± 10.25	31.33 ± 9.90	1.79	.95
	SF	IHG	28.33 ± 15.28	85.83 ± 12.38	15.05	.001
		Control	18.33 ± 12.38	17.50 ± 18.17	0.23	.81
	VT	IHG	22.33 ± 10.15	85.33 ± 8.33	24.94	.001
		Control	19 ± 10.03	11.67 ± 6.45	2.62	.61
	GH	IHG	21.33 ± 8.50	82.13 ± 9.89	19.43	.001
		Control	18.93 ± 10.08	11.47 ± 6.56	2.55	.074
	Total	IHG	850.33 ± 160.729	2964.33 ± 200.739	38.77	.001
		Control	809.33 ± 200.311	612.67 ± 26.5	3.58	.082
PH	IHG	94.33 ± 24.76	322.13 ± 31.92	24.51	.001	
	Control	88.77 ± 33.88	60.30 ± 24.35	3.28	.065	
MH	IHG	94.33 ± 26.57	335.17 ± 33.60	25.17	.001	
	Control	80.44 ± 26.19	76.06 ± 35.83	0.59	.56	

Note. SF-36: Short Form survey 36-item, PF: Physical Functioning, BP: Bodily Pain, RP: Role limitations due to Physical problems, RE: Role limitations due to Emotional problems, GM: general Mental Health, SF: Social functioning, VT: Vitality (energy and fatigue), GH: General Health perceptions, PH: Physical health, MH: Mental health.

Table 4. Comparison of the DASS-21 variables within (paired t-test) exercise and control groups.

	Variable	Group	Baseline	Post Test	Within group	
					t	p
DASS-21	Depression	IHG	9.60 ± 3.46	6.47 ± 3.54	4.96	.001
		Control	8.27 ± 4.16	9.60 ± 3.64	2.64	.78
	Anxiety	IHG	8.73 ± 2.96	5.80 ± 2.51	8.19	.001
		Control	9.20 ± 3.25	10.27 ± 3.36	2.21	.059
	Stress	IHG	9.80 ± 2.39	6.67 ± 2.25	3.59	.003
		Control	10.07 ± 3.57	11.47 ± 3.42	3.50	.1
	Total	IHG	28.13 ± 6.11	18.93 ± 5.78	7.99	.001
		Control	27.53 ± 9.10	31.33 ± 8.96	5.92	.09

Note. DASS-21: Depression, Anxiety and Stress Scale - 21 Items.

DISCUSSION

The purpose of this study was to investigate the effect of isometric handgrip exercise at home on hemodynamic and psychological factors of women with hypertension during the quarantine period of COVID-19. The results showed a decrease in systolic blood pressure (6 mm Hg), diastolic blood pressure (2 mm Hg), and mean arterial pressure (2 mm Hg) along with improved quality of life, stress, anxiety and depression in participants who followed the handgrip exercise program.

IHG exercise and blood pressure

Infection control and safety precautions are essential given the concerns about the increasing spread of COVID-19. Staying at home is a basic safety step that could prevent from extensive infection. However, staying at home for a long time can lead to behaviors that increase inactivity and related diseases, such as CVD and hypertension.

High blood pressure is the most important correctable factor of cardiovascular diseases that affects more than 1,000,000,000 people worldwide, imposing a significant financial and life burden on societies. Lifestyle modifications, such as regular exercise, have been used to prevent and control high blood pressure (BP) (Cornelissen & Smart, 2013). Therefore, physical activity and regular exercise in a safe environment (home) can be an important strategy for a healthy life during COVID-19 crisis effective in the treatment of hypertension (Schiffirin et al., 2020).

IHG exercise is considered a non-drug treatment in hypertensive patients, which can decrease blood pressure and its related factors, so that through 2-3 mm Hg decrease in systolic blood pressure, it is possible to reduce the death rate due to stroke by 6% and CVD by 4% (Shakoor et al., 2020).

Blood pressure decrease due to IHG exercise can be attributed to two dominant mechanisms: sympathetic inhibition and changes in vascular reactivity following exercise. In fact, isometric handgrip exercise activity reduces blood pressure through its effect on baroreceptors, weakening baroreflex control and reducing sympathetic nerve traffic along with predominance of parasympathetic system (vagal tone) (Heffernan & Jae, 2020). Some researchers believe that after exercise, dopamine beta hydroxylase decreases in the hypothalamus, reducing the peripheral activity of epinephrine in response to emotions and other stimuli and contributing to decreased blood pressure. It has also been reported that the decrease in sympathetic nerve activity and the improvement of presser reflex function after exercise are due to the continuous decrease of angiotensin II and angiotensin receptors in CNS (Badrov, Freeman, Zokvic, Millar, & McGowan, 2016). The

noteworthy point is that exercise training can probably reinforce ACE2-Ang1-7-Mas receptor axis, increase the synthesis of vasodilator pathway activator and create an anti-inflammatory and anti-fibrotic effect, which simultaneously inhibits ACE-Ang II-AT1 receptor pathway (Heffernan & Jae, 2020).

In particular, isometric handgrip exercises with repeated contractions, local ischemia and subsequent hyperemia raise the shear stress, which is followed by vasodilation because of increase in two vasodilator factors, namely FMD and nitric oxide (NO) (Chew et al., 2020; van Assche et al., 2017), decreasing vascular resistance and subsequently blood pressure.

In addition, after isometric handgrip exercise training, modulation of oxidative stress has been shown as a possible mechanism for the improvement of high blood pressure in the study by Peters et al. (2006) who investigated the role of ROS in reducing blood pressure during isometric handgrip exercises. They showed that in isometric handgrip exercises, ischemia and reperfusion caused by release of contraction increase the antioxidant capacity and decrease the activity of ROS, which reduce the damage to blood vessels. Perhaps handgrip exercise can be effective in improving endothelial function by reducing free oxygen radicals (Shakoor et al., 2020; van Assche et al., 2017). Vascular endothelial growth factor and fibroblast growth factor have been mentioned in relation to the improvement of endothelial function as a result of exercise training, both of which cause an increase in NO and dilation of blood vessels, followed by the decrease in blood pressure. Moreover, under hypoxia conditions, hypoxia-inducible factor-1 increases the expression of vascular endothelial growth factor gene (Cornelissen & Smart, 2013).

Therefore, perhaps the most important mechanism behind the blood pressure-lowering effects of exercise has been attributed to the enhancement of the arterial wall distensibility, reduction of peripheral resistance, and improvements in endothelial function.

It seems that IHG reduces blood pressure by increasing the number of capillaries in active skeletal muscle, rising cardiac output, decreasing vascular resistance due to vasodilation, reducing blood flow resistance, improving blood vessel neural regulation, decreasing peripheral resistance, and reducing the heart rate during rest (Cornelissen & Smart, 2013; TAYLOR et al., 2017).

IHG exercise, quality of life and DASS21 (stress, anxiety and depression)

The outcomes of this study showed that the IHG exercise training significantly improved quality of life variables in hypertensive women, mainly physical and mental health aspects.

The global COVID-19 pandemic has brought significant changes in lifestyle and has affected the physical and mental health of many individuals, particularly those suffering from hypertension. As mentioned above, with the increasing incidence of COVID-19, while staying at home is almost the only effective measure to prevent the infection in a majority of people and can simultaneously lower the risk of COVID-19, quarantine could increase the prevalence of chronic diseases such as high blood pressure as well as leading to the rise in psychiatric diseases and mood-psychological disorders, including higher levels of anxiety, depression and stress. Quarantine also affects mental health and can disrupt quality of life, self-image, and personal relationships (Schiffirin et al., 2020). Moreover, depression and anxiety have a negative effect on several dimensions of quality of life, including physical activity, and in patients with high blood pressure, the quality of life related to health is poorer compared to those with normal blood pressure (De Sousa et al., 2021; Strohle, 2009).

The present study investigated the potential benefits of IHG exercise on DASS21 scores in hypertensive women during the COVID-19 pandemic. Our findings suggest that the participants who engaged in IHG exercise had a significant reduction in their depression, anxiety, and stress levels as measured by the DASS21 compared to the control group who did not engage in any exercise. These results support previous findings that exercise can have a positive impact on mental health outcomes.

Nevertheless, exercise has been widely recommended as a non-drug approach to reduce the consequences of social distancing/isolation during COVID-19 pandemic (Heffernan & Jae, 2020), which is commonly used to treat people with depression or anxiety. Therefore, regular exercise, physical activity, or physical exercise may be a complementary treatment for improving mental and social health. In other respect, lack of exercise and inactivity have been reported as an important factor increasing depression and anxiety. In the meantime, exercise is a factor that can reduce stress in the body. These changes during COVID-19 epidemic reduce stress and improve the quality of life during daily activities (De Sousa et al., 2021; Li, Yu, Chen, Quan, & Zhou, 2018). These anti-anxiety, anti-depression and anti-stress effects of exercise can be explained by different mechanisms; isometric handgrip exercise is no exception, and physiological and psychological mechanisms can be mentioned in this respect (Schuch et al., 2014).

From a physiological standpoint, exercise can affect the neurotransmitters involved in anxiety, leading to the decrease in anxiety and stress via increase in beta-endorphins and uplifting hormones (De Sousa et al., 2021). Like other exercises, IHG probably strengthens the brain parts related to emotions, leading to happiness, relaxation and subsequently reduced depression (Schuch et al., 2014). Furthermore, IHG can exert its anti-depressant effect by modulating oxidative stress by decreasing the level of pro-oxidative markers as well as increasing antioxidant markers. Like aerobic exercise training, IHG is likely to increase the adaptation in thiobarbituric acid reactive species (TBARS) and the average total frequency in these individuals, leading to the improvement of various aspects of mental health (Schuch et al., 2016). It can also improve anxiety and depression and subsequently advance the quality of life through neurogenesis effects and increasing the level of brain-derived neurotrophic factor (BDNF) (De Sousa et al., 2021; Schuch et al., 2014).

From a psychological point of view, we can state that because isometric handgrip exercise has reduced blood pressure in the present research, it can probably increase the self-confidence and efficiency of an individual by improving mental conditions, as well as bettering various aspects of the quality of life and reducing people's anxiety and depression. For this reason, it can be stated that physical activity is an important and effective factor during COVID-19 pandemic or similar diseases.

Limitation of study

The study was limited by its small sample size and short duration. It is recommended that future studies include a larger sample size and longer duration to determine the long-term impact of IHG exercise on blood pressure levels. To conclude, the current study provides evidence that IHG exercise can be an effective intervention to decrease blood pressure levels during a quarantine period, where access to equipment and facilities is limited. It is important to note that while our study saw significant improvements in DASS21 and quality of life scores for the IHG exercise group, further research is needed to determine the long-term effects and optimal dosage of IHG exercise on mental health outcomes. Research on ACE2, SARS-CoV-2 infection, and physical exercise is in its infancy. Given the positive impact of regular exercise on mental, neurological and cardiovascular health, this is a vast area that needs to be explored.

CONCLUSION

The spread of COVID-19 prompted most countries in the world to take quick and protective measures in order to stop the transmission chain of this disease. For this purpose, people stayed at home to avoid contracting the disease, and in the meantime, inactivity and higher prevalence of chronic diseases such as high blood pressure became more prevalent. These circumstances can lead to mental disorders and affect psychological health. Therefore, it is necessary to develop strategies that can reduce the impact of COVID-19 on mental health, including exercise. Maintaining physical activity and regular exercise in the safe setting of home is an important strategy for healthy living during COVID-19 crisis.

Our findings suggest that regular IHG exercise may potentially serve as an effective preventative measure for hypertension and its related cardiovascular diseases during situations where physical activity may be restricted. IHG exercise activity can cause physiological changes as follows: improving blood pressure, reducing stress, depression and anxiety, and most importantly, increasing the quality of life, and these factors can be of high importance during COVID-19 pandemic.

AUTHOR CONTRIBUTIONS

Conceptualization: Elham Shakoor, Pezhman Motamedi, Farnaz Banaee. Data Collection: Elham Shakoor, Farnaz Banaee. Formal Analysis: Elham Shakoor, Pezhman Motamedi, Farnaz Banaee, Nemat Jaafari, Christine Sylvain. Supervision: Nemat Jaafari, Christine Sylvain. Writing – original draft: Elham Shakoor, Pezhman Motamedi, Farnaz Banaee, Nemat Jaafari, Christine Sylvain. Writing – review & editing: Elham Shakoor, Pezhman Motamedi, Farnaz Banaee, Nemat Jaafari, Christine Sylvain.

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No potential conflict of interest was reported by the authors.

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The AI coach: A 5-week AI-generated calisthenics training program on health-related physical fitness components of untrained collegiate students

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ABSTRACT

The study aims to investigate the effect of a 5-week artificial intelligence-generated calisthenics training program (AIGCTP) on health-related physical fitness components, including flexibility, cardiovascular endurance, and muscular endurance. Utilizing a quasi-experimental design, the study employed a one-group pre-test-post-test design for within-group comparisons and a two-group pre-test-post-test design for between-group comparisons. Participants included 87 untrained collegiate students, divided into the AIGCTP group (43 participants) and a human-made calisthenics training program (HMCTP) group (44 participants), selected via purposive sampling. A paired t-test was used for within-group comparisons, and an independent sample t-test was used for between-group comparisons. The findings indicated that the AIGCTP effectively improved the flexibility of the lower extremities and the muscular endurance of the core and upper extremities. However, female participants did not show significant improvements in any health-related physical fitness components, whereas male participants demonstrated improvements in the flexibility of the lower extremities and muscular endurance of the upper extremities. The HMCTP was effective in improving the flexibility and muscular endurance of the lower and upper extremities for all participants. Between-group comparisons revealed that the cardiovascular endurance of the HMCTP group was significantly superior to that of the AIGCTP group, irrespective of sex. Additionally, males in the HMCTP group exhibited significantly higher muscular endurance of the lower extremities compared to those in the AIGCTP group. The study suggests that AI can be used for fitness training, but professional-made programs are superior in some areas. Future research should replicate these findings, examine more fitness components, and explore longer training durations for further validation.

Keywords: Physical education, Muscular endurance, Flexibility, Cardiovascular, Artificial intelligence, Calisthenics.

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INTRODUCTION

Artificial intelligence is the science and engineering concerning developing systems that display human characteristics and behaviour (Tecuci, 2012). It mimics the human level of intelligence, such as logical reasoning, learning, and problem-solving (Morandín-Ahuerma, 2022). It is widely in the field of medicine (Yu et al., 2018; Lopez-Jimenz et al., 2020; Hamet & Tremblay, 2017; Zhuo et al., 2020; Xu et al., 2021), human biology (Hamet & Temblay, 2017), nutrition (Sak & Suchodolska, 2021), and education (Chen et al., 2020; Zawacki-Richter et al., 2019; Boulay, 2016; Zafari et al., 2022). Not only in rigid disciplines, but it also thoroughly used in social life and economic activities which contributes to solving various social problems through robotic technologies (Lu et al., 2017). It can even complete tasks that require empathy (Huang & Rust, 2018). Despite numerous uses of artificial intelligence, it has limitations on things it can perform based on the information that is fed to it (Wang, 2019). It has even been capable of extinguishing human jobs (Huang & Rust, 2018). While artificial intelligence exhibits remarkable capabilities across various fields, including medicine, human biology, nutrition, education, and social problem-solving, its potential limitations and impact on human employment must be carefully considered and managed.

Physical fitness is defined as the capability of an individual to perform daily tasks with vigour (Pate, 1988). It is completed by different components, which are divided into two, health-related and Skill-related physical fitness components (Wilder et al., 2006; Caspersen et al., 1985). Health-related physical fitness components are heavily influencing an individual's health (McKelphin, 2015). On the other hand, skill-related physical fitness components refer to parameters that are essential for motor skills and movement pattern execution (deMet & Wahl-Alexander, 2019). For the purpose of this study, health-related physical fitness components such as cardiovascular endurance, muscular endurance, and flexibility were focused on. Enhanced cardiovascular endurance is linked with better high health status, such as increased integrity of cerebral white matter (Johnson et al., 2012), lowered risk of high blood pressure (Sui et al., 2017), higher capability to execute different activities (Wong et al., 2015), and a chance of reduced coronary heart disease and mortality (Gander et al., 2015). The low level of this component causes many health-related issues. Low cardiovascular fitness correlates with higher body mass index and increased waist circumference, elevating susceptibility to cardiovascular disease (Berge et al., 2019; Carbone et al., 2020). It also correlates with psychological distress and is established as a predictor of psychological health (Zeihner et al., 2019). High cardiovascular fitness is associated with increased mental toughness, particularly among athletes (Latif et al., 2022). Muscular endurance, vital for fitness (Robert & Hockey, 1973), predicts lower BMI (Ding & Jiang, 2020; Garcia-Hermoso et al., 2019), reduces obesity risk, and is linked to lower all-cause mortality and cardiovascular disease risk (Corder et al., 2019), emphasizing its role in weight management and disease prevention. Despite its health significance, it is essential to know the possible effects of having a low level of this component. Low muscular endurance adversely affects athletic performance, increases injury risk, and correlates with cardiovascular diseases and metabolic factors (Ambegankar et al., 2012; Artero et al., 2012; Walker et al., 2017). It also impacts psychological well-being, increasing susceptibility to anxiety and psychiatric conditions (Ganasarajah et al., 2019; Ortega et al., 2012). Premature mortality, especially through an elevated risk of suicide before the age of 55, further underscores the implications of low muscular endurance (Ortega et al., 2012). Flexibility, crucial for physical well-being, is particularly important in athletics, positively influencing essential fitness components such as muscle power and strength (Arntz et al., 2023). Poor trunk flexibility is linked to arterial stiffness, affecting athletic performance and causing lower back pain in elite divers (Carrol & Mock, 2023; Šrmpf et al., 2019). Therefore, maintaining and enhancing health-related physical fitness components such as cardiovascular endurance, muscular endurance, and flexibility is crucial for overall health, disease prevention, and both physical and psychological well-being.

Artificial intelligence exercise prescription refers to the application that uses artificial intelligence to generate a training program based on the prompt given to the application. Meanwhile, Artificial intelligence-generated training programs were rising in the discipline of fitness. Artificial intelligence was used in assistance through recommendations based on neural networks and logistic regression based on its user (Tran et al., 2018; Ijsrem journal, 2023) through evolutionary computation and swarm intelligence (Fister, 2017). Its training program output was suggested to be an effective way to improve leg power, agility, vertical pulling movements, and squat movement (Du, 2021). Also, it can generate high-specificity training programs, which improves physical fitness (Wang & Park, 2021). It can also substitute for opponents by mimicking fundamental athlete movements, enhancing the quality of training sessions (Lei, 2023). Also, it can even provide feedback on the movement patterns of the exercisers during weight training. (Novatchkov and Baca, 2013). It was found that AI-generated training programs from ChatGPT 3.5 and ChatGPT 4.0 were objectively the same regardless of sex and could be effectively used for training purposes with human intervention (Washif et al., 2024). However, it was also argued that the usage of AI in exercise prescription served as supplemental tools (Cheng et al., 2023) and cannot substitute for personalized progressive and health condition-specific training programs provided by health care and fitness professionals (Zaleski et al., 2024). With this, several studies developed AI-generated systems that assist professionals in work, such as exercise prescriptions for therapy (Ishraque et al., 2018; Pharbu et al., 2020). While AI-generated training programs offer effective and efficient fitness solutions with benefits such as improving physical fitness and mimicking natural athlete movements, They should be viewed as supplemental tools to support, rather than replace, personalized training provided by healthcare and fitness professionals.

The literature about artificial intelligence on fitness was diverse. However, it needs to include careful investigation of Artificial intelligence-generated training programs and their effect on physical fitness. Also, it is essential to compare the trend of the traditional training program that humans created. With this, individuals will have an idea and caution about using AI on their fitness journey. Lastly, It was suggested that the impact of Artificial intelligence on fitness should be furthered explored (Prashar et al., 2023), and its validity and reliability should be put in rigor checking (Saadati. 2023). The study aims to investigate the effect of a 5-week Artificial intelligence-generate Calisthenics training program on health-related physical fitness components such as flexibility, cardiovascular endurance, and muscular endurance. Specifically, it also investigated the effect of an adopted calisthenic training program. A comparative analysis was done between artificial intelligence-generated and adopted calisthenic training programs regarding their effectivity on improving the aforementioned physical fitness components. Lastly, it has a sex-specific approach to its investigation between the independent variables and dependent variables.

METHODOLOGY

Research design

The study utilized a quasi-experimental design. Specifically, it used one group pre-test-post-test design on the within-group comparison. As for the between-group comparison, a two-group pre-test-post-test design was utilized. The experimental design was implemented to fully understand the causal relationship between the independent variables (Human-made and Artificial Intelligence training programs) and dependent variables (Selected health-related physical fitness components).

Sampling and participants

The study's participants were 87 untrained collegiate students who were selected using a purposive sampling method. The inclusion criteria were set, which are (1) a bonafide student of the locale of the study, (2) no formal or habitual training, and (3) no medical issues that can be worsened or triggered by moderate to

vigorous activity. Table 1 shows the distribution of the participants based on group and sex. Artificial Intelligence-generated calisthenics training program group (AIGCTP) was the group who were administered by the 5-week Artificial Intelligence-generated calisthenics training program. The said training program was generated using ChatGPT 3.5. The group comprises 24 females, who comprise 27.59% of the participants. 19 male participants completed the 21.84 %. In totality, the group consists of 49.43% of the AIGCTP group. The Human-made calisthenics training program group (HMCTP) was administered by an adopted calisthenics training program from a study. The group had the remaining 50.57% of the participants, composed of 44 members. Female participants comprised 20, which is 22.99% of the participants. As for male participants, they consist of 49.43%. The HMCTP group comprises 50.57% of the participants by having 44 participants. The study had 87 participants.

Table 1. Distribution of sex of the participants per group.

	Female	Male	Total
AIGCTP	24(27.59%)	19(21.84%)	43(49.43%)
HMCTP	20(22.99%)	24(27.59%)	44(50.57%)
Total	44(50.57%)	43(49.43%)	87(100%)

Table 2 shows the body composition of both groups. The AIGCTP group had a mean height of 164.97 ± 7.61 cm and a mean weight of 61.91 ± 10.70 kg. In totality, the body mass index of the group was 22.79 ± 3.90 . On the other hand, the HMCTP group had a mean height of 164.97 ± 7.61 cm and a mean weight of 64.63 ± 11.88 kg. This constitutes the mean body mass index of 23.91 ± 4.24 . Despite the groupings, the participants had a mean height of 164.74 ± 7.31 and a mean weight of 63.28 ± 11.33 , contributing to the mean body mass index of 23.36 ± 4.09 .

Table 2. Distribution of the body composition of the participants per group.

	AIGCTP	HMCTP	Total
Height	164.97 ± 7.61	164.51 ± 7.08	164.74 ± 7.31
Weight	61.91 ± 10.70	64.63 ± 11.88	63.28 ± 11.33
BMI	22.79 ± 3.90	23.91 ± 4.24	23.36 ± 4.09

Instruments

Several validated and reliable field tests were utilized to quantify the selected health-related physical fitness components used as dependent variables in the study. First, the Sit and Reach Test was used. It is recognized as a valid and reliable field test for measuring the flexibility of the hamstrings and lower back (Amiri-Khorasani et al., 2017). To perform the Sit and Reach Test, tape a measuring stick to the floor with a 24-inch piece of tape at the 15-inch mark, and have the participant warm up with non-ballistic hamstring and lower back exercises. Sitting barefooted with legs extended and feet 12 inches apart, the athlete should slowly reach forward along the measuring stick, exhaling and dropping their head between their arms while keeping hands together and knees extended. The best of three trials is recorded to the nearest 0.25 inches or 1 cm, with scores below 15 inches indicating the athlete could not reach their feet. Secondly, a field test that measures cardiovascular endurance was used; the Three-Minute Step Test is recognized as a validated and reliable test for cardiovascular endurance, having been utilized across different age groups (Petric et al., 2017). A step height of 12 inches (30.5 cm) is used to administer this test. Participants are instructed to step up and down on the platform at a rate of 96 beats per minute for three minutes. Immediately after the three minutes, participants sit down and measure their heart rates for one full minute. The heart rate is then recorded. Thirdly, the Wall sit test was used to quantify the muscular endurance of the lower extremities. It is recognized as a reliable field test for assessing lower-body muscular endurance among children (Boyer et

al., 2013). To perform this test, the participant should stand with their back against a wall, with feet positioned shoulder-width apart. The participant then slowly slides down the wall until their knees are at a 90-degree angle. This position is held for as long as possible, and the time the position is maintained is recorded. The fourth field test is the Plank Test, a well-supported by numerous studies as a reliable and valid method for assessing core muscle endurance in children and older adults (Bohannon et al., 2017) and youth (Laurson et al., 2022) was utilized in quantifying muscular endurance of the core. To administer this test, the participant begins in a prone position, supporting their weight on their toes and forearms. The body must be kept in a straight line from head to ankles. The participant holds this position for as long as possible, with the duration of time maintained being recorded. Lastly, the muscular endurance of the upper extremities was measured through a One-minute Push-up test. The test is recognized for its robust inter-rater and intra-rater reliability. It confirms its usage as a reliable field test for measuring upper extremity muscular endurance (Fielitz et al., 2016). To perform this test, the participant starts in a plank position with arms straight and hands placed shoulder-width apart. The participant then lowers their body until the chest nearly touches the floor, then pushes back up to the starting position. This cycle is repeated as many times as possible within one minute, and the total number of push-ups completed is recorded. This protocol effectively assesses the muscular endurance of the upper extremities.

Data gathering procedure

Adherence to the training programs

The participants underwent a thorough discussion of the training program. This involves the explanation and demonstration of each exercise incorporated in the programs. Also, guidelines, which include the specification of the training, such as preparatory exercises, instruction on the execution of exercises, and cooldown exercises, were given to the participants. Lastly, the participants were also told to strictly adhere to the training program by refraining from other forms of exercise for ten weeks. Protocols were done to minimize possible threats to internal validity.

Sequence of the field test administration

The study instruments were administered to the participants with a strategic pattern to prevent compounding effects on subsequent tests. Initially, a whole-body warm-up and dynamic stretching were implemented to prepare the participants' bodies. The Sit and Reach Test was administered first, as it was considered a non-fatiguing test. This was followed by muscular endurance testing. The study included three muscular endurance tests: the one-minute push-up test, the plank test, and the wall sit test. These tests were performed with an hour of recovery between each to ensure that the participants' phosphagen (Bognadis et al., 1995; Dawson et al., 1997) and anaerobic glycolytic (Buchheit & Laursen, 2013) energy systems were fully recovered. This recovery period also ensured that subsequent muscular endurance tests were free from the compounding effects of the prior tests. After the muscular endurance tests, the cardiovascular endurance test, a three-minute step test, was administered to the participants.

Pre-testing

The participants underwent the respective field tests for the selected health-related physical fitness components, following the sequence of tests meticulously.

Implementation of the training programs

A day after the pre-testing, the implementation of the respective training programs per group commenced. The AIGTCP group was administered by the 5-week artificial intelligence-generated Calisthenics training program, which was created using ChatGPT 3.5. The prompt includes the specifics of the training program

using the principles of frequency, intensity, time, and type. Below is the exact prompt inputted in the ChatGPT 3.5.

Prompt: Please create a 5-week calisthenics training program with three times sessions per week. Each session should last for 60-90 minutes. The intensity should be tailored for untrained collegiate students.

Using this prompt, a training program was created. Below is the tabular version of the 5-week AI-generated Calisthenics program for untrained collegiate students.

Table 3. 5-week artificial intelligence-generated calisthenics training program.

Weekly schedule	Session duration	Workout structure
<ul style="list-style-type: none"> Three times a week (e.g., Monday, Wednesday, Friday) 	<ul style="list-style-type: none"> 60 to 90 minutes each. Each session is divided into a Warm-up, Main Workout, and Cool-down phase. 	<ul style="list-style-type: none"> Intensity: Exercises are performed at a moderate pace where students can complete all repetitions with good form but feel challenged by the last two reps of each set.
Warm-Up (15 minutes)		Main workout (40-65 minutes)
<ul style="list-style-type: none"> 5 minutes of light cardiovascular exercise (jogging, jumping jacks). 10 minutes dynamic stretches (arm circles, leg swings, lunges). 	<ul style="list-style-type: none"> Intensity: Exercises are performed at a moderate pace where students can complete all repetitions with good form but feel challenged by the last two reps of each set. 	
Circuit 1: Upper body & core (repeat circuit 3 times)	Circuit 2: Lower body & agility (repeat circuit 3 times)	Circuit 3: Core & balance (repeat circuit 3 times)
<ul style="list-style-type: none"> Push-Ups - 3 sets of 8-12 reps. Dips (using a bench) - 3 sets of 8-10 reps. Plank - 3 sets of 30-45 seconds. 	<ul style="list-style-type: none"> Bodyweight Squats - 3 sets of 12-15 reps. Lunges - 3 sets of 10 reps per leg. Box Jumps (or step-ups if no box available) - 3 sets of 8-10 reps. 	<ul style="list-style-type: none"> Leg Raises - 3 sets of 10-12 reps. Russian Twists - 3 sets of 15 reps per side. Bird-Dog (alternating arms and legs) - 3 sets of 10 reps per side.
Cool-Down (10-15 minutes)		
<ul style="list-style-type: none"> 5 minutes of slow walking or gentle jogging to bring the heart rate down. 5-10 minutes of static stretching focusing on all major muscle groups. 		
Notes on progression and intensity		
<ul style="list-style-type: none"> Progression: Increase the number of reps or sets every two weeks by 10-20% as fitness improves. 	<ul style="list-style-type: none"> Intensity Adjustments: If the workouts become too easy, variations can be introduced to increase the difficulty, such as elevating feet for push-ups or adding a light backpack for squats and lunges. Rest Between Circuits: Aim for 1-2 minutes of rest between circuits to maintain a good workout pace without leading to excessive fatigue. 	

On the other hand, the human-made calisthenics training program was made by adopting a calisthenics training program of a study. Originally, the training program was designed for 10 weeks. For the purpose of similarity of training duration, it was compressed into 5 weeks. The HMCTP group participated in a 5-week

whole-body calisthenic program involving three sessions per week (Masagca, 2024). Each session comprised six exercises targeting the upper and lower body and the core. The training program progressed by introducing progressively more kinetically demanding exercises. In each session, the participants were asked to do warm-ups and dynamic stretching as preparatory exercises. To conclude the session, cooldown exercises in the form of static stretching. The adopted 5-week whole-body calisthenic program is outlined in the Table 4.

Table 4. 5-week human-made calisthenics training program.

Training Program A (Week 1-2)		
Upper body	Core	Lower body
Wall push up	Dead bug position	Kneeling hip hinge
Chair push up	Straight leg Lift raise	Standing double leg hip hinge
Training Program B (Week 3-4)		
Negative Knee Push up	Dead bug with hip, knee, and shoulder extension (Same side)	Chair Squat
Knee pushes up	Leg raises	Squat with a chair as assistance
Training Program C (Week 5)		
Negative Push-ups	Dead bug with hip, knee, and shoulder extension (Contralateral)	Body weight squats
Push-ups	Isometric hold leg raises	Hinge Squat

Post testing

The participants underwent the same field-testing protocol after 48 to 72 hours of recovery. This recovery period was set in order to minimize the effect of the last training sessions on the components that need to be measured (Goulart et al., 2020; Robineau et al., 2016).

Data analysis

The study utilized a paired t-test for the within-group comparison of each calisthenics training program on the selected health-related physical fitness components. As for the between-group comparison, an independent sample t-test was used. The significance level was set to $p < .05$ for discrepancies to be categorized as significant.

Potential ethical issues

The participants were given a comprehensive briefing on the study, which included a discussion about their rights within the study context. Afterwards, individuals were asked to provide informed consent by completing a consent letter. Subsequently, a Physical Readiness Questionnaire was administered to ascertain the presence of any concealed medical conditions among the subjects. To conclude, it is essential to emphasize that the acquired data was handled with utmost confidentiality and disclosed to the owner upon their request.

RESULTS

The AIGCTP Group underwent various physical fitness tests for flexibility, muscular endurance, and cardiovascular endurance before and after the administration of the artificial intelligence-generated 5-week calisthenics training program. Table 5 shows the pre-test and post-test data for the AIGTCP Group. Also, it has sex-specific within-group comparisons. Despite sex, the flexibility of the lower extremities was significantly increased ($SART^{Pretest} = 46.43 \pm 8.83$, $SART^{Posttest} = 53.80 \pm 21.94$, $t = 2.82$, $p < .05$). This was also the case for the muscular endurance of the upper extremities ($OMPUT^{Pretest} = 15.86 \pm 9.77$,

OMPUT^{Posttest} = 22.48 ± 12.36, $t = 3.45$, $p < .05$). contradictorily. The muscular endurance of the core was found to be significantly increased by the said training program (PT^{Pretest} = 76.44 ± 36.88, PT^{Posttest} = 64.57 ± 41.76, $t = 2.13$, $p < .05$). The cardiovascular endurance (3MST^{Pretest} = 146.26 ± 24.02, 3MST^{Posttest} = 154.98 ± 80.35, $t = 0.74$, $p = .46$) and muscular endurance of the lower extremities (WST^{Pretest} = 51.40 ± 35.59, WST^{Posttest} = 51.19 ± 36.15, $t = -0.07$, $p = .95$) were insignificantly changed by the administration of the training program. For female participants, insignificant changes were observed throughout all of the health-related physical fitness components such as flexibility of the lower extremities (SART^{Pretest} = 46.16 ± 8.99, SART^{Posttest} = 54.68 ± 28.18, $t = 1.88$, $p = .07$), cardiovascular endurance (3MST^{Pretest} = 146.52 ± 25.83, 3MST^{Posttest} = 160.68 ± 77.38, $t = 1.01$, $p = .32$), and muscular endurance of the lower extremities (WST^{Pretest} = 49.26 ± 26.99, WST^{Posttest} = 49.14 ± 25.14, $t = -0.03$, $p = .97$), core (PT^{Pretest} = 68.01 ± 31.33, PT^{Posttest} = 54.28 ± 35.86, $t = -1.72$, $p = .10$), and upper extremities (OMPUT^{Pretest} = 12.29 ± 6.13, OMPUT^{Posttest} = 14.76 ± 5.21, $t = 1.95$, $p = 0.06$). Finally, it was seen that the male participants' lower limb flexibility (SART^{Pretest} = 46.79 ± 8.85, SART^{Posttest} = 52.63 ± 9.68, $t = 4.73$, $p < .05$) and upper limb muscular endurance (OMPUT^{Pretest} = 20.61 ± 11.74, OMPUT^{Posttest} = 32.63 ± 11.72, $t = 3.15$, $p < .05$) were both significantly higher. However, insignificant changes were suggested for cardiovascular endurance (3MST^{Pretest} = 145.89 ± 21.98, 3MST^{Posttest} = 147.47 ± 85.64, $t = 0.07$, $p = .94$), muscular endurance of the lower extremities (WST^{Pretest} = 54.21 ± 45.17, WST^{Posttest} = 53.89 ± 47.60, $t = -0.06$, $p = .95$) and the core (PT^{Pretest} = 87.53 ± 41.37, PT^{Posttest} = 78.11 ± 45.45, $t = -1.22$, $p = .24$).

Table 5. Pre and Post-test of the AIGCTP Group.

	Pre-test	Post-test	t-value	p-value
All				
SART	46.43 ± 8.83	53.80 ± 21.94	2.82	<.05
3MST	146.26 ± 24.02	154.98 ± 80.35	0.74	.46
WST	51.40 ± 35.59	51.119 ± 36.15	-0.07	.95
PT	76.44 ± 36.88	77.57 ± 41.76	2.13	<.05
OMPUT	15.86 ± 9.77	22.48 ± 12.36	3.45	<.05
Female				
SART	46.16 ± 8.99	54.68 ± 28.18	1.88	.07
3MST	146.52 ± 25.83	160.68 ± 77.38	1.01	.32
WST	49.26 ± 26.99	49.14 ± 25.14	-0.03	.97
PT	68.01 ± 31.33	54.28 ± 35.86	-1.72	.10
OMPUT	12.29 ± 6.13	14.76 ± 5.21	1.95	.06
Male				
SART	46.79 ± 8.85	52.63 ± 9.68	4.73	<.05
3MST	145.89 ± 21.98	147.47 ± 85.64	0.07	.94
WST	54.21 ± 45.17	53.89 ± 47.60	-0.06	.95
PT	87.53 ± 41.37	78.11 ± 45.45	-1.22	.24
OMPUT	20.61 ± 11.74	32.63 ± 11.72	3.15	<.05

The HGCTP Group underwent various physical fitness tests for flexibility, muscular endurance, and cardiovascular endurance before and after the administration of the adopted calisthenics program (Masagca, 2024) for 5 weeks. Table 6 shows the pre-test and post-test data for the HGCTP Group. Despite sex, the flexibility of the lower extremities was significantly increased (SART^{Pretest} = 45.12 ± 9.62, SART^{Posttest} = 50.30 ± 10.33, $t = 3.87$, $p < .05$). This was also the case for the muscular endurance of the upper extremities (OMPUT^{Pretest} = 19.81 ± 8.30, OMPUT^{Posttest} = 24.72 ± 10.91, $t = 2.81$, $p < .05$) and the muscular endurance of the lower extremities (WST^{Pretest} = 52.71 ± 23.44, WST^{Posttest} = 74.78 ± 69.04, $t = 2.65$, $p < .05$). The

cardiovascular endurance ($3MST^{Pretest} = 115.07 \pm 35.70$, $3MST^{Posttest} = 105.40 \pm 24.94$, $t = -1.93$, $p = .06$) and muscular endurance of the core ($PT^{Pretest} = 88.43 \pm 65.85$, $PT^{Posttest} = 77.88 \pm 57.84$, $t = -1.51$, $p = .14$) were insignificantly changed by the administration of the training program. For female participants, insignificant changes were observed throughout all of the health-related physical fitness components such as flexibility of the lower extremities ($SART^{Pretest} = 44.68 \pm 8.60$, $SART^{Posttest} = 47.24 \pm 7.91$, $t = 1.77$, $p = .09$), cardiovascular endurance ($3MST^{Pretest} = 110.63 \pm 35.35$, $3MST^{Posttest} = 106.44 \pm 28.02$, $t = -0.11$, $p = .91$), muscular endurance of the lower extremities ($WST^{Pretest} = 52.38 \pm 17.40$, $WST^{Posttest} = 59.08 \pm 18.42$, $t = 1.29$, $p = .21$), core ($PT^{Pretest} = 71.68 \pm 27.43$, $PT^{Posttest} = 65.47 \pm 25.50$, $t = -1.16$, $p = .26$), and upper extremities ($OMPUT^{Pretest} = 16.42 \pm 7.13$, $OMPUT^{Posttest} = 16.84 \pm 6.34$, $t = 0.24$, $p = .81$). Finally, it was seen that the male participants' lower limb flexibility ($SART^{Pretest} = 45.46 \pm 10.53$, $SART^{Posttest} = 52.77 \pm 11.47$, $t = 3.53$, $p < .05$), cardiovascular endurance ($3MST^{Pretest} = 120.83 \pm 33.18$, $3MST^{Posttest} = 104.63 \pm 22.96$, $t = -3.94$, $p < .05$), upper limb muscular endurance ($OMPUT^{Pretest} = 22.50 \pm 8.30$, $OMPUT^{Posttest} = 30.96 \pm 9.71$, $t = 3.21$, $p < .05$), and lower limb muscular endurance ($WST^{Pretest} = 52.98 \pm 27.68$, $WST^{Posttest} = 87.21 \pm 89.85$, $t = 2.43$, $p < .05$) were all significantly higher. However, insignificant changes were suggested for the muscular endurance of the core ($PT^{Pretest} = 101.69 \pm 83.15$, $PT^{Posttest} = 87.81 \pm 73.29$, $t = -0.24$, $p = 1.17$).

Table 6. Pre and Post-test of the HGCTP Group.

	Pre-test	Post-test	t-value	p-value
All				
SART	45.12 ± 9.62	50.30 ± 10.33	3.87	<.05
3MST	115.07 ± 35.70	105.40 ± 24.94	-1.93	.06
WST	52.71 ± 23.44	74.78 ± 69.04	2.65	<.05
PT	88.43 ± 65.85	77.88 ± 57.84	-1.51	.14
OMPUT	19.81 ± 8.30	24.72 ± 10.91	2.81	<.05
Female				
SART	44.68 ± 8.60	47.24 ± 7.91	1.77	.09
3MST	110.63 ± 35.35	106.44 ± 28.02	-0.11	.91
WST	52.38 ± 17.40	59.08 ± 18.42	1.29	.21
PT	71.68 ± 27.43	65.47 ± 25.50	-1.16	.26
OMPUT	16.42 ± 7.13	16.84 ± 6.34	0.24	.81
Male				
SART	45.46 ± 10.53	52.77 ± 11.47	3.53	<.05
3MST	120.83 ± 33.18	104.63 ± 22.96	-3.94	<.05
WST	52.98 ± 27.68	87.21 ± 89.85	2.43	<.05
PT	101.69 ± 83.15	87.81 ± 73.29	-0.24	1.17
OMPUT	22.50 ± 8.30	30.96 ± 9.71	3.21	<.05

Table 7 shows the comparison between AIGTCP and HGTCG on the selected health-related physical fitness components. Despite sex, among all of the components, only the cardiovascular endurance was found to be significantly different between the two groups ($3MST^{AIGTCP} = 154.98 \pm 80.35$, $3MST^{HGTCG} = 105.40 \pm 24.94$, $t = 3.82$, $p < .05$). However, the flexibility of the lower extremities ($SART^{AIGTCP} = 53.80 \pm 21.94$, $SART^{HGTCG} = 50.30 \pm 10.33$, $t = 0.94$, $p = .97$), and muscular endurance of lower extremities ($WST^{AIGTCP} = 51.19 \pm 36.15$, $WST^{HGTCG} = 74.78 \pm 69.04$, $t = 2.00$, $p = .15$), core ($PT^{AIGTCP} = 64.57 \pm 41.76$, $PT^{HGTCG} = 77.88 \pm 57.84$, $t = 1.23$, $p = .62$), and upper extremities ($OMPUT^{AIGTCP} = 22.48 \pm 12.36$, $OMPUT^{HGTCG} = 24.72 \pm 10.91$, $t = 0.90$, $p = .61$) were found to be insignificantly different between each group. For female participants, only the cardiovascular endurance was significantly different between the two groups ($3MST^{AIGTCP} = 160.68 \pm 77.38$,

3MST^{HGTC} = 106.44 ± 28.02, $t = 0.01$, $p < .05$). Contradictorily, Flexibility of the lower extremities (SART^{AIGTC} = 54.68 ± 28.18, SART^{HGTC} = 47.24 ± 7.91, $t = 0.27$, $p = .27$), muscular endurance of lower extremities (WST^{AIGTC} = 49.14 ± 25.14, WST^{HGTC} = 59.08 ± 18.42, $t = 0.15$, $p = .15$), core (PT^{AIGTC} = 54.28 ± 35.86, PT^{HGTC} = 65.47 ± 25.50, $t = 0.25$, $p = .25$), and upper extremities (OMPUT^{AIGTC} = 14.76 ± 5.21, OMPUT^{HGTC} = 16.84 ± 6.34, $t = 0.24$, $p = .24$) were insignificantly different between the two group. For male participants, cardiovascular endurance and muscular endurance of lower extremities were significantly different between the two groups. The cardiovascular endurance (3MST^{AIGTC} = 147.47 ± 85.64, 3MST^{HGTC} = 104.63 ± 22.96, $t = 0.02$, $p < .05$) and muscular endurance of lower extremities (WST^{AIGTC} = 53.89 ± 47.60, WST^{HGTC} = 87.21 ± 89.85, $t = 0.15$, $p < .05$) showed significant differences. Flexibility of the lower extremities (SART^{AIGTC} = 52.63 ± 9.68, SART^{HGTC} = 52.77 ± 11.47, $t = 0.97$, $p = .35$), muscular endurance of the core (PT^{AIGTC} = 78.11 ± 45.45, PT^{HGTC} = 87.81 ± 73.29, $t = 0.62$, $p = .22$), and upper extremities (OMPUT^{AIGTC} = 32.63 ± 11.72, OMPUT^{HGTC} = 30.96 ± 9.71, $t = 0.61$, $p = .37$) were insignificantly different between each group.

Table 7. Post-test data comparison between AIGTCP Group vs HGCTP Group

	AIGTCP	HGCTP	t-value	p-value
All				
SART	53.80 ± 21.94	50.30 ± 10.33	0.94	.97
3MST	154.98 ± 80.35	105.40 ± 24.94	3.82	<.05
WST	51.119 ± 36.15	74.78 ± 69.04	2.00	.15
PT	77.57 ± 41.76	77.88 ± 57.84	1.23	.62
OMPUT	22.48 ± 12.36	24.72 ± 10.91	0.90	.61
Female				
SART	54.68 ± 28.18	47.24 ± 7.91	0.27	.27
3MST	160.68 ± 77.38	106.44 ± 28.02	0.01	<.05
WST	49.14 ± 25.14	59.08 ± 18.42	0.15	.15
PT	54.28 ± 35.86	65.47 ± 25.50	0.25	.25
OMPUT	14.76 ± 5.21	16.84 ± 6.34	0.24	.24
Male				
SART	52.63 ± 9.68	52.77 ± 11.47	0.97	.35
3MST	147.47 ± 85.64	104.63 ± 22.96	0.02	<.05
WST	53.89 ± 47.60	87.21 ± 89.85	0.15	<.05
PT	78.11 ± 45.45	87.81 ± 73.29	0.62	.22
OMPUT	32.63 ± 11.72	30.96 ± 9.71	0.61	.37

DISCUSSION

The artificial intelligence-generated calisthenics training program was implemented for five weeks among a group of untrained collegiate students. Within-group comparisons were done. It was found that the AIGTCP group has significantly increased lower extremity flexibility and muscular endurance of the core and upper extremities. The result of the present study was supported by a previous study about an AI-based assistant training system and its causal relationship with specific physical fitness parameters. In the previous study, muscular endurance was found in the upper extremities. The aforementioned training system has improved the muscular endurance of vertical pulling muscles. (Du,2021), This was observed by increased pull-up repetitions after administering the aforementioned training program. In the present study, the artificial intelligence-generated calisthenics training program also improved the muscular endurance of the upper extremities, mainly horizontal pushing. The previous study's AI-generated training program improved

sprinting and standing long jumps (Du, 2021). This can also be indirectly explained by the present study result, as sprinting performance positively correlates with muscular endurance of hip flexion and extension and the core (Ogata et al., 1998; Delecluse, 1997; Phyne et al., 2008). Also, the correlation between prone bridge performance and sprint acceleration was established (Afandi et al., 2021; Shaikh et al., 2019; Santos et al., 2019). This means that the improvement in sprinting performance due to artificial intelligence-prescribed exercise is indirect in the muscular endurance of the core. This is the same case for the flexibility of the lower extremities. It was suggested that the flexibility of the hamstring muscles has a high correlation with long jump performance (Rahim et al., 2020). Also, flexibility training on the lower extremities has increased jumping ability (Konstantinos et al., 2015). This signifies that the improvement in jumping performance is due to artificial intelligence-prescribed exercise (Du, 2021), which is also an indirect improvement in flexibility. The AIGCTP insignificantly improved the participants' Cardiovascular and muscular endurance. No previous studies directly support the insignificant causal relationship between the AI-generated training program and the physical fitness components, cardiovascular endurance, and muscular endurance of the lower extremities. With this, the result of the study was authentic. However, the result should be reviewed and validated by replicating the study. However, it can be explained by principles of training. The training program created through artificial intelligence was suggested to be lacking in generating specific exercises that may improve the muscular endurance of the lower extremities. Training specificity is essential in training to promote desired adaptations (Coffey & Hawley, 2017; Brearley & Bishop, 2019). Although lower extremities exercises were suggested, these target the isotonic contraction of the lower extremities muscles. The wall sit test tested the isometric contraction capability of the said muscle group. As for cardiovascular endurance, there was also a problem with the specificity of the generated training. An aerobic calisthenics training program was more specific and suitable than a calisthenics training program in improving cardiovascular endurance (Sakinah et al., 2022). The effects of the aforementioned training program were also investigated with sex-specificity. For female participants, all of the selected health-related physical fitness components were insignificantly changed by the training program. As for male participants, only the flexibility of the lower extremities and muscular endurance of the upper extremities were significantly increased by the implementation of the training program. With this, the result of the present study is suggested to be validated by exploring the causal relationship of Artificial Intelligence integration on fitness modalities and physical fitness components. Moreover, sex-specific investigations should be carried out.

Also, within-group comparisons were done for the human-generated calisthenics training program, which was implemented for 5 weeks. It improves the flexibility and muscular endurance of the lower and upper extremities of the participants. On flexibility, the calisthenics training program was established to improve the hamstring muscles after implementation of it in students (Sakinah et al., 2022), soccer players (Panihar & Rani, 2022), and the sedentary population (Girish & Mathew, 2022). Also, calisthenics exercise improves the muscular endurance of the upper extremities among the obese population (Sakinah et al., 2022). Specifically, push was found to be an effective modality in improving the upper extremity muscular endurance and strength (Kotarsky et al., 2018); as for lower extremities' muscle endurance, calisthenics was as effective as repetitive sprinting in improving the muscularity of the lower extremities (Ölmez & Akcan, 2021). Also, Improved muscular endurance through improved aerobic endurance was seen in cyclists who engaged in calisthenics training (Kul et al., 2022). For those with cerebral palsy, calisthenic exercises improve the lower extremities' muscularity and aerobic capacity (You and Choi, 2022). No previous studies directly support the insignificant causal relationship between the Human-generated training program and the core's physical fitness components, cardiovascular endurance, and muscular endurance. With this, the result of the study was authentic. However, the result should be reviewed and validated by replicating the study. However, it can be explained by principles of training. The training program was lacking in generating specific exercises that may improve the muscular endurance of the core muscles. Training specificity is essential in training to

promote desired adaptations (Coffey & Hawley, 2017; Brearley & Bishop, 2019). Although core exercises were suggested, these target the isotonic contraction of the core muscles. The plank test tested the isometric contraction capability of the said muscle group. As for cardiovascular endurance, there was also a problem with the specificity of the generated training. An aerobic calisthenics training program was more specific and suitable than a calisthenics training program in improving cardiovascular endurance (Sakinah et al., 2022). The effect of the training program based on sex was also studied. For female participants, the training program insignificantly changed all of the selected health-related physical fitness components. Male participants were observed to have increased all of the health-related physical fitness components except the muscular endurance of the core. With this, the result of the present study is suggested to be validated by exploring the causal relationship between calisthenics and physical fitness components. Moreover, sex-specific investigations should be carried out.

Between-group comparisons were done for the AIGCTP and HGCTP groups. Despite sex, it was found that the cardiovascular endurance of the HGCTP group was significantly superior to that of the AIGCTP group. This was the same case for the male and female participants. For males, muscular endurance of the lower extremities of those HGCTP was significantly higher than that of the AIGCTP. Studies about the comparison of AI-generated training programs versus traditional training programs were few.

CONCLUSION

The artificial intelligence-generated calisthenics training program effectively improved the flexibility of the lower extremities and muscular endurance of the core and upper extremities. Specifically, females do not improve in all health-related physical fitness components. However, males had an improvement in both flexibility of the lower extremities and muscular endurance of the upper extremities. The human-generated calisthenics training program was suggested to be effective in improving the flexibility and muscular endurance of the lower and upper extremities of all the participants. Specifically, females do not improve in all health-related physical fitness components. Improvements in Flexibility of the lower extremities, cardiovascular endurance, and muscular endurance of the lower and upper extremities were seen in male participants. Between-group comparisons were done for the AIGCTP and HGCTP groups. Despite sex, it was found that the cardiovascular endurance of the HGCTP group was significantly superior to that of the AIGCTP group. This was the same case for the male and female participants. For males, muscular endurance of the lower extremities of those HGCTP was significantly higher than that of the AIGCTP. The result of the study implies that the use of artificial intelligence in exercise prescription for fitness is possible. However, it still cannot be substituted for professional-made fitness training programs as they are still superior in some aspects. It was suggested that further studies should be done on this subject in order to validate the results of the study. Future researchers should focus on validating the results of the present study through replication and expanding the physical fitness components used as dependent variables of the study. Lastly, a higher duration of the training programs is also recommended.

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Characteristics of physical performance in professional female soccer athletes during a national competition

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ABSTRACT

Objectives: Identify the descriptive characteristics of physical performance in different positions, compare physical performance between the first and second half of the match, and determine the association between physical performance variables in professional female soccer athletes during a national competition. **Method:** Fourteen professional women's soccer players participated in the study. Data from fifteen matches of the A1 division of the 2023 Brazilian Championship were collected using GPS devices. Athletes who participated in at least one complete match during the championship's classificatory phase were included. **Results:** The forwards and midfielders have covered greater distances at high and low intensity and maintained a higher average speed than the other positions. However, all positions have reached similar maximum speed values (25.9 ± 1.9 km/h). Significant differences were found between the first and second halves favourable to the first half for total distance ($\Delta = -9.7\%$; $p = .002$), distance per minute ($\Delta = -7.8\%$; $p = .010$), and sprint distance ($\Delta = -11.4\%$; $p = .000$), but not for maximum speed ($\Delta = -0.4\%$; $p = .728$). Pearson's correlation coefficient indicated associations between physical performance variables ranging from 0.567 to 0.850. **Conclusions:** Based on a descriptive analysis, it is suggested that different positions of professional female soccer athletes presented different physical demands during the competition. Lower performance was observed in the second half compared to the first for total distance, distance per minute, and sprint distance, but not for maximum speed. Moderate to high associations were also observed between physical performance variables.

Keywords: Performance analysis, Exercise, Sports medicine, Workload.

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INTRODUCTION

Soccer is a sports modality with intermittent physiological demands, requiring physical efforts performed repeatedly in various technical and tactical movements (Dolci et al., 2020). In this dynamic and unpredictable environment, players run at different intensities with and without the ball, generating a physiological demand requiring a complex energy system interaction throughout the match (Turner & Stewart, 2014).

Studies use displacement variables to compare professional athletes' physical performance levels between matches (Andersson et al., 2010) or between playing positions (Mohr et al., 2008). Through global positioning system (GPS) devices, it is possible to monitor the total distance (Oliva-Lozano et al., 2023), distance per minute (Casamichana et al., 2019), sprint distance (Oliveira Junior et al., 2021), maximum speed (Nobari et al., 2021), among other variables with low levels of coefficient of variation (Scott et al., 2016) to make comparisons in order to understand better the physical performance of athletes during matches.

Some studies present divergent results when comparing soccer matches' first and second halves, showing reduced physical performance (Panduro et al., 2022) or maintaining across different variables (Hewitt et al., 2014; Strauss et al., 2019). This behaviour appears similar when comparing physical performance between positions, in which advantages were found for a given position in a specific variable (e.g., midfielders covering greater total distances than defenders) (Andersson et al., 2010), but no significant differences were found in other variables (e.g., maximum speed was similar between all positions) (Panduro et al., 2022). Furthermore, little is known about the association between physical performance variables in a group of athletes.

Considering that most studies with elite athletes had their samples composed of professional male soccer players (Baptista et al., 2020; Bradley et al., 2010; Carling & Dupont, 2011), the current study presents the possibility of understanding better the behaviour of physical performance variables in a sample of female athletes. The comparison of volume and intensity variables by each playing position and between different halves of the match can provide data to the physical performance analysis to develop substitution strategies during a match, rest of an athlete during the season, regulation of physical performance between the first and second half of the match, determine physiological demands, and structure training programs to increase physical performance (Lopes et al., 2023). Another difference concerns the physical performance variables during a national women's soccer competition to facilitate interpretations of different matches and championships based on this knowledge. Likewise, determining the characteristics of match activity by playing positions in a women's soccer team can help select new talents or indicate potential position changes.

Therefore, the present study aimed to identify the descriptive characteristics of the variables total distance, distance per minute, sprint distance, and maximum speed between the playing positions of the athletes of a professional women's soccer team in the A1 division of the 2023 Brazilian Championship. The study also aimed to compare the physical performance between the first and second halves and determine the association between the physical performance variables in the group of athletes from this same competition. It was hypothesized that there would be significant differences between the two halves of the match for physical performance, with higher values in the first half compared to the second; associations between all physical performance variables would be direct, strong, and significant.

MATERIALS AND METHOD

Sample

Fourteen professional women's soccer players aged 26 ± 5 years, height 1.67 ± 0.06 m, and body mass 61.2 ± 6.3 kg participated in the study. Athletes from an elite team that participated in at least one full match in the A1 division of the 2023 Brazilian Championship were eligible for the study. Athletes absent due to injury throughout

the season were excluded. The procedures recorded here were routine used by the technical staff in charge of the performance analysis and were part of the program established by the head coach throughout the competition. All athletes were informed about the procedures and gave their informed consent.

Study design

This retrospective study used physical performance data collected via GPS devices from a professional women's athletes soccer team participating in the national competition's first stage (round-robin tournament). This competition featured sixteen teams of the elite of Brazilian women's soccer. The teams faced each other in singles matches without return, accumulating fifteen matches in four months.

Procedures

Playertek GPS (Catapult Sports, Melbourne, VIC, Australia) at 10 Hz was used for data collection. The GPS devices were positioned on the athletes' vests, activated ten minutes before the start of the matches, and deactivated immediately after the matches. The devices were positioned in the athletes' interscapular region. All devices were named, and all athletes used the same unit in all matches. The outcome variables were operationally defined according to the manufacturer:

- Total distance (km): sum of all distances the athletes cover during a match at any speed.
- Distance per minute (m/min): distance each athlete covers within sixty seconds.
- Sprint distance (m): sum of distances covered at a high intensity (18 km/h or above for women's soccer).
- Maximum speed (km/h): the highest speed the athlete reaches during the match, regardless of the distance covered in this effort.

Game variables were monitored in real-time using the PlayertekPlus application (Catapult Sports, ver. 1.3.9, Melbourne, VIC, Australia), and the data was exported to the Playertek platform using Sync tool software (Catapult Sports, ver. 5.69, Melbourne, VIC, Australia) on a computer. On the platform, making cuts with each athlete's minutes during the matches was necessary. Subsequently, the changes were saved and exported to a calculation spreadsheet (Microsoft Excel, Office 365, Microsoft Corporation, Redmond, WA, USA), where the study data were stored.

Physical performance variables were collected from fourteen athletes: two forwards, two midfielders, three defensive midfielders, three full-backs, and four central backs. After the fifteen matches, statistical analyses were carried out considering the average of the variables based on the number of complete matches for each athlete and their divisions between the first and second half. The average and standard deviation of the athletes' matches in the competition was 6.1 ± 3.2 . The number of completed matches for each athlete was:

- Central back: athlete 1 (12 matches), athlete 2 (2 matches), athlete 3 (5 matches) and athlete 4 (5 matches).
- Full-back: athlete 5 (10 matches), athlete 6 (6 matches) and athlete 7 (2 matches).
- Defensive midfielder: athlete 8 (6 matches), athlete 9 (2 matches) and athlete 10 (7 matches).
- Midfielder: athlete 11 (6 matches) and athlete 12 (8 matches).
- Forward: athlete 13 (11 matches) and athlete 14 (4 matches).

Statistical analysis

Due to the number of athletes selected for the study ($n = 14$), performing inferential statistics to determine the difference between the playing positions became unfeasible. For this reason, descriptive statistics were carried out to characterize the athletes through the mean, standard deviation, and minimum and maximum values.

Considering all athletes, the Shapiro-Wilk test was used to verify the normality of data distribution for all physical performance variables. A dependent t-test was used to determine whether there was a significant difference for all variables between the first and second halves of the matches during the competition. The delta ($2^{\text{nd}} \text{ half} \times 100 / 1^{\text{st}} \text{ half} - 100$) was used to identify the relative variation between the first and second half. Pearson's correlation coefficient (r), followed by the significance level (P), was used to determine the degree of association between the physical performance variables. Associations with r values below 0.29 were considered very weak, between 0.3 to 0.49 weak, 0.5 to 0.69 moderate, 0.7 to 0.89 strong, and above 0.9 very strong (Mukaka, 2012). All analyses were performed using GraphPad Prism (GraphPad Software Inc., ver. 10, San Diego, CA, USA), and the significance level adopted was $p < .05$.

RESULTS

Table 1 shows the descriptive analysis by positions for the study's four physical performance variables. The physical performance variables did not deviate from normality ($p > .05$). Figure 1 shows the average and individual differences in the physical performance between the first and second half of the athletes in the competition. Table 2 presents the association values between the physical performance variables of the entire team.

Table 1. Descriptive analysis of mean \pm standard deviation (minimum - maximum) by the position of physical performance.

Variables	CB (n = 4)	FB (n = 3)	DM (n = 3)	MF (n = 2)	FW (n = 2)	General (n = 14)
Total distance (km)	9.0 \pm 0.3 (8.8 - 9.5)	8.4 \pm 1.2 (7.1 - 9.4)	8.9 \pm 0.6 (8.5 - 9.6)	9.6 \pm 0.1 (9.5 - 9.7)	9.7 \pm 0.1 (9.7 - 9.7)	9.0 \pm 0.7 (7.1 - 9.7)
Distance per minute (m/min)	91.6 \pm 3.2 (87.9 - 95.5)	85.4 \pm 13.0 (70.4 - 93.2)	97.4 \pm 6.4 (90.0 - 101.5)	97.5 \pm 0.4 (97.2 - 97.8)	98.9 \pm 0.6 (98.4 - 99.3)	93.4 \pm 7.8 (70.9 - 101.5)
Sprint distance (m)	546.7 \pm 182.9 (346.5 - 781.3)	727.6 \pm 323.5 (371.5 - 1003.5)	578.1 \pm 95.2 (479.9 - 670.0)	916.3 \pm 146.4 (812.7 - 1019.8)	789.2 \pm 9.5 (782.5 - 795.9)	679.6 \pm 182.9 (346.5 - 1019.8)
Maximum speed (km/h)	26.6 \pm 1.1 (25.7 - 28.2)	25.3 \pm 3.3 (21.6 - 28.1)	24.5 \pm 2.2 (22.3 - 26.7)	26.8 \pm 1.3 (25.9 - 27.8)	26.8 \pm 0.5 (26.4 - 27.1)	25.9 \pm 1.9 (21.6 - 28.2)

Note. Note: CB: central back; DM: defensive midfielder; FB: full-back; FW: forward; MF: midfielder.

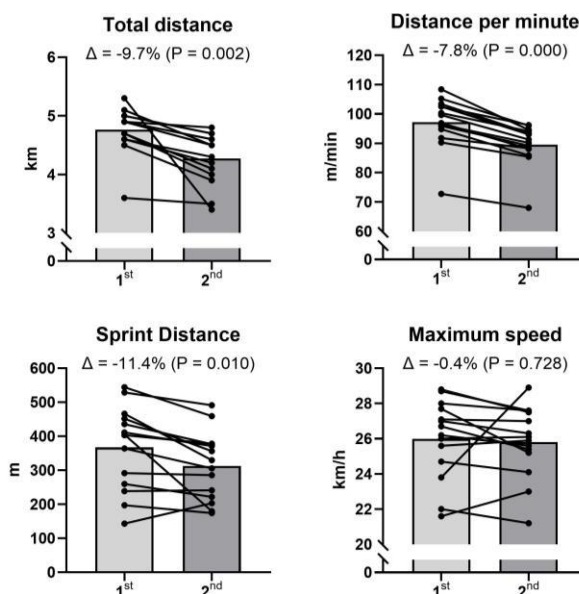


Figure 1. Comparison between the first and second half of physical performance for all athletes and matches.

Table 2. Pearson's correlation coefficient and significance level (P) of physical performance variables for all athletes and matches.

Variables	DM (m/min)	SD (m)	MS (km/h)
TD (km)	0.632 (0.015)	0.850 (0.001)	0.644 (0.013)
DM (m/min)		0.567 (0.034)	0.668 (0.009)
SD (m)			0.621 (0.018)

Note: DM: distance per minute; MS: maximum speed, SD: sprint distance; TD: total distance.

DISCUSSION

The present study had three distinct objectives. Therefore, the discussion was segmented into three subgroups to address the objectives and hypotheses presented, interpret the results, compare with studies in the literature, and inform the limitations and applicability.

Descriptive analysis

Andersson et al. (2010) observed the displacement actions using monitoring cameras in seventeen Swedish and Danish professional female soccer athletes, divided into three groups by position: nine defenders, five midfielders, and three forwards. The results suggest a similarity with those found in the present study, in which midfielders (10.6 ± 0.3 km) had an advantage compared to defenders (9.5 ± 0.9 km) for total distance in international games. It was also possible to observe that the distance of the sprints did not present a significant difference for midfielders (316 ± 51 m) and defenders (221 ± 32 m). A possible explanation for this disagreement may have been the non-subdivision of the group of defenders between central backs and full-backs. The forwards were excluded from the statistical analysis by the authors, who considered the low sample size for this position.

Datson et al. (2017) classified groups by positions closest to those in the current study, comparing the physical performance of professional female soccer athletes in international matches. For this purpose, five different positions were presented, with twenty-five central defenders, twenty-eight wide defenders, thirty-one central midfielders, seventeen wide midfielders, and sixteen forwards. As in the present study, the central midfielders were the athletes with the greatest total distance covered (10.9 ± 0.7 km), and for the distance covered at high-speed running, a variable similar to the sprint distance, lower average values were recorded for the central defenders (423 ± 79 m).

Maximum speed appears to be similar between positions in the present study (25.9 ± 1.9 km/h). However, there are divergent results in the literature, with a study indicating that there was no significant difference in maximum speed between positions (Panduro et al., 2022) while another indicating that defenders (21.9 ± 2.3 km/h) and forwards (22.1 ± 2.4 km/h) presented higher maximum speed values compared to midfielders (21.4 ± 2.1 km/h) (Vescovi, 2012). The tactical aspect may be a factor that influences this variable, indicating that depending on the team's playing style, the maximum speed an athlete can reach may be one of the criteria for selection.

Carrying out a one-way analysis of variance could indicate a false negative result. A significant difference between positions in specific physical performances could be observed with a larger sample of athletes. In this case, we would commit a type 2 error by not rejecting the null hypothesis when it could show a significant difference. With a higher sample, the studies by Panduro et al. (2022) and Vescovi (2012), for example, used a sample size of ninety-four and seventy-one women, respectively, and observed a significant difference between different positions for the sprint distance variable. It is therefore suggested that new studies be carried out with a greater number of athletes from different clubs to test the alternative hypothesis and

possibly show that there would be a significant difference in performance variables between positions. These comparisons could also be made throughout a given competition and observe evolution over time. However, it must be considered that different teams have different playing philosophies and, therefore, different physical qualities compared to other teams.

Inferential analysis

One of the present study's hypotheses was that there would be a significant difference in the athletes' physical performance between the first and second half of the matches during the competition. The hypothesis was confirmed for the variables total distance, distance per minute, and sprint distance; however, it was rejected for maximum speed. Table 3 summarizes some studies that discussed the difference between halves for these physical performance variables collected by GPS devices in female soccer athletes.

Table 3. Studies that compared physical performance between the first and second halves using GPS devices.

Studies	Sample	Comparisons	Summary of results
Present study	14 W Professionals 26 ± 5 years	TD, DM, SD, and MS between the first and second half in 15 matches	TD: 1st ≠ 2nd half ($4.8 \pm 0.4 \neq 4.3 \pm 0.4$ km). DM: 1st ≠ 2nd half ($97.2 \pm 8.7 \neq 89.6 \pm 7.1$ m/min). SD: 1st ≠ 2nd half ($367.2 \pm 112.9 \neq 312.4 \pm 100.1$ m). MS: 1st = 2nd half ($26.0 \pm 2.3 = 25.8 \pm 2.0$ km/h).
Hewitt et al. (2014)	15 W Professionals 24 ± 1 years	TD and SD between the first and second half in 13 matches	TD: 1st = 2nd half ($4.9 \pm 0.1 = 4.7 \pm 0.1$ km). SD: 1st = 2nd half ($173.0 \pm 15.0 = 165.0 \pm 18.0$ m).
Panduro et al. (2022)	94 W Professionals 23 ± 4 years	TD, SD, and MS between the first and second half of 8 teams in a season	TD: 1st ≠ 2nd half (central midfielders: $5.3 \pm 0.5 \neq 5.2 \pm 0.5$ km). SD: 1st ≠ 2nd half (central and external midfielders: $328 \pm 129 \neq 295 \pm 134$ and $459 \pm 158 \neq 404 \pm 169$ m). MS: 1st = 2nd half.
Strauss et al. (2019)	30 W Semi-elite 23 ± 2 years	DM between the first and second half in 10 matches	DM: 1st = 2nd half ($82.8 \pm 11.7 \neq 76.4 \pm 15.6$ m/min).

Note: DM: distance per minute; MS: maximum speed, SD: sprint distance; TD: total distance; W: women; =: $p > .05$; ≠: $p < .05$.

Hewitt et al. (2014) observed a significant reduction in the total distance covered between the first fifteen minutes and the final thirty minutes of the match (-11.4%; $p < .05$) but not between the first and second half (-4.9%; $p > .05$) in a group of fifteen professional female soccer athletes. Panduro et al. (2022) reported that greater distances were covered in the first half only for central midfielders when observing eight Danish Women's League teams. A review study suggests this was probably due to fatigue accumulated during the match, leading to a drop in physical performance in the second half (Mohr et al., 2005). The present study found a significant decrease of 9.7% in the total distance covered between the first and second half of the match. However, this result must be interpreted with caution due to the contextual variables of the matches and competition (Lago-Peñas, 2012).

Strauss et al. (2019) found no significant difference between the first and second half for the distance per minute. This result differs from the present study (1st vs. 2nd half = -7.8%) and can be explained by the high minutes of the same athletes (starters) in the different competition matches analysed in this work. Even so, the average values of distance per minute of the second half of the game of the professional athletes monitored by the present study (89.6 ± 7.1 m/min) seem to be greater than the average values of the first half of the game of the semi-elite athletes analysed by Strauss et al. (2019) (82.8 ± 11.7 m/min) due to category difference.

The sprint distance presented divergent results between studies. While the present study observed a significant decrease of 11.4% in sprint distance between the first and second half of the match, Hewitt et al. (2014) found no difference. However, Panduro et al. (2022) observed a significant difference for very-high-speed running (sprint distance here) between the first and second half only for central midfielders, with higher values found in the first half. A possible reason for this discrepancy in the literature was the lack of a standard for what should be understood as sprint distances and high-intensity distances (Mäkiniemi et al., 2023). The definition of sprint distance varies for distances covered at speeds above 18, 21, 23, and 25 km/h, among other cutoff points (Vescovi, 2012). Variable definitions may also vary depending on the operational settings of the GPS devices.

Panduro et al. (2022) analysed the maximum speed difference between the match's first and second half. In the same way, as in this study, no significant difference was observed for this variable between the halves of the match. Despite the drop in game volume (shorter total distance and sprint distance), the peak speed probably did not change because some decisive plays were carried out at high speeds (Schulze et al., 2022).

One of the study's limitations is that contextual variables such as changes in tactical scheme, climate variations, easier and more difficult matches, and expulsions, among other possibilities, cause behavioural variations during matches and competitions and influence the responses observed in physical performance (Augusto et al., 2021). This can cause changes in behaviour between the halves of the match and generate incongruity in the results found in the literature for the physical performance variables discussed here.

Correlational analysis

Through the association test between physical performance variables, it was possible to identify moderate and significant correlations between total distance and distance per minute ($r = 0.632$, $p = .015$) and between total distance and maximum speed ($r = 0.644$, $p = .013$). This may be an indication that the athletes who have covered the greatest distances are not always the ones who cover the most space on the playing field or who reach the highest peak speed. However, there was a strong association between total distance and sprint distance ($r = 0.850$, $p = .001$). This may indicate that the athletes who covered greater distances also achieved greater distance values at high intensity in the analysed competition.

Distance per minute showed moderate associations compared to sprint distance ($r = 0.567$, $p = .034$) and maximum speed ($r = 0.668$, $p = .009$). Considering these results, it seems that the athletes with higher average speed values were not necessarily those who maintained a higher running intensity or reached higher maximum speeds, highlighting the interrelationship between the volume and intensity of the game.

The moderate correlation found between sprint distance and maximum speed ($r = 0.621$, $p = .018$) did not present the expected result. The initial hypothesis was that athletes who covered greater sprint distances would also have the greatest maximum speed potential. However, the athletes with the highest peak speed were not essentially those who reached the highest sprint distances. It seems that top speed is linked to the ability to accelerate and decelerate (Kobal et al., 2022).

CONCLUSIONS

Based on a descriptive analysis, it was concluded that different positions of professional female soccer athletes present different physical demands during a national competition. The forwards and midfielders seem to have covered greater distances at high and low intensity and maintained a higher average speed

than the midfielders, full-backs, and central backs. However, all positions appear to have reached similar maximum speed values.

According to an inferential analysis, lower physical performance was observed in the second half of the match compared to the first for total distance, distance per minute, and sprint distance, but not for maximum speed. This is probably due to the fatigue accumulated during the match, which led to a drop in physical performance in the second half. However, this result must be interpreted with caution due to the contextual variables of the matches and competition.

The total distance, distance per minute, sprint distance, and maximum speed obtained moderate to strong correlations, all of which were direct and significant. These associations indicated an interrelationship between the volume and intensity of physical performance variables during a competition.

AUTHOR CONTRIBUTIONS

Domingues HC carried out the conceptualization of the study, design of methodology, data curation, and original draft preparation; Soares ALC carried out the conceptualization of the study, design of methodology, data curation, data analysis, and original draft preparation; Gonet DT carried out the conceptualization of the study and draft review; Gomes PSC carried out the conceptualization of the study, design of methodology, data analysis, draft review, and research supervision.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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Comparison of match-play characteristics of junior and professional tennis players

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ABSTRACT

The main purpose of this study was to compare the match-play characteristics of junior and professional tennis players on clay, grass, and hard courts. The match-play characteristics of players who competed and won the matches in the first-round singles main draws of the 2022 French Open, Wimbledon, and US Open Tournaments were obtained from the official web pages. A total of 576 matches (junior = 192, professional = 384) consisting of 288 males and 288 females were analysed. The results of the study indicated that professional players demonstrated significantly higher average set duration and ace per set than juniors on each of the court surfaces. Junior boys had significantly higher return points won on grass and hard courts than professionals. Professional female players performed significantly higher first serve points won and total points won on grass court than junior girls. It was observed that in professional males the variables of first serve points won, ace per set, and double faults per set were significantly higher on grass and hard courts, compared to clay court. Moreover, females performed significantly higher unforced errors per set than males on each of the courts.

Keywords: Performance analysis, Grand slams, Racket sports, Match-play outcomes, Court surface, Match analysis.

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INTRODUCTION

Sport performance is influenced by a multitude of interconnected factors that encompass physiological, psychological, and environmental dimensions (Bali, 2015). Physiologically, an athlete's fitness level, including their fatigue, muscular strength, and flexibility, significantly impacts their performance (Paul et al., 2016; Verschueren et al., 2020). Additionally, nutrition plays a crucial role, as optimal fuelling and hydration contribute to sustained energy levels and enhanced endurance (Malsagova et al., 2021). From a psychological perspective, an athlete's mindset, self-confidence, motivation, and ability to manage stress directly influence their performance outcomes (Murphy, 2012). Moreover, environmental factors such as weather conditions, altitude, and facilities' accessibility can either bolster or impede performance (Davids & Baker, 2007; Brocherie et al., 2015; Bishop & Girard, 2013). The complex interaction among these factors underscores the need for a holistic approach when considering strategies for enhancing sports performance (Bali, 2015; Gomez-Ruano et al., 2020).

The utilization of performance analysis in sports has arisen as a crucial method for improving athletes' and teams' results, as it offers a data-centred structure to enhance training, tactics, and decision-making processes (Hughes & Franks, 2004). Therefore, computerized systems for sports analysis were developed to document athletes' movements and technical manoeuvres, leading to subsequent explorations through descriptive investigations across diverse sports (McGarry et al., 2002). The analysis of match and training performances seeks to uncover both the strengths and areas that require improvement of the players, with the goal of detecting the important training priorities (Lames & McGarry, 2007).

Notational analysts focus on enhancing and assessing sports performance, relying heavily on video analysis and related technology (Hughes & Bartlett, 2002). With increasing technological accessibility to athletes in various sports, the field of performance analysis has advanced over recent years, demonstrating its crucial role in athlete growth, coaching methods, and a substantial edge in competition (Krizkova et al., 2021). During the past few years, a growing body of literature on sports sciences is focused on performance analysis of racket sports such as tennis, table tennis, and squash (Lees, 2003). Technological progress, encompassing visual tracking systems and wearable sensors, has simplified the analysis of the specific requirements in tennis (Pluim et al., 2023). With the similar purpose of the present study, Martin & Prioux (2016) also analysed the match-play statistics of tennis competitions. The present study investigated three different questions of: (1) Are there any differences between junior and professional tennis players in terms of match-play variables on different court surfaces? (2) Are there any court surface related differences in match-play characteristics for both junior and professional players? (3) Are there any differences between male and female tennis players in terms of match-play characteristics on different court surfaces? With the purpose of investigation of these three questions, the present study is different from the study of Martin & Prioux (2016). In addition, the included matches that played on the hard court took place in Australian Open Tournament, while the matches played on the hard court surface in the present study was in the US Open Tournament.

METHOD

The match-play characteristics of players who competed and won the matches in the first-round singles main draws of the 2022 French Open, Wimbledon, and US Open Tournaments were obtained from the official web pages. A total of 192 junior (girls = 96, boys = 96) and 384 professional (women = 192, men = 192) matches (192 matches from each tournament) for each tournament) were analysed. No missing matches or injured players who could not complete their matches were found in tournaments.

The data were collected from the official websites of the three included tournaments. Then, collected data were manually transferred to Microsoft Excel (Microsoft Corp., Version 2016) software. The entire data were double-checked by the authors. Subsequently, the data were transferred to SPSS 27 (IBM Corp., 2020) software to conduct the statistical analysis. Prior to statistical analyses, the normality of the data was checked for each of the analyses. The only non-normal distributed data were males' ace and unforced error variables. However, according to Ghasemi and Zahediasl (2012), violation of normality of data could not cause biased estimations with a sample size larger than 30 or 40. As a result, non-normality of these variables was ignored. One way analysis of variance (ANOVA) was used to measure the effects of court surface. An independent samples t-test was used to analyse the gender and competitive level differences. To measure the effect size in t-tests, Cohen's *d* (Cohen, 1988) was used and classified as: 4.0 (extremely large) effect sizes (Hopkins et al., 2009). Besides, eta squared (η^2) was calculated in ANOVA as: $\eta^2 = 0.01$ (small), $\eta^2 = 0.06$ (medium), $\eta^2 = 0.14$ or higher (large) (Cohen, 1988).

RESULTS

Table 1 represents the descriptive statistics of female players by court surface and t-test results. Three statistically significant differences in match-play characteristics were found in matches played on grass court. Results indicated that professional female players showed a significantly ($p < .05$, $d = -0.50$) higher percentage of winning first serve points, compared to juniors. Moreover, junior female players performed significantly ($p < .01$, $d = 1.27$) more unforced errors per set than professional female players. Moreover, professional female players performed significantly ($p < .05$, $d = 0.43$) higher total points when compared to junior players. No statistically significant differences observed among the other match-play characteristics on grass court. The results demonstrated not statistically significant ($p > .05$) differences between junior and professional players in any of the match-play characteristics on clay court. Since there were no data of winner per set, unforced error per set, net points won and total points won for junior players on the official website of Roland Garros Tournament, comparison could not be made. On hard court, the results revealed that professional female players had significantly ($p < .05$, $d = -0.62$) higher average set duration than juniors. Furthermore, junior female play performed significantly ($p < .05$, $d = 0.53$) higher return points won than professionals. The other characteristics were observed to be similar ($p > .05$).

The descriptive statistics of male players by court surface and t-test results are given in Table 2. The results showed that professional players obtained a significantly ($p < .05$, $d = -0.50$) higher average set duration than juniors on grass court. In addition, aces per set of professional players was significantly ($p < .05$, $d = -0.46$) higher than junior players. Junior players performed significantly ($p < .01$, $d = 0.86$) higher percentage of return points won. Professional players won significantly ($p < .01$, $d = -1.87$) higher total points than juniors. The reason for this difference may be that professional matches are played over 5 sets. The other match-play characteristics on grass court were similar ($p > .05$). On clay court, professional players performed significantly ($p < .05$, $d = -0.50$) higher average set duration, compared to juniors. Additionally, they performed significantly ($p < .05$, $d = -0.53$) higher aces per set. Junior players were observed to have significantly ($p < .01$, $d = 0.61$) higher double fault per set, compared to professionals. No other significant differences were found on clay court. Additionally, no data were found on winner per set, unforced error per set, net points won and total point won were found on the official website of Roland Garros Tournament. Thus, comparison was not possible for these characteristics. On hard court, professionals performed significantly ($p < .05$, $d = -5.52$) higher average set duration than juniors. They also performed significantly ($p < .05$, $d = -0.61$) higher aces per set. Junior players were observed to have a significantly higher percentage of break points ($p < .05$, $d = 0.56$) and return points won ($p < .01$, $d = 0.70$). Professional players acquired significantly ($p < .01$, $d = -1.94$) higher total points won, compared to juniors. This difference may have been caused by the fact that

the matches of professionals are played over 5 sets. The other match-play characteristics on hard court were similar ($p > .05$).

Table 1. Descriptive statistics of female players by court surface and t-test results.

Match-play characteristics	Junior	Professional	t	p	d
Grass court					
1 st serve (%)	59.78 ± 7.06	62.47 ± 7.30	-1.720	.089	0.37
1 st serve points won (%)	68.94 ± 7.31	72.68 ± 7.70	-2.286	.024	-0.50
2 nd serve points won (%)	48.97 ± 12.25	53.02 ± 11.25	-1.613	.110	-0.35
Average set duration (min)	40.95 ± 6.57	40.05 ± 8.84	-0.507	.613	0.11
Aces per set (#)	1.04 ± 1.03	1.28 ± 1.22	-0.974	.332	-0.21
Double faults per set (#)	1.83 ± 1.19	1.52 ± 1.13	1.269	.207	0.28
Winner per set (#)	9.90 ± 4.26	9.38 ± 2.95	0.692	.491	0.15
Unforced error per set (#)	14.76 ± 4.29	9.92 ± 3.57	5.853	.001	1.27
Net points won (%)	61.75 ± 17.68	65.10 ± 17.44	-0.886	.378	-0.19
Break points won (%)	50.47 ± 19.44	55.17 ± 18.47	-1.156	.251	-0.25
Return points won (%)	48.69 ± 6.22	47.47 ± 6.43	0.884	.379	0.19
Total points won	83.44 ± 19.33	75.50 ± 17.80	2.001	.048	0.43
Clay court					
1 st serve (%)	61.31 ± 7.23	63.05 ± 8.73	-0.969	.335	-0.21
1 st serve points won (%)	64.50 ± 8.11	67.84 ± 9.25	-1.737	.086	-0.38
2 nd serve points won (%)	50.5 ± 11.95	51.72 ± 11.95	-0.495	.621	-0.11
Average set duration (min)	42.19 ± 7.07	42.44 ± 8.00	-0.155	.877	-0.03
Aces per set (#)	0.83 ± 0.91	1.14 ± 1.04	-1.456	.149	0.31
Double faults per set (#)	1.64 ± 1.36	1.35 ± 0.99	1.153	.252	0.25
Winner per set (#)	-	10.70 ± 3.59	-	-	-
Unforced error per set (#)	-	10.67 ± 3.62	-	-	-
Net points won (%)	-	69.56 ± 17.63	-	-	-
Break points won (%)	51.63 ± 13.79	50.92 ± 13.79	0.237	.813	0.05
Return points won (%)	49.75 ± 5.69	50.42 ± 5.69	-0.504	.615	-0.11
Total points won	-	-	-	-	-
Hard court					
1 st serve (%)	60.66 ± 6.53	62.47 ± 7.74	-1.137	.258	-0.25
1 st serve points won (%)	68.16 ± 10.76	71.58 ± 8.57	-1.690	.094	-0.37
2 nd serve points won (%)	54.44 ± 13.25	51.81 ± 10.95	1.031	.305	0.22
Average set duration (min)	39.22 ± 9.42	44.46 ± 7.96	-2.859	.005	-0.62
Aces per set (#)	1.17 ± 0.95	1.65 ± 1.47	-1.666	.099	-0.36
Double faults per set (#)	1.60 ± 0.95	1.68 ± 1.10	-0.353	.725	-0.08
Winner per set (#)	9.64 ± 3.52	10.19 ± 3.56	-0.712	.478	-0.15
Unforced error per set (#)	13.15 ± 7.40	11.05 ± 4.22	1.766	.081	0.38
Net points won (%)	65.25 ± 19.81	69.48 ± 15.93	-1.130	.261	-0.25
Break points won (%)	49.19 ± 18.11	54.89 ± 17.08	-1.511	.134	-0.33
Return points won (%)	51.25 ± 7.65	47.47 ± 6.89	2.444	.016	0.53
Total points won	76.53 ± 16.75	76.72 ± 14.77	-0.056	.955	-0.01

Note. # - number.

The ANOVA results for the effects of playing surface in junior and professional players are given in Table 3. No statistically significant ($p > .05$) effect of court surface on any match-play characteristics was observed in junior girls. In addition, there was a lack of data on characteristics of winner per set, unforced error per set, net points won and total points won in the official website of Roland Garros Tournament. Therefore, comparison was not made. In professional female players, court surface was found to be significantly effective in terms of percentage of first serve points won ($p < .05$, $\eta^2 = 0.06$), average set duration ($p < .05$, $\eta^2 = 0.05$) and return points won ($p < .05$, $\eta^2 = 0.04$). Post hoc results revealed that professional female

players performed significantly higher percentage of first serve points won on grass and hard courts, than on clay court.

Table 2. Descriptive statistics of male players by court surface and t-test results.

Match-play characteristics	Junior	Professional	t	p	d
Grass court					
1 st serve (%)	62.59 ± 8.82	62.64 ± 6.27	-0.030	.976	-0.01
1 st serve points won (%)	78.59 ± 7.87	77.13 ± 6.66	0.958	.340	0.21
2 nd serve points won (%)	55.28 ± 11.71	56.80 ± 7.57	-0.765	.446	-0.17
Average set duration (min)	36.80 ± 6.91	40.51 ± 7.68	-2.304	.023	-0.50
Aces per set (#)	2.09 ± 1.40	2.89 ± 1.89	-2.113	.037	-0.46
Double faults per set (#)	1.14 ± 0.66	1.18 ± 0.73	-0.273	.785	-0.06
Winner per set (#)	10.25 ± 2.83	10.96 ± 3.15	-1.079	.283	-0.23
Unforced error per set (#)	9.78 ± 3.91	8.74 ± 2.90	1.465	.146	0.32
Net points won (%)	71.66 ± 10.11	69.33 ± 8.08	1.222	.225	0.26
Break points won (%)	54.97 ± 21.17	47.88 ± 18.78	1.672	.098	0.36
Return points won (%)	45.56 ± 6.58	40.27 ± 5.93	3.975	.001	0.86
Total points won	72.59 ± 15.31	122.89 ± 31.00	-8.651	.001	-1.87
Clay court					
1 st serve (%)	62.97 ± 7.60	63.95 ± 6.04	-0.690	.492	-0.15
1 st serve points won (%)	71.63 ± 7.38	72.59 ± 7.65	-0.592	.556	-0.13
2 nd serve points won (%)	55.78 ± 10.39	56.20 ± 9.89	-0.194	.847	-0.04
Average set duration (min)	39.67 ± 7.98	43.66 ± 8.00	-2.302	.024	-0.50
Aces per set (#)	0.99 ± 1.01	1.72 ± 1.51	-2.452	.016	-0.53
Double faults per set (#)	1.17 ± 0.85	0.77 ± 0.55	2.829	.006	0.61
Winner per set (#)	-	10.48 ± 3.26	-	-	-
Unforced error per set (#)	-	8.61 ± 2.69	-	-	-
Net points won (%)	-	71.88 ± 9.25	-	-	-
Break points won (%)	52.38 ± 16.67	47.19 ± 15.58	1.502	.136	0.33
Return points won (%)	46.41 ± 8.23	44.16 ± 6.91	1.410	.162	0.31
Total points won	-	-	-	-	-
Hard court					
1 st serve (%)	60.16 ± 6.67	60.28 ± 6.17	-0.091	.928	-0.02
1 st serve points won (%)	77.03 ± 7.40	76.98 ± 6.89	0.031	.976	0.01
2 nd serve points won (%)	55.69 ± 11.52	55.59 ± 8.98	0.044	.965	0.01
Average set duration (min)	39.35 ± 10.79	43.70 ± 7.01	-2.378	.019	-0.52
Aces per set (#)	2.06 ± 1.60	3.01 ± 1.56	-2.778	.007	-0.61
Double faults per set (#)	1.32 ± 0.95	1.33 ± 0.94	-0.019	.985	-0.01
Winner per set (#)	9.28 ± 2.49	10.50 ± 3.25	-1.862	.066	-0.40
Unforced error per set (#)	9.41 ± 3.27	9.22 ± 3.10	0.232	.817	0.05
Net points won (%)	67.94 ± 14.07	70.61 ± 15.46	-0.822	.413	-0.18
Break points won (%)	57.88 ± 20.41	48.20 ± 15.44	2.591	.011	0.56
Return points won (%)	46.31 ± 8.29	41.55 ± 5.87	3.253	.002	0.70
Total points won	72.13 ± 17.62	120.23 ± 27.64	-8.964	.001	-1.94

Note. # - number.

Average set duration of females was significantly higher on hard court than grass court. Additionally, percentage of return points won on clay court surface was significantly higher than on grass and hard courts. There were no data on total points won on official website of Roland Garros Tournament. Therefore, it was not possible to compare these characteristics. The other match-play characteristics were not significantly ($p > .05$) different. On the other side, the percentage of first serve points ($p < .01$, $\eta^2 = 0.14$) and aces per set ($p < .05$, $\eta^2 = 0.13$) were found to be significantly affected by court surface in junior boys. Besides, they performed significantly higher percentage of first serve points won on grass court, compared to clay court.

Table 3. ANOVA results for the effects of playing surface in junior and professional players.

Match-play characteristics	F	p	η^2	Post hoc
Girls				
1st serve (%)	0.391	.677	0.01	-
1st serve points won (%)	2.292	.107	0.05	-
2nd serve points won (%)	1.631	.201	0.03	-
Average set duration (min)	1.172	.314	0.03	-
Aces per set (#)	1.042	.357	0.02	-
Double faults per set (#)	0.365	.695	0.01	-
Winner per set (#)	-	-	-	-
Unforced error per set (#)	-	-	-	-
Net points won (%)	-	-	-	-
Break points won (%)	0.159	.853	0.01	-
Return points won (%)	1.227	.298	0.03	-
Total points won	-	-	-	-
Professional female players				
1st serve (%)	0.113	.893	0.01	-
1st serve points won (%)	5.662	.004	0.06	C < G, H; G = H
2nd serve points won (%)	0.272	.762	0.01	-
Average set duration (min)	4.558	.012	0.05	H > G; C = G
Aces per set (#)	2.763	.066	0.03	-
Double faults per set (#)	1.467	.233	0.02	-
Winner per set (#)	2.469	.087	0.03	-
Unforced error per set (#)	1.454	.236	0.02	-
Net points won (%)	1.436	.241	0.02	-
Break points won (%)	1.323	.269	0.01	-
Return points won (%)	4.313	.015	0.04	C > G, H; G = H
Total points won	-	-	-	-
Boys				
1st serve (%)	1.244	.293	0.03	-
1st serve points won (%)	7.5	.001	0.14	G > C; G = H
2nd serve points won (%)	0.018	.982	0.01	-
Average set duration (min)	1.045	.356	0.02	-
Aces per set (#)	6.832	.002	0.13	C < G, H; G = H
Double faults per set (#)	0.460	.633	0.01	-
Winner per set (#)	-	-	-	-
Unforced error per set (#)	-	-	-	-
Net points won (%)	-	-	-	-
Break points won (%)	0.636	.532	0.01	-
Return points won (%)	0.114	.892	0.01	-
Total points won	-	-	-	-
Professional male players				
1st serve (%)	5.842	.003	0.06	C > H; G = C, H
1st serve points won (%)	8.474	.001	0.08	C < H, G; C = H
2nd serve points won (%)	0.295	.745	0.01	-
Average set duration (min)	3.738	.026	0.04	-
Aces per set (#)	11.818	.001	0.11	C < G, H; G = H
Double faults per set (#)	9.47	.001	0.09	C < G, H; G = H
Winner per set (#)	0.461	.631	0.01	-
Unforced error per set (#)	0.648	.524	0.01	-
Net points won (%)	0.798	.452	0.01	-
Break points won (%)	0.062	.94	0.01	-
Return points won (%)	6.431	.002	0.06	C > G; H = C, G
Total points won	-	-	-	-

Note. # - number, G = Grass, H = Hard, C = Clay.

They also had significantly higher aces per set on grass and hard courts than on clay court. There were no data on winner per set, unforced error per set, net points won, and total points won on the official website of Roland Garros Tournament. Thus, comparison was not possible. The other characteristics were insignificant ($p > .05$). The results revealed that percentage of first serve ($p < .05$, $\eta^2 = 0.06$), percentage of first serve points won ($p < .01$, $\eta^2 = 0.08$), average set duration ($p < .05$, $\eta^2 = 0.04$), aces per set ($p < .01$, $\eta^2 = 0.11$), double faults per set ($p < .01$, $\eta^2 = 0.09$) and percentage of return points won ($p < .01$, $\eta^2 = 0.06$) were significantly affected by court surface in professional male players. Post hoc results showed that males had significantly higher percentage of first serve points won, aces per set, and double faults per set on grass and hard courts than on clay court surface. In contrast, they had significantly higher percentage of first serve on clay court than on hard court. Although there was a significant effect of court surface on average set duration, no significant differences were observed in the post hoc results. There were no data on total points won on the official website of Roland Garros Tournament. The other characteristics were found to be similar ($p > .05$).

Table 4. Gender differences by court surface.

Match-play characteristics	Grass			Clay			Hard		
	<i>t</i>	<i>p</i>	<i>d</i>	<i>t</i>	<i>p</i>	<i>d</i>	<i>t</i>	<i>p</i>	<i>d</i>
Juniors									
1 st serve (%)	-1.409	.164	-0.35	-0.893	.375	-0.22	0.303	.763	0.08
1 st serve points won (%)	-5.082	.001	-1.27	-3.677	.001	-0.92	-3.845	.001	-0.96
2 nd serve points won (%)	-2.106	.039	-0.53	-1.887	.064	0.47	-0.403	.689	-0.1
Average set duration (min)	2.463	.017	0.62	1.334	.187	0.33	-0.051	.959	-0.01
Aces per set (#)	-3.455	.001	-0.86	-0.696	.489	-0.17	-2.713	.009	-0.68
Double faults per set (#)	2.91	.005	0.73	1.633	.108	0.41	1.163	.249	0.29
Winner per set (#)	-0.392	.697	-0.1	-	-	-	0.471	.639	0.12
Unforced error per set (#)	4.863	.001	1.22	-	-	-	2.616	.011	0.65
Net points won (%)	-2.752	.008	-0.69	-	-	-	-0.626	.534	-0.16
Break points won (%)	-0.886	.379	-0.22	-0.196	.845	-0.05	-1.801	.077	-0.45
Return points won (%)	1.95	.056	0.49	1.89	.063	0.47	2.475	.016	0.62
Total points won	2.487	.016	0.62	-	-	-	1.025	.309	0.26
Professionals									
1 st serve (%)	-0.143	.887	-0.03	-0.683	.496	-0.12	1.769	.079	0.31
1 st serve points won (%)	-3.488	.001	-0.62	-3.165	.002	-0.56	-3.932	.001	-0.7
2 nd serve points won (%)	-2.231	.027	-0.39	-2.418	.017	-0.43	-2.137	.035	-0.38
Average set duration (min)	-0.311	.756	-0.06	-0.857	.393	-0.15	0.579	.564	0.1
Aces per set (#)	-5.717	.001	-1.01	-2.508	.013	-0.44	-5.074	.001	-0.90
Double faults per set (#)	2.029	.045	0.36	4.169	.001	0.74	1.953	.053	0.35
Winner per set (#)	-2.93	.004	-0.52	0.36	.719	0.06	-0.517	.606	-0.09
Unforced error per set (#)	2.057	.042	0.36	3.661	.001	0.65	2.55	.012	0.45
Net points won (%)	-1.756	.082	-0.31	-0.929	.355	-0.16	-0.405	.686	-0.07
Break points won (%)	2.216	.028	0.39	1.441	.152	0.26	2.323	.022	0.41
Return points won (%)	6.586	.001	1.16	5.333	.001	0.94	5.235	.001	0.93
Total points won	10.606	.001	-1.88	-	-	-	11.108	.001	-1.96

Note. # - number.

Table 4 shows gender differences by court surface. The results showed that junior boys performed significantly higher percentage of first serve points won on grass ($p < .01$, $d = -1.27$), clay ($p < .01$, $d = -0.92$) and hard ($p < .01$, $d = -0.96$) courts. Gender difference in average set duration was present only on grass court. Junior girls performed significantly higher average set duration ($p < .05$, $d = 0.62$) on grass court. Junior boys performed significantly higher aces per set on grass ($p < .01$, $d = -0.86$) and hard ($p < .01$, $d = -0.68$) courts. Double faults per set were significantly higher in junior girls ($p < .01$, $d = 0.73$) on grass court. Gender

difference in double faults per set was not significantly ($p > .05$) present on clay and hard courts. Junior girls were observed to have significantly higher unforced errors per set on grass ($p < .01$, $d = 1.22$) and hard ($p < .05$, $d = 0.65$) courts. Junior boys performed significantly higher percentage of net points won on grass court ($p < .01$, $d = -0.69$). Gender difference in percentage of return points won was observed on clay ($p < .05$, $d = 0.47$) and hard ($p < .05$, $d = 0.62$) courts. Junior females performed significantly higher percentage of return points won. Only gender difference in total points won was observed to be on grass court ($p < .05$, $d = 0.62$). Junior females performed significantly higher total points won on grass court.

There was no significant ($p > .05$) gender difference observed in match-play characteristics of second serve points won, winner per set and break points won in any of the courts. Additionally, there was no data on winner per set, unforced error per set, net points won and total points won in the official website of Roland Garros Tournament. This caused the comparison was not made. In professional players, gender difference in match-play characteristics of percentage of first serve points won, percentage of second serve points won, unforced error per set and return points won was significantly present on grass, clay and hard courts. Professional male players performed significantly higher percentage of first serve points won on grass ($p < .01$, $d = -0.62$), clay ($p < .01$, $d = -0.56$) and hard ($p < .01$, $d = -0.70$) courts, compared to females. Males performed significantly higher percentage of second serve points won on grass ($p < .05$, $d = -0.39$), clay ($p < .05$, $d = -0.43$) and hard ($p < .05$, $d = -0.38$) courts. Gender was significantly effective in aces per set in three courts. Males performed significantly higher aces per set on grass ($p < .01$, $d = -1.01$), clay ($p < .05$, $d = -0.44$) and hard ($p < .01$, $d = -0.90$) courts. Females performed significantly higher double faults per set on grass ($p < .05$, $d = 0.36$) and clay ($p < .05$, $d = 0.74$) courts. Grass court was the only court that gender difference in winner per set was present. On grass court, males performed significantly higher winner per set than females ($p < .01$, $d = -0.52$). Gender was significantly effective in unforced error per set in each three courts. Females performed significantly higher unforced error per set on grass ($p < .05$, $d = 0.36$) clay ($p < .01$, $d = 0.74$) and hard ($p < .05$, $d = 0.35$) courts. Females performed significantly higher percentage of break points won on hard court ($p < .05$, $d = 0.41$). Gender difference in percentage of return points won was observed to be in three courts. Females performed significantly higher percentage of return points won on grass ($p < .01$, $d = 1.16$), clay ($p < .01$, $d = 0.96$) and hard ($p < .01$, $d = 0.93$) courts. At the same time, gender was significantly effective in terms of total points won on grass ($p < .01$, $d = -1.88$) and hard ($p < .01$, $d = -1.96$) courts. No data on total points won on clay court was found in the official website of Roland Garros Tournament. Accordingly, no comparison was made. No significant ($p > .05$) gender difference was found in percentage of first serve, average set duration and net points won in any of court surfaces.

DISCUSSION

The main purpose of this study was to examine the match-play characteristics of match-winning tennis players and compare these characteristics of junior and elite players. It was also aimed in this study to observe the influence of court surface and gender on match-play characteristics. The findings of the study revealed that on each of the court surfaces, professional players exhibited notably longer average set durations and a higher number of aces per set compared to junior players. When compared to junior girls, boys demonstrated significantly higher return points won on grass and hard-court surfaces. Professional females performed significantly higher unforced errors per set than males, regardless of the court surface. Court surface had a significant effect on professional males. The variables of first serve points won, ace per set, and double faults per set were significantly lower on clay court, compared to grass and hard surfaces in males.

Regardless of court surface, aces per set were significantly higher in professional males when compared to junior boys. Additionally, professional females were significantly better at winning first serve points than junior girls. These findings were consistent with the findings of Fernández-García et al. (2020). Kovalchik & Reid (2017) indicated that professional males had significantly higher first serve points won than junior boys but there were no significant differences for females. On the contrary, it was observed in the results of this study that females had significantly higher first serve points than juniors on clay, grass, and hard court surfaces. This inconsistency may be caused by the reason that Kovalchik & Reid (2017) included the match data of different year intervals (from 2000 to 2015), while this study included only Grand Slam Tournaments that took place in the year 2022. Furthermore, no data on Australian Open Tournament were included in the present study.

This study reported that there were significantly higher aces and double faults on grass and hard courts than on clay court in the professional males' category. Similarly, Söğüt (2019) investigated a total of 5138 (clay = 1631, grass = 527, hard = 2980) ATP matches in males' singles category and observed that significantly more aces and double faults were performed on grass court surface than on both other courts. In relation to this difference, Martin & Prioux (2016) stated that court surface have influence on players' playing style, while these differences of match-play characteristics were caused by two main factors as coefficient of friction and coefficient of restitution of different court surfaces. Thus, it may be concluded from these studies that professional male players tend to perform more aces and double faults as type of court surface gets faster.

Gale-Ansodi et al. (2017) investigated gender-related match-play characteristics with a total of 98 (female = 49, male = 49) high-ranked tennis players with a mean age of 14.0 ± 2.9 . According to the results of the study, males performed significantly higher distance covered, maximum speed, and average speed than females. Another study (Breznik, 2013) was conducted to examine the advantages and disadvantages of being right-handed or left-handed in males and females. It was observed in the results that only in males' category, it was significantly more advantageous to be left-handed in players. It can be deduced from these results that when comparing genders and handedness, being a left-handed male is the greatest advantage in terms of demonstrating a better match performance in tennis.

There were several limitations of this study. The first limitation was that there were no data available on match-play characteristics of 2022 Australian Open Tournament on the official website of the tournament. Thus, the inclusion of matches played on 2022 Australian Open was not possible. However, same as Australian Open, US Open Tournament is played on hard court surface as well. Eventually, data of matches played on hard court were able to be reached. The second limitation was that no data of junior players on variables of winner per set, unforced error per set, and net points won were found in the official website of Rolland Garros Tournament. Additionally, total points won were not accessible for both juniors' and professionals' categories. This study investigated match-play characteristics of Wimbledon, US Open and Rolland Garros Tournaments that took place in the year 2022. Future research may focus on long-term comparison of these characteristics to provide non-exceptional results and prevent coincidental findings.

These findings highlight the importance of proper training programs for each age and court surface. There are several suggested practical implications of this study for coaches and athletes. Firstly, when training a tennis athlete, more importance should be given on court-based long-term and short-term training methods to improve the athletes' surface-related performance. Secondly, coaches should take into account the statistical match-play differences between junior and professional players to obtain more accurate information on what causes these differences. Furthermore, gender-based training on different court surfaces should be

applied on both junior and professional athletes. Longitudinal studies are required to have a deeper understanding on athletes' match-play performance and various facets of training methods.

CONCLUSION

This study examined the differences of match-play characteristics of junior and professional tennis players on clay, grass and hard-court surfaces. Professional players exhibited notably greater average set duration and aces per set compared to junior players across all court surfaces. There were notably higher return points won on grass and hard courts in junior boys than on professionals. Professional females displayed notably higher rates of first serve points won and total points won on grass courts. It was evident that among professional male players, metrics such as first serve points won, aces per set, and double faults per set were significantly elevated on grass and hard courts when contrasted with clay courts. Junior boys showcased a significantly higher percentage of first serve points won in comparison to junior girls on grass, clay, and hard courts. In professional male players, there were notably higher levels of first serve points won and aces per set when compared to their female counterparts across all three court types. This study may be a guideline for coaches and players, in terms of training methods. Further longitudinal studies are required to obtain new perspectives related to well-shaped training programs.

AUTHOR CONTRIBUTIONS

Ulusoy, İ.T.: Conception and design; analysis and interpretation of the data; article writing; review of the article final text. Söğüt, M.: Conception and design; analysis and interpretation of the data; revising it critically for intellectual content.

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Physical performance and game demands in beach volleyball: A systematic review

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ABSTRACT

The physical-conditional aspects of the game are a significant research area, focusing on game demands, strength, and kinematic features. This study aimed to synthesise the current state of the art regarding beach volleyball's physical demands. This systematic literature review was conducted in March 2024, following the PRISMA criteria and methodological quality scales. The databases consulted were SPORTDiscus, Web of Science, and Scopus. Data concerning study design, sample size, gender, age-group category, player role, and performance level were considered. The risk of bias was assessed using the 12-item MINORS methodological index scale. A total of 19 studies were included, considering male (6), female (9) or both genders (4) as a sample. According to the athletes' level of performance, 25% of the studies assessed players at the developmental or national level, 50% explored the international context, and the remaining 25% were with elite players. Data regarding game demands, mechanical outcomes related to jump and power, kinematic variables concerning distance covered and running speed, and kinetic measurements for acceleration and deceleration actions are displayed. The data provided by the current review allow a precise comparison, addressing specific performance profiles and future research challenges from the lack of knowledge about this topic.

Keywords: Sand sports, Athletic performance, Game demands, Power, Jump, Technology.

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INTRODUCTION

Beach volleyball (BV) has been part of the Olympic Games in women's and men's categories since Atalanta 1996. In recent years, it has gained popularity due to the development of numerous international competitions. In this regard, an increasing number of research studies display a broad analysis of different physical and conditioning performance factors regarding the anthropometric players' characteristics (Batista et al., 2008; Giatsis et al., 2011), the physical game demands (Medeiros et al., 2014; Palao et al., 2012), the key psychological variables (Belem et al., 2014), or the proper mechanical movements in different techniques such as the spike (Giatsis et al., 2019), joined to technology development (João et al., 2021) for an appropriate monitoring strategies (Bozzini et al., 2021) that allow an improvement in the injury risk prevention programs (Racinais et al., 2021).

Physical demands appear as one of the most studied areas. Considering the multifactorial component of BV physical demands, research has focused on analysing the time of effort and rest in male (Da Costa et al., 2022; Medeiros et al., 2014; Palao et al., 2012) and female athletes (Da Costa et al., 2022; Natali et al., 2019); the jumps and hits performed during the game (Perez-Turpin et al., 2009), also differentiating the age-group category (Medeiros et al., 2014); the distances covered (Hank et al., 2016), speed (Magalhaes et al., 2011), accelerations and decelerations (Bozzini et al., 2021; João et al., 2021), or the heart rate and blood lactate concentration in real contexts (competitions or simulated matches) (Magalhães et al., 2011; Nunes et al., 2020). On the other hand, players' physical characteristics and values have also been assessed in laboratory conditions using the maximum oxygen uptake (VO₂max) (Freire et al., 2022), the jumps related to game actions (i.e. block or spike jump) (Batista et al., 2008), or considering mechanical properties such as the height and rate of force development in different type of jumps, both in male and female players (Freire et al., 2022; Riggs & Sheppard, 2009). To contextualise the previous data, researchers have also considered the age category (Bellinger et al., 2021; Medeiros et al., 2014), the gender (Natali et al., 2019; Riggs & Sheppard, 2009), the player role (Da Costa et al., 2021; Medeiros et al., 2014), the type of set (Da Costa et al., 2022; João et al., 2021), the rally duration (Hank et al., 2016), the type of match (i.e. balanced or unbalanced according to the teams' ability (Palao et al., 2012), the level of opposition (Bellinger et al., 2021; Medeiros et al., 2014), and the set outcome (Da Costa et al., 2021; João et al., 2021), among others. Consequently, a substantial body of literature has emerged, joined to a great variety of information using different variables (i.e., SJ, CMJ or spike jump to measure the leg explosive strength) (Freire et al., 2022; Riggs & Sheppard, 2009) or performance level samples (Olympic Games contexts vs. national players). To the authors' knowledge, there are no systematic reviews about BV physical demands. Thus, the information should be carefully organised and reviewed for a better understanding, leading researchers, coaches, and players to an appropriate reference framework that promotes a valid performance profiling of physical and conditioning variables in BV. Based on the previous rationale, this systematic review aimed to synthesise the current state-of-the-art related to BV physical demands, both in-game and laboratory contexts.

MATERIAL AND METHODS

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline (Page et al., 2021).

Eligibility criteria

Regarding the inclusion criteria, the research was limited to (1) scientific experimental articles with peer review, (2) published in English, Spanish or Portuguese, and (3) whose main aim was related to the physical demands in BV. Exclusion criteria involved articles focus on (i) several sports analyses, (ii) indoor volleyball,

(iii) health and injury prevention, (iv) technical-tactical analysis, (v) psychological approach, (vi) methodological studies, or (vii) other aspects of the sports.

Information sources and search strategy

The databases consulted on March 1st, 2024, were Web of Science (Web of Science Core Collection, Current Contents Connect, Derwent Innovations Index, Grants Index, KCI-Korean Journal Database, MEDLINE, ProQuest™ Dissertations & Theses Citation Index and SciELO Citation Index), Scopus, and SPORTDiscus. After an expert's consensus, the search strategy designed to identify relevant studies was applied to the title, abstract or keywords of all databases as (“*beach volley**”) AND (“*training*” OR “*match*” OR “*competition*” OR “*game*” OR “*player*” OR “*set*” OR “*work*” OR “*internal*” OR “*external*”) AND (“*load*” OR “*demands*” OR “*intensity*” OR “*volume*” OR “*frequency*” OR “*output*” OR “*outcome*”).

Selection process

The article selection began with the automated removal of duplicates using the Mendeley Reference Manager (Mendeley Ltd., Elsevier, Version 2.92.0, 2023) software. This process was complemented with a second manual review to ensure no duplicate articles were included. Then, a title and abstract screening was performed for literature classification, and a final complete reading of selected articles was done for inclusion decision. Two independent reviewers (AGA and JMMF) conducted the selection process, and potential discrepancies were resolved by consensus.

Data collection process

The NVIVO (QSR International, Version 14.23.2, 2023) software was used to process the literature. The information generated was exported to a Microsoft Excel (Microsoft Corporation, Redmond, WA, USA) matrix where the pertinent modifications were made to record the most relevant data of each study.

Data items

The results of all physical-conditional variables were grouped into game demands and kinematic and kinetic performance in laboratory tests and matches. The game demands were considered in terms of time, total duration (match and set), work/rest effort (set and rally), as well as the number of points per set. The number of jumps and hits concerning technical action and player role per match, set, and rally were also reported. Kinematic data collected from tests and match contexts, including sprints and distances covered (total and relative), and kinetic variables, such as accelerations and decelerations (per match and zone intensity), were considered. In addition, methodological information such as the study design, sample, gender, age-group category, performance level (McKay et al., 2022) or player role were extracted from articles.

Methodological quality of included studies

The 12-item MINORS methodological index scale for non-randomized (first eight items) and comparative (last four items) studies was used to assess the methodological quality and risk of bias of the included studies (Slim et al., 2003). With a 0 to 2 scale for each item, non-randomized studies could get 16 points, while comparative studies could score 24 (Slim et al., 2003). The scoring process was carried out by two independent authors (AGA and JMMF), who scored 0 (not reported), 1 (reported but inadequate) and 2 (reported and adequate) for each item (Melendez Oliva et al., 2022; Slim et al., 2003).

RESULTS

Study selection

Figure 1 provides a graphical representation (flow diagram) of the articles' selection process. Initially, 35 articles in SPORTDiscus, 60 in Web of Science, and 68 in SCOPUS (n=163) were found. After removing duplicates (n=70), the number of articles was reduced to 93. Then, screening in the abstract section identified seven topics

whose aims were not related to BV physical demands (several sports analysis -n=4, technical-tactical analysis -n=18, psychology -n=7, health and injuries -n=14, indoor/beach volleyball comparison -n=5, training methodology -n=6, and other aspects of the sport -n=7) reduced the number of articles to 32. Finally, after a full content review, 13 articles were excluded for not being directly related to the study's aim, and the remaining 19 were selected for the review.

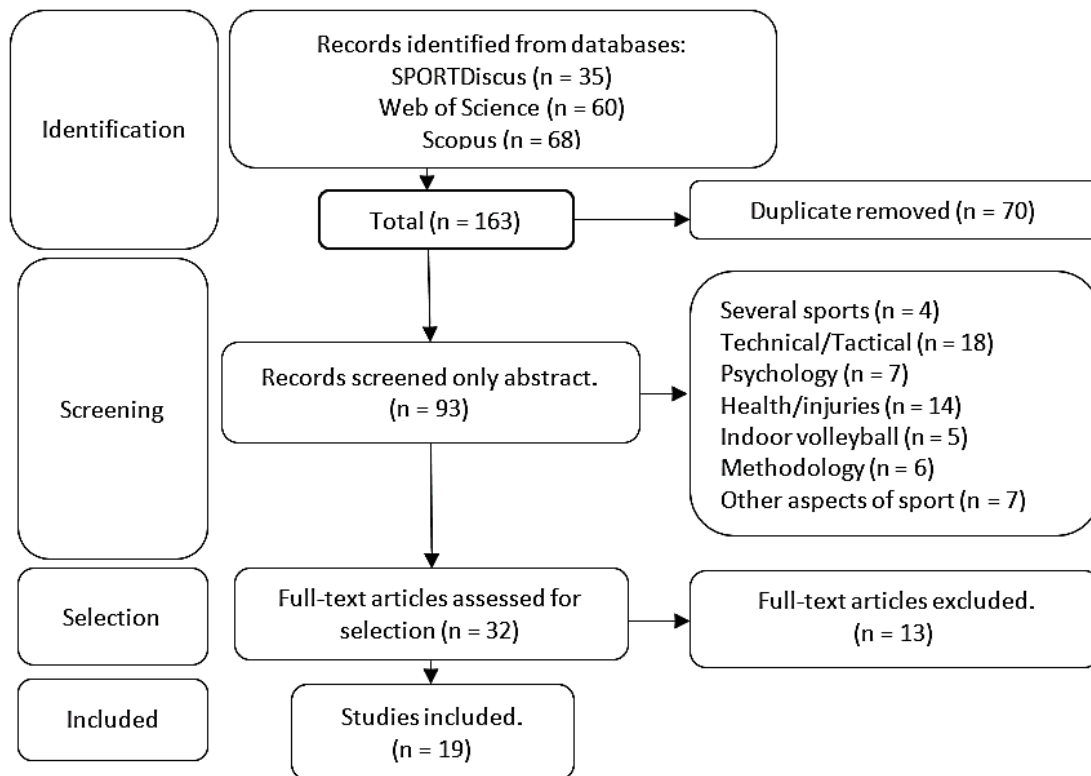


Figure 1. Flow diagram of the systematic review articles' selection process (PRISMA).

Study characteristics

The characteristics of the studies are displayed in Table 1. Overall, six studies explored male players, nine were focused on female players and the other four used both genders. Based on the data collected, a total of 28,819 matches, 60,127 sets, 9,135 rallies and 1985 jumps were considered. However, extreme caution should be addressed with this because not all the studies reported all the variables (this explains how it can be found fewer rallies than sets). According to the athletes' level of performance, 25% of the studies assessed players at the developmental or national level (tiers 2 and 3), 50% analysed players from the international context (tier 4), and the rest 25% took access to the elite worldwide players (tier 5) (McKay et al., 2022). From a methodological point of view, only one study offered information from a validity process (Schmidt et al., 2021), and two studies established an isolated descriptive design. The remaining research studies (n=16) focused on descriptive and comparative analysis, whereas four extended to a correlational analysis. No information about predictive analysis (regressions, prediction decision trees or others) was found.

Risk of bias in studies

The studies' methodological quality and risk of bias were evaluated with the MINORS index for non-randomized and comparative studies (Slim et al., 2003). The scores assigned by the reviewers to each article are shown in Table 2. From the 19 studies assessed, 21% were non-comparative (maximum score of 16),

and 79% were comparative (maximum score of 24). In the non-comparative studies, scores ranged from 10/16 (Perez-Turpin et al., 2009; Perez-Turpin et al., 2008) to 13/16 (Magalhaes et al., 2011; Schmidt et al., 2021), indicating moderate to high methodological quality. For the comparative studies, scores ranged from 18/24 (Batista et al., 2008; Freire et al., 2022; Medeiros et al., 2014; Palao et al., 2012; Riggs & Sheppard, 2009) to 20/24 (Da Costa et al., 2021; Nunes et al., 2020; Oliveira et al., 2018), showing high methodological quality (Table 2). The items with the lowest scores were: item 8 (prospective calculation of the study size) and item 9 (adequate control group), where 100% of the studies scored 0 (not reports); and item 11, (baseline equivalence groups), where 60% of the articles score 1 (different group sample).

Table 1. Study characteristics.

Authors	Aim	Method (design)	Sample		
			n	G	Performance level (**)
Perez-Turpin et al., 2008	To analyse jump patterns and to quantify jump types and their relationship to real competition	A	4 M 9 S 876 jumps	+	European (2005) (4)
Batista et al., 2008	To compare the anthropometric profile and the vertical jump of two groups of Brazilian male high-performance BV players	A B C	Group 1: Top-7; Group 2: 8th- 17 th ranked	+	Brazilian Ch (2006) (4)
Perez-Turpin et al., 2009	To analyse jump patterns and to quantify jump types and their relationship to real competition	A	4 M 670 jumps	*	European (2006) (4)
Riggs & Sheppard, 2009	To quantify and assess power characteristics during jumps in BV athletes.	A B C	14 men and 16 women	+ *	Australian athletes (3)
Magalhães et al., 2011	To analyse the physiological and neuromuscular impact of a one 3-set BV match	A B	16 men	+	Portuguese athletes (3)
Palao et al., 2012	To assess the duration and number of rallies in men's and women's BV matches	A B	28,607 M and 59,699 S	+ *	FIVB World Tour (2000-2010) (4/5)
Medeiros et al., 2014	To assess the effects of age groups and players' role in BV in relation to physical and temporal variables, considering the quality of opposition	A B C	94 S and 3,514 R	+	World Ch (2010-2011) (4/5)
Palao et al., 2015	To assess the ball contacts, jumps, hits, work time, and rest time for women's BV players in relation to their in-game role	A B	69 S and 2,708 R	*	Olympic Games (2008) (5)
Hank et al., 2016	To evaluate distances and durations of horizontal movement of elite female BV players during matches	A B	3 S and 106 R	*	World Tour (no date information) (4)
Oliveira et al., 2018	To describe and compare the training load dynamics of two Olympic BV players	A B	10 training weeks	*	Olympic Games (2016) (5)
Natali et al., 2019	To assess work-rest ratio and physical actions between males and females according to their role	A B	12 M, 20 S and 868 R	+ *	World Tour (2016) (4)
Nunes et al., 2020	To analyse and compare the match activities and percentage time spent in selected HR intensity zones in a top-level blocker and defender	A B	99 M	*	Olympic Games (2016) (5)
Bozzini et al., 2021	To evaluate internal and external training loads through a competitive season and to quantify the performance characteristics of NCAA Division I	A B	6 weeks	*	NCAA (2020) (4)
João et al., 2021	To quantify the physical demands of female BV competition regarding player position, set, and match outcome	A B	30 M and 50 S	*	Portuguese athletes (3)
Schmidt et al., 2021	To evaluate the accuracy of a commercially available inertial measurement device in VB for jump count and height in laboratory conditions	Validity	4 M, 4 S and 20 laboratory jumps	+	German senior and U19 athletes (2)

Bellinger et al., 2021	To determine the external output of female BV players during tournament match play, and to assess the effect of competition level, margin of score differential and alterations of external output within matches	A B C	30 M and 130 S	*	Australian athletes (3/4)
Da Costa et al., 2021	To compare temporal and physical indicators by considering the competition phase, set result, and role	A B	8 M, 16 S and 556 R	*	World Ch U21 (2019) (4)
Freire et al., 2022	To compare the physical attributes of male and female volleyball and BV athletes	A B	10 men and women	+ *	National athletes (3)
Da Costa et al., 2022	To compare temporal indicators according to the type of set and final score difference	A B	21 M, 42 S and 1,374 R	+	Developmental athletes (2)

Notes. BV: beach volleyball; Ch: Championship; A: descriptive design; B: comparative design; C: correlation; n: sample size and unit of measures; G: gender; +: male; *: female; M: matches; S: sets; R: rallies; (**) following McKay et al. (2022).

Table 2. Methodological risk of bias assessment using MINORS checklist.

Study	1	2	3	4	5	6	7	8	9	10	11	12	Score
Perez-Turpin et al., 2008	1	1	2	1	2	1	2	0	-	-	-	-	10/16
Batista et al., 2008	2	2	2	2	1	2	2	0	0	2	1	2	18/24
Perez-Turpin et al., 2009	1	1	2	1	2	1	2	0	-	-	-	-	10/16
Riggs & Sheppard, 2009	2	2	2	2	1	2	2	0	0	2	1	2	18/24
Magalhães et al., 2011	2	2	2	2	1	2	2	0	-	-	-	-	13/16
Palao et al., 2012	2	2	2	2	2	2	2	0	0	1	1	2	18/24
Medeiros et al., 2014	2	2	2	2	2	2	2	0	0	1	1	2	18/24
Palao et al., 2015	2	2	2	2	2	2	2	0	0	2	1	2	19/24
Hank et al., 2016	2	1	2	2	2	2	2	0	0	2	2	2	19/24
Oliveira et al., 2018	2	2	2	2	2	2	2	0	0	2	2	2	20/24
Natali et al., 2019	2	2	2	2	2	2	2	0	0	2	1	2	19/24
Nunes et al., 2020	2	2	2	2	2	2	2	0	0	2	2	2	20/24
Bozzini et al., 2021	2	2	2	2	2	2	2	0	0	2	1	2	19/24
João et al., 2021	2	2	2	2	2	1	2	0	0	2	2	2	19/24
Schmidt et al., 2021	2	2	2	2	1	2	2	0	-	-	-	-	13/16
Bellinger et al., 2021	2	2	2	2	1	2	2	0	0	2	2	2	19/24
Da Costa et al., 2021	2	2	2	2	2	2	2	0	0	2	2	2	20/24
Freire et al., 2022	2	2	2	2	1	2	2	0	0	2	1	2	18/24
Da Costa et al., 2022	2	2	2	2	2	2	2	0	0	2	1	2	19/24

Notes. The items are score; 2= Reported and adequate; 1= Reported but inadequate; 0= Not reported. Methodological items (1) A clearly stated aim; (2) Inclusion of consecutive patients; (3) Prospective collection of data; (4) Endpoints appropriate to the aim of the study; (5) Unbiased assessment of the study endpoint; (6) Follow-up period appropriate to the aim of the study; (7) Loss to follow up less than 5%; (8) Prospective calculation of the study size; (9) An adequate control group; (10) Contemporary groups; (11) Baseline equivalence of groups; (12) Adequate statistical analyses, The total ideal score being 16 for non-comparative studies and 24 for comparative studies following Slim et al. (2003).

Results of individual studies

A total of 12 studies aimed to describe the game demands in terms of effort/rest time, points played (n=7) (Da Costa et al., 2021; Da Costa et al., 2022; Hank et al., 2016; Medeiros et al., 2014; Natali et al., 2019; Palao et al., 2012, 2015), and the number of jumps and hits performed (n=5) (Medeiros et al., 2014; Natali et al., 2019; Palao et al., 2015; Perez-Turpin et al., 2009; Perez-Turpin et al., 2008) (Tables 3 and 4).

Overall, male matches had a higher duration than females (Palao et al., 2012). The set and rally duration increased as males moved to higher categories, with a higher effort and rest time in the set (Table 3). Besides, a higher number of points, jumps, and hits were performed, although a higher difference was found in jumps compared to hits in terms of the player role (blocker vs. digger) (Medeiros et al., 2014) (Table 4). A similar set work-time and rally duration was found in females compared to males (Natali et al., 2019) (Table 3). Most studies were done with top-level athletes (tiers 4 and 5) (Tables 3 and 4).

Table 3. Game demands in terms of the time of effort/rest (match, set or rally), and points played per set.

Authors	Level	Duration		Work time			Rest time		Points/set
		Match (min:sec)	Set (min:sec)	Set (min:sec)	Rally (sec)	Set (min:sec)	Rally (sec)		
Male									
Palao et al., 2012	4,5	41.7±14 (2 sets); 42±2 (3 sets)	-	-	-	-	-	-	-
Medeiros et al., 2014	4,5	-	16:19±2:26 (U19); 18:02±3:05 (U21); 18:52±2:28 (SEN)	4:41±0:49 (U19); 4:55±0:38 (U21); 5:05±0:35 (SEN)	7±1 (U19); 7±1 (U21); 8±1 (SEN)	11:38±1:54 (U19); 13:31±2:46 (U21); 13:46±2:06 (SEN)	21±3 (U19); 20±2 (U21); 21±3 (SEN)	35.8±4.4 (U19); 38.1±4.8 (U21); 37.3±2.8 (SEN)	
Natali et al., 2019	4	-	-	-	6.9±4	-	22.6±16; 19.1±7.4 (no TO)	38.3±6.6	
Da Costa et al., 2022	2	-	Set 1: 13:42±1:56; Set 2: 14:1±2:34	Set 1: 3:56±0:52; Set 2: 4:08±0:56	Set 1: 7:19±0:99; Set 2: 7.61±1.14	Set 1: 9:45±1:10; Set 2: 10:01±1:47	Set 1: 18.55±1.74; Set 2: 19.1±1.99	-	
Female									
Palao et al., 2012	4,5	39±18 (2 sets); 40±17 (3 sets)	-	-	-	-	-	-	
Palao et al., 2015	5	-	-	4:51±1:96	6.46±4.17	15:84±6:98	22.69±7.06	-	
Hank et al., 2016	4	-	-	-	7.27±3.4	-	-	-	
Natali et al., 2019	4	-	-	-	7.1±3.9	-	23±17.9; 19.3±9.8 (no TO)	38±3.6	
Da Costa et al., 2021	4	G: 28:31±6:03; F: 31:47±1:2	G: 14:15±2:58; F: 15:53±1:11	G: 3:12±0:33; F: 3:26±0:24	G: 5.76±0.47; F: 5.74±0.71	G: 11:03±2:29; F: 12:27±0:59	G: 20.27±1.59; F: 21.43±2.01	G: 33.5±5.45; F: 36±2.56	

Notes. F: final phase; G: group phase; TO: time-out.

Table 4. Game demands in terms of jumps and hits.

Authors	Level	Jumps							Hits				
		Match			Set				Rally		Set		
		Total	Serve J	Spike J	Block J	Total	Blocker	Digger	Universal	Total	Blocker	Digger	Universal
Male													
Perez-Turpin et al., 2008	4	219.0±7.4	36.5±3.2 (17%)	96.0±3.4 (44%)	86.5±2.3 (39%)	100.5±19.6	-	-	-	4.4±1.0	-	-	-
Medeiros et al., 2014	4,5	-	-	-	-	95.8±19.6 (U19); 105.4±18.2 (U21); 112.6±11.4 (SEN)	60±18.2 (U19); 64.4±13.4 (U21); 66.8±10.3 (SEN)	35.8±11 (U19); 41.4±14.1 (U21); 45.8±8.1 (SEN)	-	78±11.1 (U19); 82.4±11.7 (U21); 81.9±8.2 (SEN)	39.7±10 (U19); 38.9±10 (U21); 38.7±7.8 (SEN)	38.3±8.7 (U19); 43.5±11.5 (U21); 43.3±7.8 (SEN)	-
Natali et al., 2019	4	-	-	-	-	29.9±11.1	-	-	-	5.8±0.2	21.2±6.3	-	-
Female													
Perez-Turpin et al., 2009	4	167.5±38.5	15.88±9.99 (9%)	118.88±32.83 (71%)	32.75±4.87 (20%)	74.5±5.9	-	-	-	-	-	-	-
Palao et al., 2015	5	-	-	-	-	-	37.1±52.19	27.46±53.95	29.81±16.77	-	24.48±14.03	24.42±13.19	23.35±11.37
Natali et al., 2019	4	-	-	-	-	30.7±10.7	-	-	-	5.8±0.2	22.1±4.7	-	-

Notes. J: jump.

Table 5. Mechanical outcomes in laboratory tests.

Authors	Sample (n)	Level	Sur	Game actions Jump				Squat Jump (SJ)			Countermovement Jump (CMJ)			Abalakov Jump		
				Spike H	Block H	Spike R	Block R	Height	Force peak (N)	RFDmax (KN/s)	PP (W)	Height	Force peak (N)	RFDmax (KN/s)	PP (W)	Height
Male																
Batista et al., 2008	10/G1	4	S	-	-	334.4 ±7.9	317.9 ±7.7	-	-	-	-	-	-	-	-	-
Batista et al., 2008	10/G2	4	S	-	-	326.3 ±10	308.4 ±9.1	-	-	-	-	-	-	-	-	-
Riggs & Sheppard, 2009	14	3	R	-	-	-	-	44.45±4.73	1,961.12 ±103.9	7.76±1.92	2,639.2 ±247.57	46.86 ±3.81	2,157.29 ±161.73	12.93 ±4.37	2,588.15 ±284.13	-
Magalhães et al., 2011	16	3	R	-	-	-	-	-	-	-	-	56±4	-	-	-	-
Schmidt et al., 2021	11	2	R	47.7±7.2	49.4±5.1	-	-	-	-	-	-	-	-	-	-	-
Freire et al., 2022	10	3	R	-	-	-	-	43.3±8.3	N/BW 1.21±0.16	-	-	44.7 ±7.9	N/BW 1.3±0.23	-	-	-
Female																
Riggs & Sheppard, 2009	16	3	R	-	-	-	-	36.13±6.26	1,422.37 ±100.54	5.10±1.47	1,665.28 ±298.91	38.58 ±5.77	1,629.65 ±175.9	10.7 ±4.28	1,824.4 ±621.57	-
Oliveira et al., 2018	2	5	R	-	-	-	-	-	-	-	-	48±1.1(D); 40.6±0.8(B)	-	-	-	-
Bozzini et al., 2021	20	3	R	60.11±7.1	-	-	-	-	-	-	-	49.11 ±5.5	-	4,020.48 ±440.1	54.06 ±7.6	4,321.12 ±558.1
Freire et al., 2022	10	3	R	-	-	-	-	29.4±4.8	N/BW 1.14±0.10	-	-	32.6 ±4.1	N/BW 1.21±0.20	-	-	-

Notes. Sur: surface; R: rigid surface (mat or force platform); S: sand surface; H: height; R: reach; PP: power peak; G1: top-ten ranked players; G2: rest of the sample; D: digger; B: blocker; N/BW: Newtons/Body weight.

Table 6. Kinematic results in test⁽¹⁾ and match conditions⁽²⁾.

Authors	Sample (n)	Level	Sprint		Distance (m)	Relative distance (speed)	
			7.5 m	15 m		Blocker	Digger
Male							
Magalhães et al., 2011 ⁽¹⁾	16	3	1.38±0.05	2.43±0.06	-	-	-
Female							
Hank et al., 2016 ⁽²⁾	8	4	-	-	64.4% of TD <10 m; 18.8% <5m	-	-
Nunes et al., 2020 ^{*(2)}	2	5	-	-	-	LIR (7-11 m/s): 216.6±83.5; MIR (11-15 m/s): 35.3±25.4; HIR (15-19 m/s): 4.8±9.4	LIR: 196.5±77.4; MIR: 19.1±13.3; HIR: 2.1±8.5
Bozzini et al., 2021 ^{*(2)}	20	4	-	-	around 25 km in a training week	-	-
João et al., 2021 ^{*(2)}	12	3	-	-	-	TD: 539.2±201.5; LIR (0-4 m/s): 95.4±4.1%; MIR (4-7 m/s): 4.4±3.8%; HIR (7-13 m/s): 0.1±0.5%	TD: 543.1±195.6; LIR: 85.4±21.6%; MIR: 13.1±18.7%; HIR: 1.4±3.1%
Bellinger et al., 2021 ^{*(2)}	20	3/4	-	-	-	Senior: TD: 570.98; zone 1 (0-1 m/s): 16.91; zone 2 (1-2 m/s): 15.33; zone 3 (+2 m/s): 3.99 U23: TD: 552; zone 1: 18.96; zone 2: 13.7; zone 3: 3.39	-

Notes. TD: total distance; LIR: low intensity running; MIR: medium intensity running; HIR: high intensity running; * GPS technology data.

Table 7. Kinetic (accelerations/decelerations) results during match conditions.

Authors	Sample (n)	L	Accelerations									Decelerations						Acc/ min	Dec/ min				
			Zone 1 (0.5-0.99 m·s ⁻²)			Zone 2 (1-1.99 m·s ⁻²)			Zone 3 (2-2.99 m·s ⁻²)			Zone 1 (0.5-0.99 m·s ⁻²)			Zone 2 (1-1.99 m·s ⁻²)					Zone 3 (2-2.99 m·s ⁻²)			
			T	B	D	T	B	D	T	B	D	T	B	D	T	B	D			T	B	D	
Female																							
Nunes et al., 2020 *	2	5	-	336.6±129.8	288.5±103.5	-	187.6±66.6	194.3±61.8	-	18.9±9	17.9±8	-	370.3±119.9	343.1±120.9	-	208.5±84.3	208.5±70.3	-	19±10.4	16.5±11.1	-	-	
Bozzini et al., 2021 *	20	4	240±28	-	-	112±10	-	-	19±5	-	-	307±18	-	-	108±13	-	-	17±4	-	-	-	-	
João et al., 2021 *	12	3	-	(%) L: 61.6±16, M: 22.5±10.5, H: 15.8±12.5	(%) L: 61.7±17.1, M: 21.3±10.4, H: 16.9±13.1	-	-	-	-	-	-	-	(%) L: 62.4±13.6, M: 25.2±9.8, H: 12.2±11.3	(%) L: 57.9±15, M: 27.7±12.1, H: 14.2±13.3	-	-	-	-	-	-	-	-	
Bellinger et al., 2021 *	20	3/4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
																						S- z1: 6.19; z2: 7.19; z3: 2.78; z4: 2.16	S- z1: 6.19; z2: 7.19; z3: 2.78; z4: 2.16
																						U23- z1: 6.28; z2: 7.28; z3: 2.72; z4: 2.09	U23- z1: 6; z2: 6.12; z3: 1.99; z4: 1.34

Notes. * GPS technology data; L: level of performance; T: team; B: blocker; D: digger; L: low; M: medium; H: high; Acc: acceleration; Dec: decelerations; S: senior category; z1: zone 1 (1-2 m·s⁻²); z2: zone 2 (2-3 m·s⁻²); z3: zone 3 (3-4 m·s⁻²); z4: zone 4 (>4 m·s⁻²).

Analysing the physical capacities in laboratory conditions (out of the court), seven studies focused on mechanical athletes' features (Batista et al., 2008; Bozzini et al., 2021; Freire et al., 2022; Magalhaes et al., 2011; Oliveira et al., 2018; Riggs & Sheppard, 2009; Schmidt et al., 2021) (Table 5), meanwhile, a unique study focused on kinematics variables such as a short sprint (Magalhaes et al., 2011) (Table 6). A higher performance was found in the countermovement jump (CMJ) compared to the squat jump (SJ), with superiority in male players. Only the studies of Bozzini et al. (2021) and Schmidt et al. (2021) gave an approach in a more specific jump technique (spike, block or Abalakov movement), but on a rigid surface. The oldest study was the only one that offered results on the specific sand surface (Batista et al., 2008).

Coming back to the match context, five studies aimed to analyse kinematic variables such as distance and speed ranges (Bellinger et al., 2021; Bozzini et al., 2021; Hank et al., 2016; João et al., 2021; Nunes et al., 2020) (Tables 6). In all the cases, the lower the running intensity, the higher the distance covered. Finally, another four studies showed kinetic variables like accelerations and decelerations (Bellinger et al., 2021; Bozzini et al., 2021; João et al., 2021; Nunes et al., 2020) (Table 7). Different ranges of values were used to define different running intensities, so comparing studies remains difficult. More consensus in metrics is found in acceleration and decelerations. Thus, the blocker showed a higher impact in the lowest and highest intensity ranges.

DISCUSSION

This study aimed to display the current state-of-the-art related to BV physical demands. Overall, a similar rally length is found between genders, meanwhile, males showed higher match and set duration, with a greater increase in top-level categories. Moreover, a greater number of points, jumps, and hits are performed in male players, with a greater number of jumps, accelerations and decelerations performed by blockers, and hits in the case of defenders.

Concerning the game demands, the rally duration was similar between genders (less than 0.5 seconds of difference). Only one study reported this comparison from the same competitive level (Natali et al., 2019). The rest of the studies offer information from different competitive contexts, so the performance level is an important feature for a proper data comparison. Delving into this aspect, higher rally duration was found in women's indoor volleyball compared with men when the same competitive context was analysed (Hileno et al., 2023). The lack of information on youth categories is especially important. In this sense, Da Costa et al. (2021) comprised an international top-level context in female category, meanwhile, another study analysed male national players (Da Costa et al., 2022). This continuum in the analysis of game demands in BV could draw a proper picture of the player development process (from initial tiers to the top-level -tiers 4 and 5-).

Despite the similar time of effort in a rally, the game actions performed show a higher number of points, jumps and hits performed in male athletes, with a greater number of jumps performed by blockers and hits done by defenders (Medeiros et al., 2014). However, in the same competitive context, the difference indicated another trend, with a greater number of jumps and hits in female players (Natali et al., 2019), although no information about players' roles is reported. The comparison between players' roles should be analysed carefully. In this venue, the players' or teams' strategies and performance during the game could change this tendency because the server can "almost choose" the opponent who prefers in the attack by forcing the reception. Thus, Link and Wenninger (2019) found how the players reduce and change their performance after a spiking error in the side-out phase, with differences between genders (male tend to change to a strong spike while female players tend to change to a soft spike).

Going to an analysis of physical features in the laboratory, some information about the reach height achieved in a jump, as well as the force applied during the kinematic phase, could be used as reference values, especially in the top-level scenarios. This reference data can be obtained not related to competition characteristics but using standardised tests to obtain data about maximum jump performance capacity (e.g., countermovement jump), or trying to simulate as much as possible competition performance with similar specific conditions (e.g., technique or sand surface). However, studies by Bozzini et al. (2021) and Schmidt et al. (2021) gave an approach to a specific jump technique (spike, block or Abalakov movement) but on a rigid surface. Contrarily, the oldest study was the only one that offered results on the specific sand surface (Batista et al., 2008). This gap should be considered for future studies.

No studies reporting the jump height during the competition were found, although a comparison between player roles was made by João et al. (2021), showing a quantity of jumps according to height ranges. However, no specific information about each jump or its relationship with specific game actions was shown. In this sense, the kinetic and kinematic variables analysed in a real context are more related to the horizontal movements such as distance covered, sprints, accelerations or decelerations. Difficulties in data analysis come from the different ranges established by the authors. Despite these difficulties, the accelerations and decelerations are usually defined in the same range, and the blockers appear like the players that collect higher impact in all the intensity ranges. The blockers' function could address not only jumping more but also doing explosive movements in short ranges, although this hypothesis could be addressed in future studies. In this sense, using new technologies opens a new horizon to discover new variables that define the players' performance.

Future research lines are suggested after this systematic review based on gaps in knowledge. Thus, wider samples, especially in national or initial levels, as well as in female players, should be considered due to the lack of information related to different performance levels. To better contextualise, the environmental features like the wind, temperature, humidity, or rain may be considered due to the strong influence on players' performance and also the surface (i.e. more solid sand after rainy weather). In this sense, the tournaments are played worldwide, so the sand's density and characteristics should be considered because of its influence on jumping mechanical properties (Giatsis et al., 2004). Furthermore, other situational variables like the match status and quality of opposition should be considered in future analyses.

In terms of the methodological bias displayed in the studies, one of the main limitation is concerned to the lack of a minimum sample size. Thus, the generalization of the results should be addressed carefully due to specific or punctual assessments. Moreover, there were not control groups because of the descriptive nature of the studies. Specially in laboratory conditions, if the studies recruit a higher sample, the inclusion of a control group could be done. For a more precise comparison, higher number of teams and competitions allow a proper baseline equivalence between groups. Therefore, although more studies are needed in this topic, an improvement in the methodological features is requested.

CONCLUSION

This study offers a comprehensive overview of the current state-of-the-art regarding the physical-conditional demands of BV and provides practical implications. It highlights that, while rally durations are similar between genders, male players have longer matches and set durations and perform more points, jumps, and hits. It also notes that blockers execute more jumps, and defenders perform more hits. The analysis emphasises the need for further research, especially in youth categories, female players, and the impact of environmental

and contextual variables. The standardisation of new technology parameters, as well as the contextualisation of physical-conditional tests, is recommended.

AUTHOR CONTRIBUTIONS

Joaquín Martín Marzano-Felisatti: Study design/planning, literature analysis/search/review, data collection, data analysis, methodological quality, manuscript writing, editing and revision. José Pino-Ortega: Study design/planning, methodological quality, and manuscript revision. Jose Ignacio Priego-Quesada: Study design/planning, methodological quality and manuscript revision. José Francisco Guzmán-Luján: Study design/planning, methodological quality and manuscript revision. Antonio García-de-Alcaraz: Study design/planning, literature analysis/search/review, data collection, data analysis, methodological quality, manuscript writing, editing and revision.

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Self-perception of efficacy and attitudes towards physical activity and sport in schoolchildren: Are there differences between Primary Education and Secondary Education students in Cantabria?

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ABSTRACT

This study aimed to know the self-perception and attitudes towards physical activity and sport in Primary Education (PE) and Secondary Education (SE) schoolchildren from educational centres in Cantabria, depending on sex and educational stage. A total of 1,164 students participated (387 from 5th and 6th years of PE and 777 from SE) aged between 10 and 17 years ($M = 12.92$; $SD = 1.92$). An ad hoc questionnaire of 11 questions on self-perception (6 items) and attitudes towards physical activity and sport (5 items) was used. PE students have a better self-perception and attitude towards physical activity and sport than SE students in all the variables studied, except for the attitude that “*The practice of physical-sports activity is good for health*” ($p = .197$). In the gender factor, boys perceive themselves as having greater physical condition and capacity than girls in terms of physical activity and sports ($p < .001$) and better performance when compared with boys of the same age and same sex ($p < .001$). PE students perceive themselves as having better attitudes and more competence than SE students, at the same time that they have more fun and enjoy themselves and would be more willing to practice more physical activity and sport. In terms of gender, boys perceive themselves as better than girls and enjoy and have more fun than girls.

Keywords: Physical education, Schoolchildren, Ages, Adolescents, Perception, Entertainment.

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INTRODUCTION

Self-perception and attitudes towards physical activity and sport in schoolchildren aged 10 to 16 are multidimensional variables that involve perception of health, motivation (Navarro-Patón, Lago-Ballesteros, et al., 2020), enjoyment (Navarro-Patón et al., 2019), self-esteem, and the influence of the environment on the physical and psychological development of young people (Meier et al., 2019). Self-perception refers to how individuals see themselves in relation to their health, physical condition, and sporting abilities (García Cantó et al., 2021; Jiménez Díaz, 2020). Several studies have demonstrated the importance of self-perception for motivation and participation in physical activity (Feliz De Vargas Viñado & Herrera Mor, 2020; Maloney et al., 2023; Revuelta et al., 2016). Additionally, perceived self-efficacy regarding physical activity can influence self-esteem and willingness to participate in sports (D'anna et al., 2021).

The relationship between self-perception and physical activity has been a topic of study in the scientific literature. It has been proven that practicing physical activity can influence the self-esteem and self-perception of adolescents (D'anna et al., 2021; Moral-García et al., 2021). Likewise, the motivation to participate in sports can be related to self-determination and physical self-concept (Isorna Folgar et al., 2015; Navarro-Patón, Pazos-Couto, et al., 2020; Revuelta et al., 2016). These factors are fundamental to understanding how schoolchildren perceive their physical abilities and how this influences their participation in sports activities (Rodríguez-Fernández et al., 2020). Furthermore, the influence of the environment, including factors such as gender, age, and the type of sport practiced, can affect self-perception and attitudes towards physical activity in schoolchildren (Valladarez Herrera et al., 2023).

On the other hand, it has been shown that the perception of competence in the sports field is closely related to participation in physical activities (Hill et al., 2022). Sports participation and perceptions of competence may vary by gender and age of children. For example, perceived competence in sports has been found to be strongly associated with sedentary time in children (Hill et al., 2022). Likewise, participation in organised sports can positively influence children's self-concept and quality of life (Harbec et al., 2021). Studies have shown that the self-perception of physical condition in adolescents is related to their level of physical activity and their quality of life (Pastor-Cisneros et al., 2021) and influenced by their level of physical activity, their self-esteem, and their social environment (Cantero Castrillo et al., 2020). This self-perception can vary depending on factors such as gender, age, and level of motor competence (McIntyre et al., 2015). Likewise, the perception of physical condition can affect the quality of life and psychological well-being of young people (Fernandes & Lemos, 2022).

The beliefs of children aged 10 to 16 about enjoyment and fun in the practice of physical-sports activity are determining factors in their participation and commitment (Navarro-Patón, Pazos-Couto, et al., 2020). The enjoyment integration theory highlights the importance of maintaining children's and adolescents' sports participation through positive and fun experiences (Visek et al., 2015). Fun and enjoyment in physical activity can be key motivating factors to maintain participation over time, improving adherence to physical activity in children and adolescents (Visek et al., 2015), which generates a positive attitude towards physical activity and promotes healthy habits throughout life (Visek et al., 2015).

For all of the above, the objective of this study was to know the self-perception and attitudes towards physical activity and sport in PE and SE schoolchildren from educational centres in Cantabria (Spain), depending on sex and educational stage.

MATERIALS AND METHODS

Study design

To carry out this research, a cross-sectional descriptive study was designed (Ato et al., 2013). Self-perception and attitudes towards physical activity and sport were the dependent variables, compared according to the independent variables of gender (boys vs. girls) and educational stage (Primary Education vs. Secondary Education).

Participants

The sampling of the study was of a non-probabilistic nature, taking into account the subjects who could be accessed from the centres, both PE and SE in Cantabria (Spain).

17 educational centres proposed to participate in this study, with a total of 1,212 students. 48 were excluded for not completing all the questions in the questionnaire. Finally, the sample consisted of 1164 students (387 from the 5th and 6th grades of PE and 777 from SE).

Instrument

An Ad Hoc questionnaire was used to collect data for this research. It is made up of 3 blocks: Block 1 [general data; 3 items (Gender, age, grade and stage)]; Block 2 (Self-perception of effectiveness in physical activity and sport; 6 items) and Block 3 (Attitudes towards physical activity and sport; 5 items). The possible range of values for block 2 (self-perception) is from 1 to 5, with 1 being very bad and 5 being very good. The range of values for block 3 (attitudes) is from 1 to 4, with 1 being totally disagree and 4 being totally agree.

Procedures

After completing the consent form for the students to participate in the research, the form was applied in a single physical education session without the teacher's presence to avoid bias when answering the questions on the form. The students had 25 minutes to answer the questionnaire, and any type of doubt regarding its completion was resolved. The centres that participated in the study followed the same procedure.

The study followed the Declaration of Helsinki and was approved by the Ethics Committee of the European University of the Atlantic with code number CEI21_2022.

Statistical analysis

The possible effect of educational stage (primary vs. secondary) and gender (boy vs. girl) on the questionnaire variables [Attitudes towards physical activity and sport (5 items) and self-perception (6 items)] was analysed using a multivariate analysis of variance (MANOVA), as well as the interaction between both factors using the Bonferroni statistic. Furthermore, the effect size was calculated in terms of eta squared (η^2).

RESULTS

1,164 Primary Education (PE; 387) and Secondary Education (SE; 777) schoolchildren between 10 and 17 years old ($M = 12.92$; $SD = 1.92$) answered all the questions of the questionnaire. 590 (50.7%) were girls and 574 (49.3%) were boys. The distribution by stage was: 5th of PE (203; 17.4%); 6th of PE (183; 15.7%); 1st of SE (205; 17.6%); 2nd of SE (216; 18.6%); 3rd of SE (184; 15.8%); 4th of SE (173; 14.9%).

Self-Perception results

The results of the self-perception on the effectiveness of Physical Activity and Sport depending on gender and educational stage are presented in Table 1.

Table 1. Self-Perception results on the effectiveness of Physical Activity and Sport depending on gender and educational stage.

	Primary Education		Secondary Education	
	Boys (n = 177)	Girls (n = 210)	Boys (n = 397)	Girls (n = 380)
What is your ability when it comes to physical activity and sports (1-5)	4.28 ± 0.77	4.10 ± 0.80	4.15 ± 0.82	3.77 ± 0.90
If you compare yourself with children of the same age and the same sex, how good do you think you are at practicing physical-sports activities (1-5)	3.87 ± 0.82	3.81 ± 0.92	3.84 ± 0.87	3.50 ± 0.94
Currently, how do you consider your condition or physical fitness (1-5)	4.21 ± 0.83	4.02 ± 0.80	3.92 ± 0.92	3.59 ± 0.87
What would you say your current state of health is like (1-5)	4.46 ± 0.69	4.47 ± 0.72	4.31 ± 0.71	4.13 ± 0.73
How do you consider your body image (1-5)	3.85 ± 0.86	3.96 ± 0.85	3.58 ± 0.94	3.49 ± 0.93
How good and healthy do you think your diet is (1-5)	3.98 ± 0.84	4.20 ± 0.84	3.74 ± 0.90	3.65 ± 0.93

Note. Data are presented as mean ± standard deviation.

The results of the MANOVA, depending on the educational stage factor, indicate that there are statistically significant differences in all the self-perception variables studied (*“what is your ability when it comes to physical activity and sports”* [F (1, 1160) = 19.521, $p < .001$, $\eta^2 = 0.017$]; *“if you compare yourself with children of the same age and the same sex, how good do you think you are at practicing physical-sports activities”* [F (1, 1160) = 8.757, $p = .003$, $\eta^2 = 0.007$]; *“currently, how do you consider your condition or physical fitness”* [F (1, 1160) = 44.273, $p < .001$, $\eta^2 = 0.037$]; *“what would you say your current state of health is like”* [F (1, 1160) = 29.1319, $p < .001$, $\eta^2 = 0.025$]; *“how do you consider your body image”* [F (1, 1160) = 42.816, $p < .001$, $\eta^2 = 0.036$] and *“how good and healthy do you think your diet is”* [F (1, 1160) = 49.652, $p < .001$, $\eta^2 = 0.041$]). PE students perceive themselves as better than SE students in all the variables studied.

The results of the MANOVA, depending on the gender factor, indicate that there are statistically significant differences in *“what is your ability when it comes to physical activity and sports”* [F (1, 1160) = 27.634, $p < .001$, $\eta^2 = 0.023$]; *“if you compare yourself with children of the same age and the same sex, how good do you think you are at practicing physical-sports activities”* [F (1, 1160) = 12.457, $p < .001$, $\eta^2 = 0.011$]; *“currently, how do you consider your condition or physical fitness”* [F (1, 1160) = 22.532, $p < .001$, $\eta^2 = 0.019$]. In these variables, boys perceive themselves better and give higher scores than girls.

Regarding the interaction of both factors, there are statistically significant differences in *“if you compare yourself with children of the same age and the same sex, how good do you think you are at practicing physical-sports activities”* [F (1, 1160) = 6.439, $p = .011$, $\eta^2 = 0.006$], where girls in PE obtain higher scores than those in SE; *“what would you say your current state of health is like”* [F (1, 1160) = 4.909, $p = .027$, $\eta^2 = 0.004$], where boys and girls in PE perceive a better state of health than boys and girls in SE; and *“how*

good and healthy do you think your diet is" [F (1, 1160) = 7.984, $p = .005$, $\eta^2 = 0.007$], where boys and girls in PE perceive a better state of health than boys and girls in SE.

Attitudes results

The results of the attitudes towards Physical Activity and Sport depending on gender and educational stage are presented in Table 2.

Table 2. Attitudes results towards physical activity and sport according to gender and educational stage.

	Primary Education		Secondary Education	
	Boys (n = 177)	Girls (n = 210)	Boys (n = 397)	Girls (n = 380)
I like to practice physical-sports activity (1-4)	4.28 ± 0.77	4.10 ± 0.80	4.15 ± 0.82	3.77 ± 0.90
I enjoy and find it fun to practice physical-sports activity (1-4)	3.87 ± 0.82	3.81 ± 0.92	3.84 ± 0.87	3.50 ± 0.94
If I had more free time I would practice more physical-sports activity (1-4)	4.21 ± 0.83	4.02 ± 0.80	3.92 ± 0.92	3.59 ± 0.87
I think that boys do more physical-sports activity than girls (1-4)	4.46 ± 0.69	4.47 ± 0.72	4.31 ± 0.71	4.13 ± 0.73

Note. Data are presented as mean ± standard deviation.

The results of the MANOVA, depending on the educational stage factor, indicate that there are statistically significant differences in all the attitudes variables studied ("*I like to practice physical-sports activity*" [F (1, 1160) = 20.383, $p < .001$, $\eta^2 = 0.017$]; "*I enjoy and find it fun to practice physical-sports activity*" [F (1, 1160) = 30.373, $p < .001$, $\eta^2 = 0.026$]; "*If I had more free time I would practice more physical-sports activity*" [F (1, 1160) = 8.844, $p = .003$, $\eta^2 = 0.008$] and "*I think that boys do more physical-sports activity than girls*" [F (1, 1160) = 27.049, $p < .001$, $\eta^2 = 0.023$]), except in "*The practice of physical-sports activity is good for health*" ($p = .197$). PE students agree more with these statements about attitudes towards physical activity and sport than SE students, in all the variables studied, except in the thought that the practice of physical-sports activity is good for health, in which the scores are similar.

The results of the MANOVA, depending on the gender factor, indicate that there are statistically significant differences in all the attitudes variables studied ("*I like to practice physical-sports activity*" [F (1, 1160) = 30.929, $p < .001$, $\eta^2 = 0.028$]; "*I enjoy and find it fun to practice physical-sports activity*" [F (1, 1160) = 39.108, $p < .001$, $\eta^2 = 0.033$]; "*If I had more free time I would practice more physical-sports activity*" [F (1, 1160) = 8.504, $p = .004$, $\eta^2 = 0.007$] and "*I think that boys do more physical-sports activity than girls*" [F (1, 1160) = 46.742, $p < .001$, $\eta^2 = 0.039$]), except in "*The practice of physical-sports activity is good for health*" ($p = .538$). Boys score higher than girls in the variables studied, except in the belief that practicing physical-sports activity is good for health, in which both boys and girls present high and similar scores.

Regarding the interaction of both factors, there are statistically significant differences in "*I enjoy and find it fun to practice physical-sports activity*" [F (1, 1160) = 4.195, $p = .041$, $\eta^2 = 0.004$], where boys, both in PE ($p = .010$) and SE ($p < .001$), enjoy and have more fun than girls in PE and SE. Significant differences were also found between PE boys and SE boys, since PE boys enjoy and have more fun with physical-sports activities ($p = .017$). The same occurs when comparing PE girls with SE girls, with greater enjoyment and fun for PE girls ($p < .001$).

DISCUSSION

The objective of this study was to know the self-perception and attitudes towards physical activity and sport of Primary Education (PE) and Secondary Education (SE) schoolchildren from educational centres in Cantabria.

In view of the results obtained, the students of this research have a high self-perception of their level of skill in the practice of physical-sports activities, physical condition, current state of health, body image and healthy eating, which is similar to the results found in other previous studies (Moral-García et al., 2021; Ramos-Díaz et al., 2017; Urrutia Medina et al., 2024). On the contrary, authors such as (Ren et al., 2023) found results with a tendency towards a negative self-perception on the part of the students in terms of levels of sporting ability and physical condition. It is important to highlight that at this stage, the configuration of a positive physical self-concept is essential for the correct social development of the person, the consolidation of one's personality (Palenzuela-Luis et al., 2022; Pérez-Mármol et al., 2021), adequate psychological well-being (Penado Abilleira & Rodicio-García, 2017), and, above all, for the adoption of a healthy lifestyle, which has as a key element the practice of physical activity by the youngest (Fernández-Álvarez et al., 2020; Zurita-Ortega et al., 2018).

In relation to the educational stage factor, the students' self-perception regarding the level of ability to carry out physical and sports activity, physical condition, consideration of their body image, and nutrition is higher in PE students than in SE students. These findings are consistent with those of previous studies (Galán-Arroyo et al., 2023; Navarro-Patón, Lago-Ballesteros, et al., 2020; Navarro-Patón, Pazos-Couto, et al., 2020), where, as the age of the students increases, their physical self-concept worsens, as well as their perception of their own body image. However, research such as that of Mamani-Ramos (2023) do not show significant differences in relation to the age of the students. In other studies, such as that of Fernández-Guerrero et al. (2020) the opposite is observed, since their results show how physical self-perception improves in adolescents as the years go by.

The explanation for this decrease as age advances mainly has to do with the fact that both perceived self-efficacy (Gouveia et al., 2019; Pérez Alaejos et al., 2021), physical condition (Gouveia et al., 2019; Kovalevskaya et al., 2020) and body image (Navarro-Patón et al., 2021; Ren et al., 2023) are dimensions that become more socially and culturally pressure over time (Zeferino et al., 2021). Self-perceived competence and physical fitness are revealed daily in physical education classes, since students have to expose themselves in front of their classmates throughout the different activities and physical-sport proposals, as well as in certain tests of specific skills (Gouveia et al., 2019; Kovalevskaya et al., 2020). For its part, in relation to body image, the search for an aesthetically muscular model in men and thinness in women has become more notable over the years and can lead to the appearance of possible related eating disorders (Zeferino et al., 2021). In any case, the perception that adolescents have of themselves undergoes changes and oscillations over the years (Camacho Ruiz et al., 2023).

In reference to the gender factor, there are statistically significant differences in relation to the self-perception of ability when carrying out physical activity and sports, as well as in the perception of their physical condition, with higher levels being obtained in boys than in girls. These results coincide with other recent studies in which women obtain lower levels of physical self-concept (Cadena-Duarte & Cardozo, 2021; Fernández Guerrero et al., 2020; Poblete-Valderrama et al., 2023; Tapia López, 2019), while men reach higher values (Márquez-Barquero & Azofeifa-Mora, 2019; Sánchez-Alcaraz et al., 2018), although, in other studies, no significant differences were found in relation to the gender variable (Den Uil et al., 2023). In this sense, it is

interesting to plan and implement physical education sessions and activities that take into account the tastes, preferences, motivations and perceptions of girls, with the aim of improving their physical self-concept, avoiding stereotypical or exclusive content. to gender (Urrutia Medina et al., 2024).

Likewise, the PE area must promote a series of strategies and methodologies based, mainly, on motivation and personal improvement so that students can improve their levels of perceived competence (Karlinsky et al., 2021). Therefore, it is necessary to design scenarios so that this need is covered (Trigueros-Ramos et al., 2019). In this way, improving students' physical self-concept will lead to the adoption of healthy behaviours through physical activity in their free time, given the strong relationship between both factors (Fernández-Álvarez et al., 2020; Pérez-Mármol et al., 2021).

In relation to the students' attitudes towards physical activity and sport, the results show a high assessment in relation to taste, enjoyment, and fun with the practice of physical-sports activity, if they had more free time, they would practice more physical activity, and its consideration as good for health. These data are in line with those found in other research such as that of Alpkaya (Alpkaya, 2019) where similar results are obtained, highlighting the positive trend in relation to the taste, enjoyment, and fun of students with the practice of physical activity. Knowing the important role that satisfaction and enjoyment of physical activity play during the school stage for the creation of an active lifestyle, where true adherence to physical exercise is generated (Baena-Extremera et al., 2016), and knowing that, as the World Health Organization (WHO) (2020) points out, more than 80% of adolescents between 12 and 18 years old do not remain physically active because they do not meet the global recommendations for physical activity, physical education classes are increasingly becoming more fundamental (Maksimović & Lazić, 2023). In this sense, it is necessary that, in the area of physical education, through the intervention of teachers, positive environments are generated through the application of methodologies and content appropriate to the interests of the student, to increase their feelings of enjoyment and fun (Morales-Sánchez et al., 2021):- Thus generating an increase in their levels of physical activity practice in their free time (Baños et al., 2019; Zueck Enríquez et al., 2020).

In relation to the educational stage, the results show significant differences in reference to the taste for physical activity, enjoyment, and fun with its practice, that if they had more free time they would practice more physical-sports activities, and the perception that children practice more physical activity than girls, finding that PE students have higher perceptions than SE students. These results are in line with the findings of Romanova & Solar (2019), where students also declare a high initial tendency, which decreases as age advances. This is mainly due to the fact that as the courses progress, students experience certain partial failures in different social, family, and academic situations, which, together with a greater capacity for self-criticism, contribute to reducing the related emotional, affective, and motivational factors. to interest in physical-sports activities (Ha et al., 2024; Morales-Sánchez et al., 2021). Likewise, another important element is the levels of motivation and influence that physical education classes generate in students, since positive attitudes towards physical education classes progressively decrease as the age of the students increases (Navarro-Patón, Lago-Ballesteros, et al., 2020). In such a way that the influence of these classes on your physical activity practice will also decrease; in fact, physical education classes classified as not very fun have a directly negative relationship with the intention to practice physical activity in the future (Baños et al., 2019). This progressive decrease with age in taste, enjoyment and interest in physical activity corresponds with a parallel decrease in their levels of practice (Suga et al., 2021) confirming a pronounced abandonment in this adolescent stage (Baños et al., 2019).

Finally, regarding the gender factor, boys obtain higher scores than girls in all the variables studied (taste and enjoyment of physical activity, greater practice of physical activity in free time if they have more time,

and thinking about more physical exercise), except in the belief that practicing physical-sports activity is good for health, since both boys and girls have equally high scores. These results are related to those of Lago et al. (2018), where the resulting values in boys were higher than in girls, due to a less favourable perception towards physical activity and towards the physical education subject, an aspect that is accentuated with age (Sánchez-Alcaraz et al., 2018), the very non-coeducational stereotypes that have historically been attributed to physical education classes (Jiménez Lozano & González-Palomares, 2023), the greater number of non-positive experiences on the part of girls (Navarro Patón et al., 2022), and, most especially, the type of proposals and activities proposed in which the contents are more adjusted to the children's preferences (Serena Montañana et al., 2022). The lower self-perception of competence and capacity on the part of girls are other arguments to consider regarding the lower levels found in girls (Serena Montañana et al., 2022). Consequently, there are differences in relation to the levels of physical activity practice depending on gender, with lower levels manifesting in female students (Tapia López, 2019).

CONCLUSION

Primary Education students perceive themselves as more competent in physical and sports activities, even when compared to children of the same age and sex. Furthermore, they perceive themselves as having a good body image, physical condition, and state of health, better than Secondary Education students, in addition to thinking that their diet is healthy. Regarding gender, boys perceive better physical condition and capacity for physical and sports activity than girls. Furthermore, if they are compared with children of the same age and of the same sex, they perceive themselves to be better at practicing physical sports activities than those with whom they are compared.

On the other hand, Primary Education students agree more than Secondary Education students that they like it more, have more fun, and enjoy practicing physical activity and sports more, to the point that if they had more free time, they would practice more. Depending on sex, boys like physical and sports activities more, they have more fun, they enjoy it more, and they would practice more if they had more free time.

After the analysis of this study, the need to continue conducting research related to self-perceived efficacy as well as attitudes towards the practice of physical-sports activity by students is evident. For all of the above, it is important that professionals in the field of physical education design and implement proposals aimed at helping students improve their levels of physical self-perception as well as their tastes, attitudes, and feelings of enjoyment towards physical exercise. Thus, it would be necessary to adapt the units and contents to the tastes and interests of the students, taking special consideration of gender and educational stage, and develop motivation strategies through the implementation of methodologies that awaken enjoyment and interest in the approaches addressed. The objective is for students to see themselves as more competent, consider physical activity more attractive, and thus be able to achieve an active and healthy lifestyle.

AUTHOR CONTRIBUTIONS

Iván González-Gutiérrez: Conceptualization, methodology, validation, investigation, data curation, writing—original draft preparation, writing—review and editing, visualization, supervision, project administration. Sergio López-García: conceptualization, methodology, validation, investigation, writing—original draft preparation, writing—review and editing, visualization, supervision, project administration. Martín Barcala-Furelos: Conceptualization, methodology, validation, investigation, writing—original draft preparation, writing—review and editing, visualization, supervision, project administration. Marcos Mecías-Calvo: Conceptualization, methodology, validation, investigation, writing—original draft preparation, writing—review

and editing, visualization, supervision, project administration. Rubén Navarro-Patón: Conceptualization, methodology, validation, formal analysis, investigation, writing—original draft preparation, writing—review and editing, visualization, supervision, project administration. All authors have read and agreed to the published version of this manuscript.

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Influence of fitness level and technique on Wingate test result in different positions

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ABSTRACT

The level of anaerobic performance primarily influences the result of the 30-second Wingate anaerobic test (WANt). This study aims to determine the influence of position on the overall performance achieved in different phases of the WANt in participants with different fitness levels. Sixty participants (21.00 ± 2.24 years): 20 race cyclists, 20 competitive runners, and 20 non-athletes performed three WANts (sitting, standing, and combined position) in one week. For the analysis, we used a random mixed effect model with type and position as a fixed effect. We studied the meaning of interactions and the main effects of fixed variables ($p \leq 0,05$). Technically advanced individuals perform significantly better in standing than sitting from the 8th second until the end of the test. Technically and physically advanced individuals achieve significantly higher performance levels in the first half of the standing position test than those who are fitness-ready but without the necessary level of technique. Fit individuals without of technique achieve high performance in the second half of the WANt in the standing position. The main benefit of the work is the finding that the level of fitness and technique of pedalling have a different influence on performance in different phases of the WANt.

Keywords: Performance analysis, Anaerobic test, Cycling position, Pedalling technique, Test phase.

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INTRODUCTION

In many sports, one-off or repeated maximum effort is used in short-run sprints. The quantification of anaerobic performance is required for its evaluation (Baron, 2001; Bringhurst et al., 2020; Delextrat and Cohen, 2008; Dorel et al., 2005). The gold standard for anaerobic evaluation is the 30-second Wingate anaerobic test (WAnT). The WAnT is one of the most widely used tests of anaerobic assumptions in athletes, especially cyclists, where movement is specific, but is also used by speed skaters, hockey players, and other athletes, but also by non-athletic populations (Bahenský et al., 2020, 2020a; Jaafar et al., 2014; Krishnan et al., 2017; Ramírez-Vélez et al., 2016). The main parameters that can be measured with the WAnT are 1-s peak performance (PP), 30-s average performance (AP), and percentage of performance decline from peak to minimum (fatigue index = FI) (Vandewalle et al., 1987). Other parameters that can be evaluated include average cadence (AC) peak heart rate (PHR) and relative values: relative 1-s peak power (RPP), relative 30-s average power (RAP) and relative 5-s peak power (R5PP). Although the standard 30-second WAnT is classified as an anaerobic test, it is clear that a certain amount of aerobic work is also performed during its completion (de Poli et al., 2021; Wilson et al., 2009).

In both cycling and cross-country competitions, overall performance is determined by both aerobic and anaerobic capacity levels, the ratio of which depends on the length of the racetrack. Short bursts of anaerobic performance occur during and at the end of the races. It is common for cyclists to lift from the saddle and move to a standing position during sprints. Given the frequency of using of this position in cycling races, there is great interest in its effectiveness. The pedal slope, the direction of force, and the position of the centre of gravity change in different positions (Caldwell et al., 1998). The standing position also increases the involvement of the upper limbs (Duc et al., 2008). Previous research suggests that the standing position may be the most effective for maximum effort (Bouillod and Grappe, 2018; Kadlec et al., 2022; Li and Caldwell, 1998; Rohsler et al., 2020). However, the standing position is preferable to the sitting position only at high power intensities (Turpin et al., 2017).

Without a doubt, the specificity of the test is intricately connected to the obtained results (Kadlec et al., 2022; Marko et al., 2021). In the WAnT, the most commonly used position is seated, but some athletes move to a standing position at the end of the WAnT when great muscle fatigue has already occurred. Performance cyclists have been confirmed to achieve higher performance in the standing and combined positions (first half of the test sitting and second half standing) than in the sitting position, which is probably influenced by their excellent cycling technique (Jaafar et al., 2014). The WAnT is an ideal test for comparing anaerobic performance in different riding positions.

There is evidence that during standing pedalling, there is an increase in torque in the ankle and knee joints, whereas torque in the hip joint decreases (Li, 2004). In the standing position, there was greater activation of the rectus femoris, gluteus maximus, and tibialis anterior throughout the pedal stroke cycle. No changes in activity between standing and sitting positions were observed in the gastrocnemius and biceps femoris (Li, 2004). There was an 8% reduction in cadence for standing rides (Bouillod and Grappe, 2018; Li, 2004). Elite cyclists achieve higher performance standing than sitting; the same is true for performance cyclists. But at the same time, elite cyclists achieve significantly better performance standing than recreational cyclists (Bertucci et al., 2008). This shows that excellent technique is not necessary for effective standing rides, but a certain level of technique is sufficient. No changes in speed were observed for elite cyclists during the transition from sitting to standing (Bouillod and Grappe, 2018). When comparing the metabolic cost of sitting and standing riding through O₂ uptake, the higher energy intensity of standing riding has been demonstrated (Ryschon and Stray-Gundersen, 1991).

This study aimed to determine the influence of position on performance and performance progress at the WAnT in participants with different levels of fitness and pedalling techniques. In contrast to the majority of studies, we conducted measurements for these parameters in three distinct positions: sitting, standing, and a combination of both. Given the absence of studies exploring performance variations during the WAnT, our objective was also to discern potential differences between positions and among groups at various stages of the test. We hypothesise that the preferred position in the Wingate test will be different from group to group depending on the level of fitness and technique of pedalling. Additionally, we hypothesise that the technique of pedalling will have an influence on the Wingate test result. The question is what that influence will be, especially from the point of view of the course of the test.

METHODS

Participants

The study involved 60 males (Table 1), 20 competitive (elite) bikers at a national level, 20 middle- and long-distance runners at the national level, and 20 non-athletes, all of comparable age. Inclusion criteria included age about 20 years, optimal health, no injuries in the last year, for athletes regular training at least six times a week for at least two years. For non-athletes, the criterion was the absence of regular physical activity; in the last year, the Weekly leisure activity score was greater than or equal to 30 (Godin, 2011). The members of the non-athlete group reach values 18–29. All participants or their parents completed a written informed consent. There was no compensation for any of the participants, and all protocols and procedures conformed to the Declaration of Helsinki statements and were approved by The Ethical Committees of the Faculty of Education, University of South Bohemia study on October 19, 2018 (002/2018).

Table 1. Characteristics of participants.

	Cyclists	Runners	Non-athletes
Age (years)	20.77 ± 1.84	20.86 ± 2.78	21.37 ± 1.94
Body Mass (kg)	77.04 ± 6.96	67.52 ± 9.32	79.95 ± 15.66
Height (cm)	183.50 ± 5.08	181.25 ± 6.20	179.00 ± 7.77
Fat Percentage (%)	11.41 ± 3.63	11.43 ± 3.93	21.37 ± 1.94
Weekly training (hrs)	11.13 ± 1.48	10.75 ± 1.50	0.33 ± 0.31

Design and procedures

The current study was a randomized experimental design that examined the differences in anaerobic parameters in different riding positions and groups of participants during anaerobic tests in elite, competitive cyclists, runners, and non-athletes. Sixty participants with different fitness levels and different pedalling techniques visited the Laboratory of Load Diagnostics to complete the WAnTs in three different riding positions (sitting, standing, and combined) on a cycle ergometer in a randomized fashion, with one day of rest between tests. During each WAnT, the following relative anaerobic performance variables were collected: RPP, RAP, FI, R5PP, AC, and PHR. The WAnT tests were performed under the same conditions for all participants. Each participant was instructed to avoid intensive activity the day before each WAnT.

Measures

Participants completed the three 30-second WAnTs over one week, and each test was 48 hours apart. Three variations of the same test were completed. Participants were randomly split (randomizer.org) into six possible orders of the WAnT completion. The purpose of this study was to compare the relative anaerobic performance characteristics (RPP, RAP, FI, R5PP, AC, PHR) in a group of race cyclists, race runners, and a group of non-athletes while undergoing three different WAnTs in three different riding protocols, and to see

if there were differences between the groups. All participants completed three variants of the test: a sitting-only test (SIT), a standing-only test (STD), and a combined test (COMB), in which participants started sitting and moved to a standing position halfway through (after 15 seconds) the test (see Table 2).

Before each test, participants were asked to abstain from caffeine for 12 hours and alcohol for 48 hours. Each participant was instructed to avoid intensive activity and train maximally at a low to moderate intensity for less than 1 hour the day before each WAnT. Conditions in the lab were similar across all three visits (20–22 °C). First, height, body composition, and weight were assessed using a digital device called InBody 770 (Cerritos, CA, USA). All WAnTs were completed on a LODE Excalibur Sport (Lode B.V., Groningen, The Netherlands) ergometer, and individualized seat and handlebar positions were determined. The participants were explained the design of the test before the test. All tests were preceded by a 5-minute standardized warm-up (Figure 1), which included two short sprints. Output data were measured and analysed with Lode Ergometry Manager 10 (Lode B.V., Groningen, The Netherlands) software. Heart rate during each test was monitored with a Polar chest strap (model T34, Polar, Finland). All participants completed the WAnT tests with cycling straps, and verbal encouragement was given during all tests.

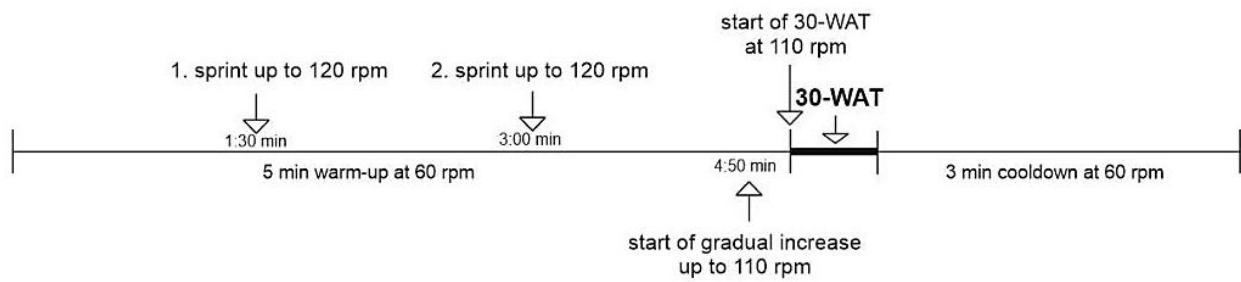


Figure 1. The design of the WAnT protocol.

Statistical analysis

The sample size calculations were done using the software G*Power (G*Power 3.1.7.). Repeated-measures analysis between factors was used to calculate the power analysis, indicating a total sample size of 42, with an assumed type I error of 0.05 and a power of 0.80. The analysed data are attached by fixed effect (type) and repeated measurements (position). The position is repeated measurement since it was measured on the same people. Therefore, we used the analysis of the random mixed effect model (Zuur et al., 2009) with type and position as a fixed effect; the dependence among different positions was solved by adding the random effect, the individual. Inside this model, we studied the significance of interactions and the main effects of fixed variables. Since the results are difficult to interpret, we also analysed the data using functional methods in order to find the times when the differences between types of sportsmen and positions are. First, we did the functional one-way ANOVA for three different data sets, i.e., stand data, site data, and combined data. The grouping factor in this functional model was always the type of sportsman, i.e., the fixed effect. For this analysis, we chose the false discovery rate envelope method (Mrkvička and Myllymäki, 2023) since it allows for graphical interpretation and is suitable for finding all differences in the null model due to the usage of false discovery control of multiple testing problems. Another advantage of this method which we use here is a possibility of using any test statistics, due to the permutation nature of the method.

The output figures show the two different test statistics (the mean group function: Figure 2 and the difference between two mean group functions: Figure 3) together with the 95% false discovery rate envelope (grey zone), which is the area where the test statistic should lie under the H₀. Since the null hypothesis is the

equality of mean group functions for all three categories, the deviance of the first test function from the grey zone shows the significant difference between the particular group and the overall group. The deviance of the second test function from the grey zone shows the significant difference between the two groups. This deviation, shown by bold dots outside the grey zone, specifies where and at what times the functional test is significant, i.e., for which time the group mean differs from the overall mean or the two groups differ.

As a next step, we want to explore the differences between different positions, but since it is a repeated measurement factor, we analysed only the interaction effect (the main effect was, anyway, not significant in random mixed effect analysis). For that reason, we used as a test statistic the difference of the group mean (type) between different positions, e.g., mean function for cyclists in the sit position minus mean function for cyclists in the stand position, and we applied again functional ANOVA with the group factor the type of sportsman. Since here we apply the comparison for three different test statistics (sit-stand, sit-comb, stand-comb), we performed the tests with a significance level equal to $0.05/3$ in order to account for multiple testing problems. The division comes from Bonferroni's multiple testing adjustment (Dunn, 1961). This analysis shows for which times the difference between two positions for certain groups of sportsmen differ from the mean differences computed over all types of sportsmen. This is equivalent to the study of the interaction effect between the two factors but in the functional style.

RESULTS

Table 2 presents the performance parameters in the individual participant groups and in the individual bike positions. During the sitting position, all performance parameters except for RAP, the cyclists dominate in front of the runners. The elite cyclists group achieves the best RPP, R5PP, and AC in the standing position. The combined position yields the best RAP and the highest PHR. The seated position results in the highest FI. Consequently, for cyclists during the WAnT, the standing position proves most advantageous, while the combi position serves as an alternative for RAP. Runners show optimal performance and the highest cadence when seated. In the standing position, they achieve the highest FI, and in the combi position, the highest PHR. Hence, the WAnT position in a seated stance is most favourable for runners. The non-athletes group attains the best R5PP and RPP in the standing position, where the highest PHR and FI are also achieved. In the seated position, they reach the highest RAP and AC. Therefore, for non-athletes, the WAnT position in a seated stance emerges as the most suitable choice.

Table 2. Power output outcomes for three different WAnT protocols.

	Cyclists		
	Sit	Stand	Middle
Relative 30-s Average Power – RAP ($W \cdot kg^{-1}$)	9.40 ± 0.67	9.69 ± 0.66	9.70 ± 0.57
Relative 5-s Peak Power – R5PP ($W \cdot kg^{-1}$)	11.95 ± 1.12	12.33 ± 1.45	11.85 ± 1.28
Relative 1-s Peak Power – RPP ($W \cdot kg^{-1}$)	14.83 ± 1.66	15.35 ± 1.87	14.63 ± 1.38
Fatigue Index – FI	53.10 ± 9.39	51.91 ± 7.31	52.50 ± 11.69
Average Cadence – AC (rpm)	133.0 ± 8.1	136.2 ± 7.3	135.6 ± 7.3
Peak Heart Rate – PHR (bpm)	180.9 ± 11.7	180.5 ± 8.3	181.9 ± 10.4
	Runners		
	Sit	Stand	Middle
Relative 30-s Average Power – RAP ($W \cdot kg^{-1}$)	9.49 ± 0.48	9.13 ± 0.57	9.26 ± 0.56
Relative 5-s Peak Power – R5PP ($W \cdot kg^{-1}$)	11.35 ± 1.09	10.74 ± 0.91	11.24 ± 1.29
Relative 1-s Peak Power – RPP ($W \cdot kg^{-1}$)	13.47 ± 1.44	12.93 ± 1.17	13.31 ± 1.43
Fatigue Index – FI	46.63 ± 8.11	48.58 ± 8.58	47.37 ± 6.22
Average Cadence – AC (rpm)	136.5 ± 9.2	130.9 ± 7.6	132.6 ± 7.4
Peak Heart Rate – PHR (bpm)	181.7 ± 11.7	182.8 ± 8.3	184.1 ± 13.2

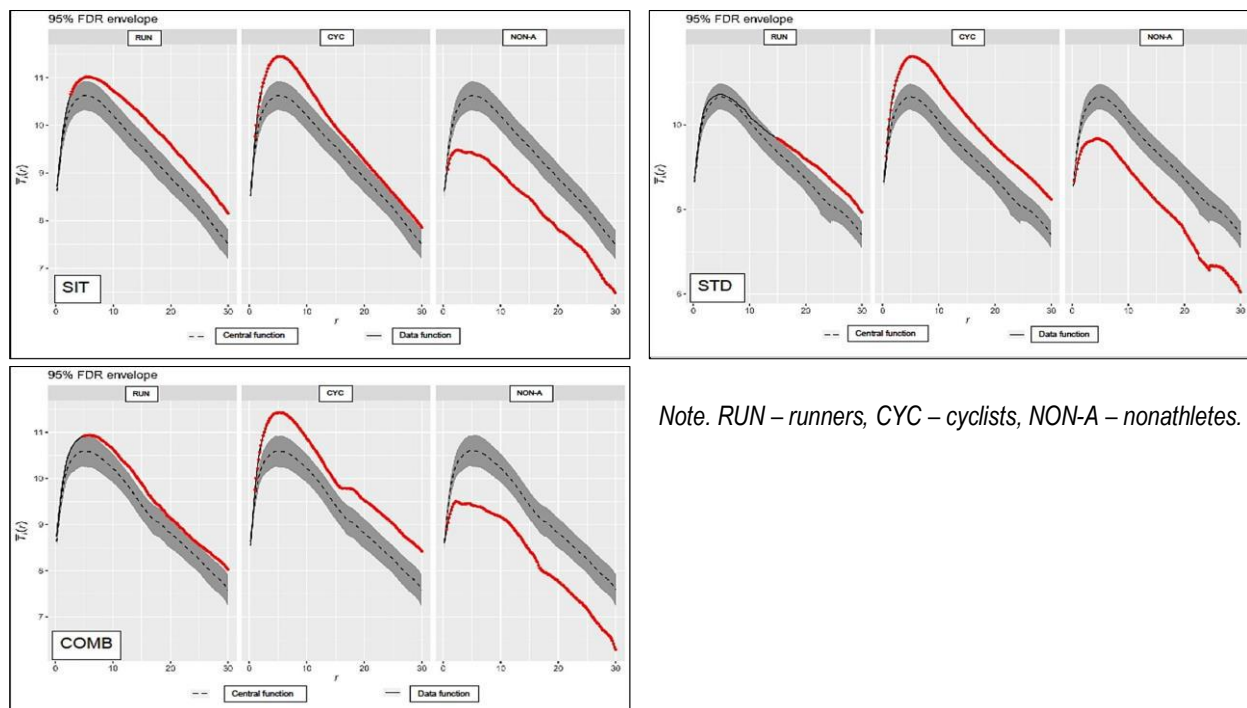
	Non-athletes		
	Sit	Stand	Middle
Relative 30-s Average Power – RAP ($W \cdot kg^{-1}$)	7.77 ± 1.12	7.43 ± 1.15	7.68 ± 1.16
Relative 5-s Peak Power – R5PP ($W \cdot kg^{-1}$)	8.26 ± 1.92	8.67 ± 2.17	8.23 ± 2.19
Relative 1-s Peak Power – RPP ($W \cdot kg^{-1}$)	10.66 ± 1.71	11.16 ± 2.46	10.99 ± 2.05
Fatigue Index – FI	47.12 ± 9.40	55.81 ± 15.81	53.55 ± 12.83
Average Cadence – AC (rpm)	112.9 ± 13.9	109.7 ± 15.0	112.4 ± 15.4
Peak Heart Rate – PHR (bpm)	184.5 ± 11.8	189.2 ± 11.2	186.8 ± 14.1

Performances achieved in individual positions are different from group to group. The effect of sport is significant in all endpoints. The effect of position is not significant for any summarizing characteristics. However, differences between positions vary between different types of athletes (see Table 3).

Table 3. Significance of individual factors in random mixed effect models.

	Interaction between position and sport	Effect of sport	Position
RAP ($W \cdot kg^{-1}$)	0.0019 **	2.2e-16 ***	0.1617
R5PP ($W \cdot kg^{-1}$)	0.0578	2.2e-16 ***	0.7389
RPP ($W \cdot kg^{-1}$)	0.0679	8.03e-16 ***	0.6244
FI	0.0973	0.0449 *	0.1216
AC (rpm)	0.0066 **	2.2e-16 ***	0.2058

Note: * $p < .05$, ** $p < .01$, *** $p < .001$ ***.



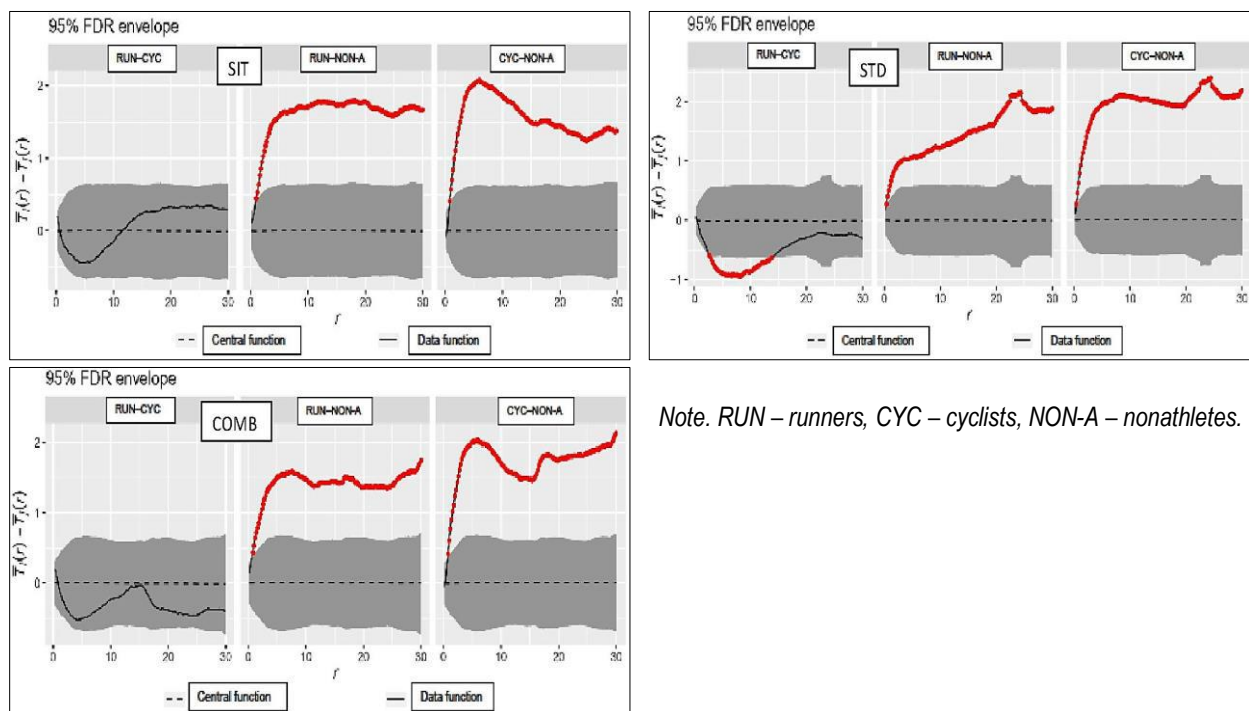
Note. RUN – runners, CYC – cyclists, NON-A – nonathletes.

Figure 2. WAnT protocols in the sitting (SIT), standing (STD) and combined (COMB) position.

The quality of the difference between the positions in the different stages of the test for each group is presented in Figures 2–4. These show the WAnT performance pattern recorded every 0.2 s in the individual positions for a group of runners, cyclists, and non-athletes. The Figure 2 show the performance of each group in the individual positions compared to the entire set of participants. The bold line outside the grey zone

shows a significantly different result. The grey zone represents an area in which the null hypothesis is not rejected. A group of runners achieve significantly better performance in the sitting position from the 3rd to the 30th second. Cyclists achieve significantly better results throughout the test, achieving the largest difference from the other groups in the first 13 seconds of the test. A group of non-athletes achieved significantly worse results in the sitting position compared to the other groups.

In the standing position shown in Figure 2, runners achieve significantly better results than other groups from the 15 second until the end of the test. Cyclists achieve significantly better results throughout the WAnT; again, in the first 10 seconds, the difference is greatest compared to other groups. A group of non-athletes is recorded with significantly the smallest result throughout the WAnT. In the combined position (the first 15 s in the sitting position and the second 15 s in the standing position), runners achieved a significantly better result than others tested from 5th to 30th, with the WAnT runners achieving a significantly better result than others tested from 5th to 30th with the WAnT. For cyclists, a significantly better result is recorded throughout the WAnT, with the largest difference to other groups being recorded during the first 10 s of the test and then after 15 seconds when the position change occurred. For the non-athlete group, significantly the lowest performance is recorded throughout the WAnT. For all groups, there was an optical improvement in performance due to the position change at 15s.



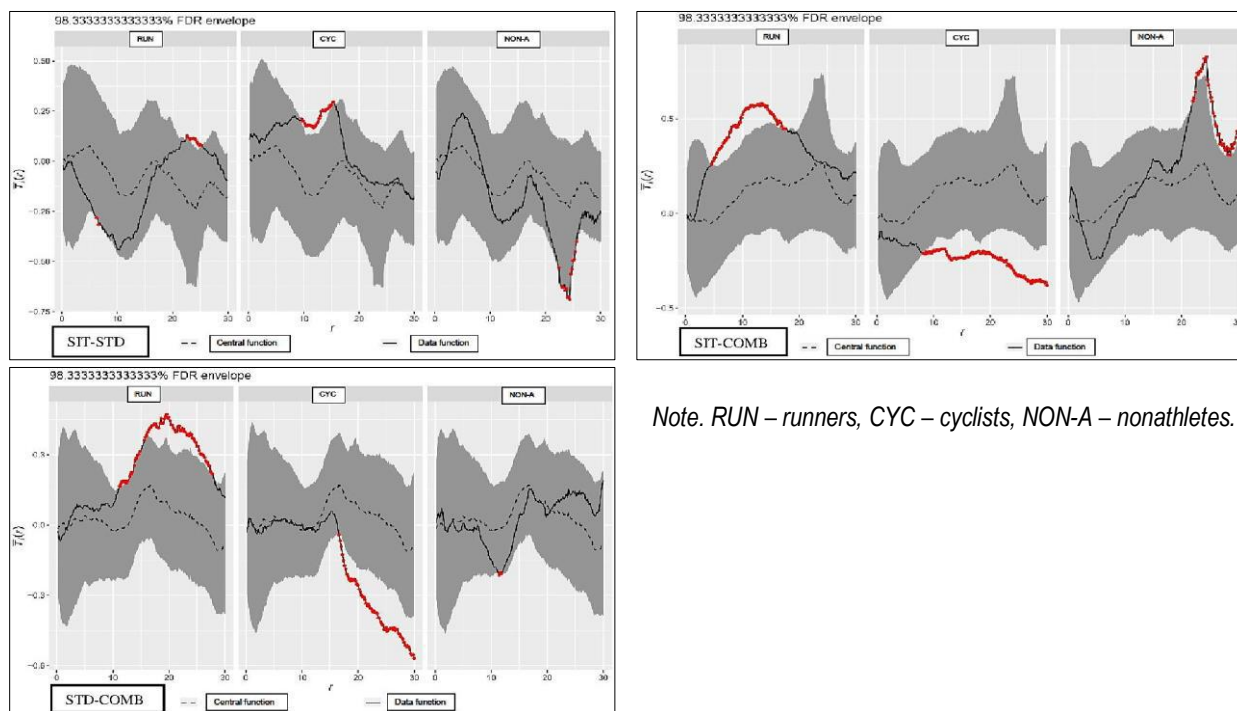
Note. RUN – runners, CYC – cyclists, NON-A – nonathletes.

Figure 3. Performance differences in WAnTs in the sitting (SIT), standing (STD) and combined (COMB) position between different groups of participants.

The Figure 3 show the performance difference between groups in each position. Cyclists achieve higher performance in sitting position than runners for the first 12 seconds of the test, then runners dominate. Performance differences between groups are not significant at any stage of the test. Non-athletes achieve significantly lower performance in the sitting position throughout the WAnT compared to both runners and cyclists. Cyclists achieve a higher level of performance during the whole standing test than runners; this difference is significant between the 2nd and 14th seconds. Non-athletes achieve significantly lower

performance than both runners and cyclists, even in standing positions. In the combined position, cyclists perform better than runners throughout the test, but the difference is insignificant. Halfway through the test, there is a clear improvement in the performance of cyclists over runners. Non-athletes achieve significantly less performance than runners and cyclists in the combined position.

The Figure 4 show the difference in performance between individual positions in individual groups of participants. For a group of runners, there is a significant difference in favour of the sitting position in 5–17 sec, between the sitting and standing positions. For a group of cyclists, there is a significantly better standing result from 8–30 sec. For a group of non-athletes, there is a significantly better sitting performance in 22–30 sec. For runners, when comparing sitting and combined performance, significantly better sitting performance is recorded in 11th-14th s and 16th-28th s. For cyclists, significantly better performance is seen in the combined position from the 17th to 30th s test. For non-athletes, significantly better performance is seen only in the 13th-14th s test. The difference in standing and combined performance is described in the Figure 4 as well. For runners, the combined performance is significantly higher in the 6th and 7th sec; in the standing position, they achieve significantly better performance in the 13th-16th sec. A group of cyclists achieved significantly better performance in the standing position in the 9th-16th seconds. For non-athletes, significantly better performance was achieved in the combined position in the 22nd-26th sec.



Note. RUN – runners, CYC – cyclists, NON-A – nonathletes.

Figure 4. Performance differences between WAnTs in sitting and standing, sitting and combined, standing and combined position.

DISCUSSION

The main aim of this study was to assess how performance during the WAnT is influenced by position (sitting, standing, and combined) across diverse participant groups, taking into account variations in fitness levels and pedalling techniques among cyclists, runners, and non-athletes. This was demonstrated by comparing anaerobic power output characteristics (RPP, RAP, R5PP, FI, PHR, AC) in elite cyclists, runners, and non-

athletes. At the same time, they completed three distinct WAnTs in 3 different position protocols. Since the results could be more transparent, we also looked at performance differences in different positions during the tests.

We hypothesise that the preferred position in the Wingate test will be different from group to group depending on the level of fitness and technique of pedalling. Additionally, we hypothesise that the technique of pedalling will have an influence on the Wingate test result. This was correct. Although we found no general significant influence of the position on the values of individual parameters measured at the WAnT. However, there is a general relationship between the level of fitness and the results of selected parameters at the WAnT (RAP and AC). Our findings also confirm a significant relationship between the level of performance and the selected position at the test for individual groups according to the level of fitness and technique of pedalling. We found that for cyclists who represent technically and fitness-worthy individuals, the optimal position for the WAnT is the standing or combined position, which partly confirms the already published conclusions (Kadlec et al., 2022, Merkes et al., 2020, Reiser et al., 2002). In evaluating speed skaters who are representatives of fitness-ready individuals and athletes technically at the intermediate level, Wilson et al. (2009) did not find significant differences between the results of the sitting and standing tests. Individuals with high anaerobic fitness levels but without sufficient technique pedalling (runners) and non-athletic individuals achieve the best performance in the WAnT in the sitting position. This position appears to be the best for the WAnT for individuals prepared in fitness but without the necessary pedalling technique and for individuals without fitness and technique (McLester et al., 2004).

This study provides valuable insights into the specific phases of the WAnT, where distinctions exist among various athlete groups in each position. For elite cyclists, the optimum level of technique and fitness allows a higher level of performance to be achieved during the whole standing test than for individuals who possess a high level of fitness but without the necessary pedalling technique (group of runners). While in the first half of the test, the difference is significant. In the sitting position, cyclists achieve higher performance than runners for the first 12 seconds of the test, after which the runners achieve better performance. In the combined position, cyclists perform better than runners throughout the test, but the difference is insignificant. For cyclists, there is also significantly better performance in the standing position than in the sitting position in the 8th-30th sec. Cyclists also perform significantly better in the standing position in the 9th-16th sec than in the combined position. It indicates a better pedalling efficiency in the standing position in this test phase than in the sitting position.

A comparison of the performances of runners and cyclists is shown above. However, since the 15th-second test, runners have performed significantly better than the whole test set. In the combined position, runners have performed significantly better in the 5th-30sec. Runners have achieved significantly better performance in the 4th to 18th seconds in the sitting position compared to the standing position. From the 15th to the 28th seconds, runners performed significantly better in the standing position than in the combined position. This is even though since the 15th sec, the combined position represents the standing position. The change of position in the 15th second allows for a temporary improvement of performance in the second half of the test, even though runners do not have the necessary technique of pedalling standing.

For a non-athlete group, we can see significantly the lowest performance in all positions, significantly lower than that of cyclists and runners. This is the expected result (Bar-Or, 1987, Ramírez-Vélez et al., 2016). There are no significant comprehensive differences between the performances in individual positions, which is confirmed by the already published conclusions (Costa et al., 2022). Non-athletes perform significantly better in the 22nd-30th sec sitting position than in the standing position. They perform significantly better in

the combined position than in the standing position between the 22nd and 26th. It indicates that the change of position has a temporary positive effect on their performance.

To generalize the results, obtaining the results of athletes of a more diversified fitness level would be necessary. Thus, the limits of the work include the absence of multiple groups of athletes of different levels. Our results show that in the absence of a pedalling technique, a high level of speed-strength disposition (fitness) can significantly influence performance in the second half of the WAnT in the standing position. A sufficient level of fitness and the absence of technique results in a significantly smaller decrease in performance in the second half of the WAnT in the sitting position. It also allows significantly better performance in the sitting position than in the standing position. In technically advanced individuals, the best results are achieved in the combined and standing position.

CONCLUSION

The level of anaerobic fitness determines the result of the WAnT. An important finding is the influence of pedalling technique on performance during the WAnT. Technique and fitness have a significant influence on the results of the WAnT. Individuals without a rational riding technique achieve individually the best results in the WAnT in the sitting position. For technically advanced individuals with a high level of fitness, the best results are achieved in the combined and standing positions. The level of fitness and technique of pedalling have different influences on performance in the various phases of the WAnT; this is the main benefit of this work. Technically advanced individuals perform significantly better in standing than sitting from the 8th second until the end of the test. The optimum level of technique and fitness will allow a significantly higher level of performance in the first half of the test in the standing position than only for individuals with fitness but without the necessary level of technique. Without a good pedalling technique, a high-speed force disposition can significantly influence performance in the second half of the WAnT in the standing position, also causing a smaller decrease in performance in the second half of the WAnT in the sitting position. These conclusions may be helpful in the realization of the WAnT and its evaluation. They show the influence of technique on performance and the influence of fitness.

AUTHOR CONTRIBUTIONS

Conceptualization, P.B., D.M., M.K., P.B.J. and D.B. ; methodology, P.B., M.K., P.B.J., D.B. and T.M.; software, R.M. and T.M.; validation, P.B., M.K., P.B.J. and D.M.; formal analysis, P.B., D.B., R.M. and T.M.; investigation, P.B. and D.B. ; resources, P.B. and R.M.; data curation, P.B., P.B.J. and D.B.; writing—original draft preparation, P.B., D.M., M.K., P.B.J., D.B. and T.M.; writing—review and editing, P.B., D.M., M.K., P.B.J., D.B., R.M. and T.M.; visualization, P.B., D.B.; supervision, P.B., D.B. and T.M. All authors have read and agreed to the published version of the manuscript.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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Motivations, barriers, and social media volume usage influence on exercise: Similarities and differences between college athletes and nonathletes

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ABSTRACT

Exercise contributes to a healthy lifestyle. Nonetheless, many people are insufficiently active. This study investigated exercise motivation, barriers to exercise, and the impact of social media volume usage among 18-25 year olds from a Midwestern university (USA). Data was collected via survey. Overall, the sample noted the psychological and fitness sub models and the positive health and strength and endurance subscales to be most important. There was a significant difference between college athletes and nonathletes for two sub models and seven subscales. College athletes noted time constraints and nonathletes noted their lack of motivation and time constraints (equally) as top barriers. Overall, the primary barriers to exercise were rated as less impactful ($p < .001$) by the college athletes (45.3 ± 34.2) compared to nonathletes (69.2 ± 28.3). Social media usage was prevalent in our sample, and it might be differentially impacting users. Highest-volume users rated barriers to be more impactful than lowest-volume users ($p = .035$). Social media is a current-culture culprit that helps “*not enough time*” persist as a key barrier to exercise. The impacts of social media on fitness and activity need further investigation.

Keywords: Physical education, Motivational strategies, Exercise motivation inventory, Physical activity.

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INTRODUCTION

Exercise is beneficial to many domains of health (e.g., physical, mental) and lowers the risk of all-cause mortality (Centers for Disease Control and Prevention, 2022; U.S. Department of Health and Human Services, 2018). Exercise motivation is focused on understanding why people exercise, and it can be broadly categorized into intrinsic (fuelled by internal rewards; enjoyment, competence) and extrinsic (achievement of tangible rewards; appearance, social interaction) motivation (Buckworth et al., 2007; Morris et al., 2022).

In Spanish and Lithuanian university-going populations, top motivators for exercise included positive health, physical appearance, and fitness (Ednie & Stibor, 2017; Sukys et al., 2019). In university-going participants in the United States of America (USA), females indicated a greater concern with body weight and body-related motives, whereas male counterparts were more influenced by ego-related motives (e.g., challenge) (Kilpatrick et al., 2005). Participants in individual sports have higher levels of intrinsic motivation compared to participants in fitness groups, while the latter are spurred by body-related extrinsic motivation (Frederick & Ryan, 1993). In general, sport participants appear more likely to highlight intrinsic (e.g., competition, enjoyment) motivation as being important, while regular exercise participation is linked to extrinsic (e.g., health- and appearance-related) motivation (Kilpatrick et al., 2005).

Across two American universities, 173 students were surveyed from classes focused on wellness for life concepts. In total, 88 students (50.9%) noted a desire to engage in more regular exercise, and they identified better organizing their time as a key motivator to accomplish this outcome (Hare et al., 2016). It is valuable to highlight that even a single, semester-long university course focused on physical activity can bring physical benefits (Offutt et al., 2016). Among students in aerobic-activity (e.g., jogging, walking) classes, participation ($n = 46$) resulted in improvements in estimated maximal aerobic ability and grip strength ($p < .05$) (Offutt et al., 2016). For those in sport-activity (e.g., pickleball, self-defence, strength training) classes, participation ($n = 45$) resulted in improvement in vertical jump and grip strength ($p < .050$) (Offutt et al., 2016). Semester-long wellness classes have also been shown to promote enhanced perception of the value of multi-dimensional wellness for future health (Hare et al., 2016).

Barriers, actual or perceived, act in opposition to motivators, and they limit or inhibit exercise behaviour (Buckworth et al., 2007). Internal barriers (e.g., lacking willpower, not enjoying exercise) relate to an individual's personal decision-making, while external barriers (e.g., lacking access to facilities, being impeded by weather) are defined as factors beyond an individual's control (Ziebland et al., 1998). Internal and external barriers may influence singularly or collectively to deter exercise participation.

Time constraints have commonly been highlighted as a key barrier to exercise engagement (Ebben & Brudzynski, 2008; Hare et al., 2016; López de Subijana et al., 2015; Tappe et al., 1989). Lack of interest or desire (Tappe et al., 1989) and lack of support (Cowley et al., 2021; Ebben & Brudzynski, 2008; Sukys et al., 2019) among university-going students have also been noted. COVID-19 is a unique barrier that was recently and universally experienced. Among a sample from our Midwestern university, the virus created change in daily routines in the college athletes that led to elevations in symptoms of depression, anxiety, and stress (Garver et al., 2021). This finding was more prominent among females than males, and supporting qualitative data described the influence as “*disappointing*,” “*frustrating*,” and “*saddening*” (Garver et al., 2021). There is evidence that life stage influences barriers, and young adults are highlighted in this regard—they often experience greater independence, increased transition, and alterations in living arrangements (Vaterlaus et al., 2015). With interest, Vaterlaus and colleagues (2015) found a belief among young adults that social media use could negatively impact exercise opportunities by displacing time and serving as a distraction.

Social media and its effect on exercise motivation and exercise barriers is an emerging area of research. There are some young adults (18-25 years) who purport social media to be a motivator for exercise. These young adults report that posting pictures of themselves looking their best, or seeing pictures of others who have lost weight, are motivational (Vaterlaus et al., 2015). Evidence to the contrary also exists. Holland and Tiggemann (2017) found that women who regularly posted fitspiration photos were more likely to have maladaptive characteristics (e.g., disordered eating, body dissatisfaction) compared with women who regularly posted travel-focused photos. Fitspiration preaches health, but some creators are demonstrating increased negative characteristics for exercise. An example, among university-going participants in the United Kingdom, more time spent on social media negatively impacted body idealizations (e.g., inspiration to be thinner, distorted view of oneself) and affected exercise motivation (e.g., compulsive exercise) (Graff & Czarnomska, 2019).

This study sought to investigate motivations, barriers, and social media volume usage on exercise among individuals (college athletes vs. nonathletes) associated with a Midwestern university. Researchers hypothesized (H₁) that motivations would be dependent on the subpopulation, with college athletes swayed more toward performance-focused ideas and nonathletes toward general fitness or health, (H₂) that college athletes would find their barriers to be less impactful in terms of magnitude than nonathletes, and (H₃) that highest-volume social media users would find barriers to be more impactful than lowest-volume users when collapsed across college athlete-nonathlete categorization.

METHODS

Participants

Participants were associated with a mid-size, Midwestern university. Inclusion criteria required participants be at least 18 years of age and associated with the university in some way (e.g., student, staff). A total of 143 participants clicked into the survey. Three individuals entered but made no selections—they were removed from ongoing analysis. Further, there was limited participation by individuals over 25 years of age ($n = 10$ total; 26 to 59 years of age). Literature has indicated that life stage impacts motivators and barriers for exercise (Vaterlaus et al., 2015); thus, results focus on the individuals 18-25 years of age ($n = 130$). Of the 130 individuals entering the survey, 102 (78.5%) completed the full survey, 10 (7.7%) completed 50-95% of the survey, and 18 (13.8%) completed 5-40% of the survey. There was no compensation for participation.

The average age of the sample ($n = 129$; 1 person did not answer) was 20.5 years ($SD = 1.6$). The sample identified primarily as female ($n = 92$) and white ($n = 111$). These and related data about sex, age, and race are noted in Table 1. Five participants had a high school education (or equivalent), 111 had some college education, ten were college graduates, one held a master's degree, and three participants did not respond. There were 56 participants who were current college athletes, 55 who were not college athletes, and 19 participants who did not respond. Asked if they were “*current exercisers*” based on recognized guidelines (Centers for Disease Control and Prevention, 2022), 97 (74.6%) selected “*yes*,” 29 (22.3%) selected “*no*,” and four (3.1%) did not respond.

Measures

The Exercise Motivation Inventory-2 (EMI-2) was used to assess exercise participation motives (Markland & Ingledew, 1997). The EMI-2 consists of 51 questions that require each participant to pick a number on a 6-point Likert scale. The ‘0’ indicates “*Not true for you at all*” and ‘5’ indicates “*Very true for you*.” The EMI-2 consists of the following 5 sub models and 14 subscales (noted within parentheses) (Markland & Ingledew, 1997):

- Psychological (stress management, revitalization, enjoyment, and challenge);
- Interpersonal (social recognition, affiliation, and competition);
- Health (health pressures, ill-health avoidance, and positive health);
- Body-related (weight management and appearance);
- Fitness (strength and endurance and nimbleness).

Table 1. Selected descriptive and frequency data for the sample of 18-25 year olds (n =130).

Variable	Characteristic	Frequency	Percent
Sex	Female	92	70.8
	Male	35	26.9
	No response	3	2.3
	Prefer not to answer	0	0
Age (years)*	18	10	7.8
	19	24	18.6
	20	39	30.0
	21	26	20.2
	22	15	11.6
	23	8	6.2
	24	4	3.1
	25	3	2.3
Race	White	111	85.4
	Black	8	6.2
	Latino	4	3.1
	Asian	3	2.3
	Undisclosed/Other	4	3.1

Note. *One participant did not disclose age.

Scores are calculated by finding the average for each subscale and sub model. All scores are summative, and none are reverse coded or scored.

In the EMI-2, specifically, but in other areas of the survey, the '0' indicated something such as, "Not true for you at all." To protect from unanswered questions, or skipped questions erroneously becoming "0" responses, the research team set the default response of some questions to "-1." This meant the participant had to drag the scale from "-1" to their desired answer. As an example, the directions for each set of EMI-2 questions consisted of the following language, "Move the slider away from -1" to indicate which number (0 to 5) is true for you personally. Questions with a -1 response were deemed invalid and eliminated. Therefore, the n's associated with various results reflect a number less than 130—the number of participants included in the main results.

The exercise barriers chart was adapted from previous researchers (Ebben & Brudzynski, 2008). The chart in the present study consisted of 20 items that could prevent an individual from exercising. Four examples spanning the range of items included, "There is not enough time in the day to exercise," "I dislike exercising in public," "Weather conditions deter me from exercise," and "I really do not know how to set up a program or use equipment in the correct and effective ways." Participants reviewed all 20 items and then typed their top three barriers in a textbox just below the chart. After the participant picked their top three barriers, they ranked the "magnitude" of how much that particular barrier impacted their exercise choices by using a drag and drop visual analogy scale ranging from 0-100. The '0' represented "Never" and the '100' represented

“Always.” The “magnitude” related to how strongly, frequently, or both, that barrier was perceived to be by the respondent. Participants ranked the magnitude of each of their top three barriers separately.

Questions regarding social media were placed near the end of the survey. Sample questions included, “Do you use social media to get workout inspiration?” and “How much time do you spend on the specific social media or internet sites you see below? (If available, feel free to check screen time data on your phone to give the best answers possible): Facebook, Instagram, Snapchat, TikTok, YouTube.” Participants selected from among six choices (e.g., “Not applicable to me,” “1 hour per week,” “3 hours per week”) for each specific social media or internet site. Overall usage was summed, and participants were categorized into tertiles (highest-, middle-, and lowest-volume) for comparison.

Procedures

The University of Central Missouri Institutional Review Board approved the study prior to the start of data collection. The survey was made available in the late spring of 2023 and administered through Qualtrics. Participants were able to complete the survey at any time, on any device, and at the location of their choosing. They were directed to the survey through various means including flyers and emails.

Participants began the survey by completing an informed consent form and confirming that they were at least 18 years of age. After consenting, participants completed the survey questions. There were five demographic questions. Thereafter, the 51 questions of the EMI-2 began (Markland & Ingledew, 1997). The questions were broken into three sets to reduce the likelihood of monotony and focus in answering. The first set of EMI-2 questions contained 18 queries. Between the first and second set of EMI-2 questions, participants responded to questions regarding sport participation or primary mode of exercise. The second set of EMI-2 questions contained 15 queries. Between the second and third set of EMI-2 questions, participants were given a chart containing 20 barriers. They were instructed to pick their three main barriers and then rank the impact each had on their exercise participation. Questions regarding social media usage and the related influence on exercise were placed thereafter. When the third set of EMI-2 questions (the final 18 questions) was completed, a screen confirmed completion and thanked them for their responses.

Analysis

Researchers utilized IBM SPSS version 28.0 for all analyses including frequencies, descriptives, and tests of significance. To compare between groups (e.g., college athletes vs. nonathletes, females vs. males, highest- vs. lowest-volume usage) independent samples t-tests were conducted. Levene’s tests were utilized to test for equality of variances. Unless otherwise noted, data are presented as means \pm standard deviation ($M \pm SD$). Statistical significance was set at $p < .05$.

RESULTS

Time to complete the survey

The mean duration to complete the survey was skewed greatly by several extreme outliers (e.g., 434,594 s; 170,815 s). When outliers were removed, the mean duration to complete the survey was approximately 487 s ($n = 121$) ($M = 487.3$, $SD = 314.0$).

Exercise motivation

Fundamental results for the included sample ($n = 130$) revealed that two sub models for the EMI-2 were deemed near-equally most important, the psychological sub model ($M = 3.6/5.0$, $SD = 1.0$) and the fitness

sub model ($M = 3.5/5.0$, $SD = 1.0$). The most important subscales were positive health ($M = 4.3/5.0$, $SD = 0.8$) and strength and endurance ($M = 4.1/5.0$, $SD = 1.1$).

EMI-2 sub models and subscales

An independent-samples t-test was used to compare the mean EMI-2 sub model and subscale scores between college athletes and nonathletes. There was no significant difference between for the psychological, health, or fitness sub models ($p > .05$). There were significant differences for the interpersonal and body-related sub models (Table 2).

There was no significant differences between college athletes and nonathletes for the stress management, social recognition, health pressures, positive health, appearance, strength and endurance, or nimbleness subscales ($p > .05$). However, there were significant differences for the revitalization, enjoyment, challenge, affiliation, competition, ill-health avoidance, and weight management subscales (Table 2).

Table 2. Reporting of the significant differences between college athletes vs. nonathletes for Exercise Motivation Inventory-2 (EMI-2) sub model and subscale scores.

Sub model	Subscale	College athletes (M ± SD)	Nonathletes (M ± SD)	Levene's Test of equal variances assumed	p-value or t (degrees of freedom) and p-value
Psychological	-	-	-	-	$p > .05$
	Revitalization	3.7 ± 1.0	3.3 ± 1.2	Yes	t (95) = 1.982, $p = .050$
	Enjoyment	3.9 ± 1.0	3.3 ± 1.4	No	t (85.289) = 2.584, $p = .011$
	Challenge	3.8 ± 1.1	3.2 ± 1.2	Yes	t (93) = 2.410, $p = .018$
Interpersonal	-	3.3 ± 0.9	2.2 ± 0.9	Yes	t (64) = 4.874, $p < .001$
	Affiliation	3.2 ± 1.3	2.3 ± 1.3	Yes	t (78) = 2.972, $p = .004$
	Competition	4.1 ± 1.1	2.4 ± 1.5	No	t (73.771) = 5.782, $p < .001$
Health	-	-	-	-	$p > .05$
	Ill-health avoidance	3.0 ± 1.4	3.7 ± 1.1	No	t (73.771) = -2.749, $p = .008$
Body-related	-	2.9 ± 1.2	3.7 ± 1.0	Yes	t (67) = -3.035, $p = .003$
	Weight management	2.9 ± 1.4	3.8 ± 1.1	Yes	t (77) = -3.462, $p < .001$
Fitness	-	-	-	-	$p > .05$

Note: The EMI-2 is the work of Markland and Ingledew (1997).

EMI-2 results between sexes

An independent-samples t-test was used to explore the EMI-2 sub models and scales between females and males (collapsed across the sample). Zero participants choose "prefer not to answer" or "other" for sex, but three participants skipped the response. Accordingly, up to 127 participants were included in this analysis, with the exact subject number being dependent on completion of the EMI-2 survey questions. Overall, there was no significant differences for any of the sub models or subscales between sexes ($p > .05$). Nonetheless,

the ill-health avoidance subscale was trending towards significance (females: $M = 3.5$, $SD = 1.2$; males: $M = 3.0$, $SD = 1.4$; $t(85) = 1.96$, $p = .053$).

Barriers to exercise

Recall that participants reviewed a list of 20 items (i.e., actual or perceived barriers) and then typed their top three barriers in a textbox. Collapsed across the sample, a tally of responses revealed the following barriers were most impactful: “I need to do better at managing my time to exercise more often” ($n = 40$), “I am not motivated to exercise” ($n = 31$), “There is not enough time in the day to exercise” ($n = 31$), “Weather conditions deter me from exercising” ($n = 23$), and “I would exercise but I am just lazy” ($n = 23$). The tally appears higher than the $n = 130$ sample because each person identified up to three barriers. Table 3 provides frequency data for the first, second, and third most common barriers for the college athletes and nonathletes.

Table 3. First, second, and third most common barriers to exercise and frequency of the barrier for college athletes vs. nonathletes.

Barrier	College athletes	Nonathletes
First	“I need to do better at managing my time to exercise more” ($n = 19$)	“I am not motivated to exercise” and “I need to do better at managing my time to exercise more” (both, $n = 21$)
Second	“Weather conditions deter me from exercising” ($n = 15$)	-
Third	“I do not have an exercise partner to go with” and “I would exercise but I am just too lazy” (both, $n = 13$)	“There is not enough time in the day to exercise” ($n = 20$)

The magnitude of each barrier was rated from ‘0’ [Never] to ‘100’ [Always] based on how strong, frequent, or both, that barrier was perceived to be. The data violated Levene’s Test for Equality, and adjustments were made. Overall, in accordance with H_2 , the independent samples t-test revealed that college athletes ($M = 45.3$, $SD = 34.2$) deemed their primary barrier to be less impactful than nonathletes deemed their primary barrier ($M = 69.2$, $SD = 28.3$), $t(89.657) = -3.750$, $p < .001$. The same was true for the secondary (college athletes: $M = 35.3$, $SD = 28.5$ vs. nonathletes: $M = 54.0$, $SD = 27.1$; $t(93) = -3.280$, $p = .001$) and tertiary (college athletes: $M = 28.3$, $SD = 22.2$ vs. nonathletes: $M = 46.9$, $SD = 25.2$; $t(90) = -3.755$, $p < .001$) barriers.

Social media use

Investigation revealed that out of 130 participants, 78 participants (60.0%) reported using social media to gain workout inspiration, 27 participants (20.8%) did not, and 25 participants (19.2%) did not respond. There was a wide range of weekly social media usage reported (2-63 hr), and the included sample of 105 participants averaged 25.0 ($SD = 12.2$) hr a week. An independent-samples t-test revealed there was no significant difference between time spent on social media for college athletes and nonathletes, $p > .05$. However, when participants were collapsed and divided into tertiles based on weekly social media usage, an interesting finding arose. The highest-volume users ($n = 32$) averaged 39.0 ($SD = 8.8$) hr a week and the lowest-volume users ($n = 29$) averaged 13.0 ($SD = 4.3$) hr a week. As a directional t-test, in accordance with H_3 , highest-volume users rated their barriers ($M = 54.8$, $SD = 23.9$) to be more impactful than lowest-volume users ($M = 43.3$, $SD = 23.6$), $t(59) = -1.852$, $p = .035$.

DISCUSSION

The sample included 130 participants who overwhelmingly identified as female, white, and educated beyond high school. Of those noting the designation, 56 participants were current college athletes and 55 were not. The sample was predominated by “current exercisers” ($n = 97$). Summarized, researchers hypothesized (H_1)

that motivations would be dependent on the subpopulation, (H₂) that college athletes would find their barriers to be less impactful than nonathletes, and (H₃) that highest-volume social media users would find barriers to be more impactful than lowest-volume users. There is data to support each hypothesis.

Collapsing data across groups, two sub models—the psychological sub model and the fitness sub model—were most important in the present sample. For the subscales, positive health and strength and endurance were most important. Previous researchers have investigated exercise motivation in university-going populations and found similar results. Sukys et al., (2019) identified health and fitness as chief motivators for their sample, while Ednie and Stibor (2017) found positive health to be a top motivator among their cohort. Ebben and Brudzynski (2008) found the top motivators of in their sample to be health, fitness, stress reduction, and more. The fact that researchers across different universities, with use of different survey tools, and from pre-pandemic to post-pandemic timepoints have found health and fitness to be key motivators for traditional, college aged samples speaks to the potential wide-spread impact and staying power of these motivators for this population.

College athletes were more motivated by the interpersonal sub model, as well as the revitalization, enjoyment, challenge, affiliation, and competition subscales, compared with nonathletes. Nonathletes were more motivated by the body-related sub model, as well as the ill-health avoidance and weight management subscales, compared with the athletes. We interpret these findings to fall in line with our hypothesis (H₁). Performance-focused ideas (college athletes: interpersonal sub model, revitalization, enjoyment, challenge, affiliation, and competition subscales) and general fitness or health (nonathletes: body-related sub model, ill-health avoidance and weight management subscales) are well-represented by the responses of our sample. Kilpatrick and colleagues (2005) have previously found that individuals who participated in sports were more intrinsically motivated (e.g., competition, affiliation, and challenge) compared to those engaging in regular exercise routines. Our findings are in concurrence such that college athletes ranked the interpersonal sub model and competition, affiliation, challenge, and enjoyment subscales higher than nonathletes. These findings are undergirded by the work of Frederick and Ryan (1993) who emphasized that individuals in sports are intrinsically driven due to autonomy. Our sample, like Frederick and Ryan (1993), also found nonathletes to rank the body-related sub model higher than college athletes. We speculate that nonathletes who exercise may become more cognizant of their body and thus are driven to activity for extrinsic attributes (e.g., weight management, ill-health avoidance) noted in the present study. The aggregated data suggests that a different source of motivation may compel nonathletes (swayed towards appearance) compared with athletes (swayed by intrinsic and extrinsic attributes of sport) to their various engagements.

Focused on post-pandemic research, our findings align with the outcomes of Vučković and colleagues (2022). These researchers measured motivation in college students and found that previous/current athletes rated the majority of the EMI-2 subscales (e.g., revitalization, enjoyment, challenge, social recognition, positive health, appearance, strength and endurance, nimbleness, and stress management) significantly higher than noncompetitors/nonathletes. There is considerable overlap—their data and ours identified revitalization, enjoyment, challenge, affiliation, and competition to be higher in athletes vs. nonathletes (Vučković et al., 2022).

While previous researchers have noted differences in motivation between females and males (Ednie & Stibor, 2017; Kilpatrick et al., 2005; Sukys et al., 2019), we did not find significant differences for any subscale or sub model between sexes. However, the ill-health avoidance subscale was trending toward it, with females ranking it higher (i.e., more important) than males ($p = .053$). A vital aspect of our work was that we afforded participants the opportunity to select sex from non-binary options and none chose to do so. Providing this

data (“zero participants choose ‘prefer not to answer’ or ‘other’ for sex”) is in line with emerging focus on the sex-data gap (Garver et al., 2023) and improved representation and inclusion in exercise-science research (Davis et al., 2024, Navalta et al., 2024). We urge others to provide similar details in their works—in this case, zero is data to acknowledge.

Common in the literature (Cowley et al., 2021; Ebben & Brudzynski, 2008; Hare et al., 2016; López de Subijana et al., 2015; Sukys et al., 2019; Tappe et al., 1989), the current sample highlighted time-focused (paraphrased as “*better at managing my time*” and “*not enough time in the day*”) barriers and an overall lack of motivation (paraphrased “*not motivated*” and “*I am just lazy*”) as impediments. Specific to the athletes, perhaps they identify time management issues due to their dual-focus on both academics and athletics. There was no question posed to the college athletes in the current study about their feelings toward these competing demands; thus, we can only speculate it may have been influential. We do know our college athletes felt that they needed to manage their time more effectively and that lacking an exercise partner was an accompanying barrier, a result not recognized by the nonathlete counterparts. Athletes may be accustomed to camaraderie and team-based relationships and have an engrained reliance on it. Nonathletes stated their most common barrier as lacking motivation, but they further followed the main trend of the study by noting that they needed to better manage their time. For nonathletes, exercise may not be as high of a priority as it is not tied to their daily or near-daily habits through required practices or games. This may be why many nonathletes lack motivation or do not make time in their day to complete physical activity.

College athletes and nonathletes chose their top three barriers from the same list. When ranking the perceived magnitude of the barriers, an interesting finding arose. College athletes deemed all three of their top barriers to be significantly less impactful than nonathletes deemed their respective top three barriers. This supports our hypothesis (H₂). Maybe college athletes do not or cannot let barriers hinder them from exercise or perhaps they find their motivations to be more compelling, in some way. We should not dismiss that this might be a finding related solely to lack of choice—a non-negotiable, set schedule and following a coach’s instruction. Regardless, a brief search of the literature failed to reveal other studies that have asked this subsample about the “*magnitude*” of their perceived exercise barriers. We urge others to investigate this finding using a similar method.

We hypothesized (H₃) that social media volume usage may relate to perceived impact of barriers based on previous research (Graff & Czarnomska, 2019; Holland & Tiggemann, 2017). Our highest-volume users (n = 32) averaged 39.0 hr weekly, which is 5.6 hr each day. The lowest-volume users (n = 29) averaged 13.0 hr weekly, which is 1.9 hr each day. In accordance with H₃, the highest-volume users rated their barriers to be more impactful than lowest-volume users (Table 3). This is particularly problematic when aligned with the fact the sample highlighted time-focused barriers (e.g., “*better at managing my time*”) as their main concern. Time-focused barriers can only be addressed through effective allocation of the 24-hr that each of us is given daily. Time has been an oft-cited barrier across the history of studies focused on exercise barriers, and the current researchers believe that social media is a current-culture culprit that helps “*not enough time*” persist as a key barrier to exercise.

The present study is affected by several limitations. The convenience sample beget attrition (and skipped questions), and only 102 participants completed the full survey. Loss of data most directly impacted statistical power for the sub models of the EMI-2. Additionally, the present research had to be narrowed to focus on traditional, college aged individuals, and it was skewed toward those identifying as female, white, active, and educated. Lastly, we gathered physical activity and social media volume usage data via self-report. Use of objective measures of physical activity and screen time usage statistics are recommended in future studies.

CONCLUSIONS

This research is important as it focuses on motivations and barriers to exercise—exercise is critical to multiple dimensions of wellness. The main motivators for the sample were the psychological and fitness sub models and the positive health and strength and endurance subscales. For barriers, college athletes noted needing to better manage time to exercise more, and nonathletes noted the same, as well as not being motivated. College athletes perceived the magnitude of their barriers to be significantly less than nonathletes when rated on a simple, self-created scale. We encourage others to use this same, simple scale to see if these findings are replicated in similar and different samples. Social media usage was prevalent among our participants, and the highest-volume users rated their barriers to be more impactful than the lowest-volume users. Social media might be differentially impacting users based on volume of engagement, and the impacts of social media need further investigation. We encourage others to use our findings to promote participation in exercise for athletes and nonathletes alike.

AUTHOR CONTRIBUTIONS

SLB: conceptualization, methodology, analysis, writing—original draft, and review and final editing. MJG: conceptualization, methodology, analysis, writing—original draft, review and final editing, and project supervision. AR: conceptualization, methodology, analysis, and review and final editing.

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DISCLOSURE STATEMENT

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Mechanisms of adaptations in cardiorespiratory fitness with exercise prescriptions differing in volume and intensity in middle-age men

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ABSTRACT

Background: To examine the mechanisms of adaptations in cardiorespiratory fitness with different dose of amount and intensity exercise training in middle-aged men. **Methods:** A total of 67 sedentary subjects aged 40-49 yr were assigned to participate for 12 weeks in a control group or in one of three exercise groups: 1) low volume/moderate intensity 2) low volume/vigorous intensity and 3) high volume/vigorous intensity. They were tested for VO_{2max} , cardiac output (Q) and stroke volume (SV) before and after training and maximal arterial-venous oxygen difference ($a-vO_{2diff}$) calculated by the Fick Equation. **Results:** Contrasted to control group, VO_{2max} increased similar in both LVVI and HVVI groups after 12 weeks; It indicated that the intensity of exercise appears to make a greater benefit than the amount of exercise on VO_{2max} . However, Maximal cardiac output (Q_{max}) and $a-vO_{2diff}$ contributed to increase VO_{2max} were differences in both of vigorous intensity groups. In LVVI group, Q_{max} together with maximal $a-vO_{2diff}$ contributed to the greater VO_{2max} ; in HVVI group, the majority of the increment in VO_{2max} was relied on larger Q_{max} whereas a widened $a-vO_{2diff}$. **Conclusion:** It is appropriate to recommend vigorous intensity exercise to improve cardiorespiratory fitness and encourage higher amount to confer additional benefit for Q_{max} .

Keywords: Sport medicine, Cardiorespiratory fitness, Maximal oxygen uptake, Cardiac output, Arterial-venous oxygen difference.

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INTRODUCTION

There is accumulating evidence that cardiorespiratory fitness, represented by maximal oxygen uptake (VO_{2max}) (Åstrand, 2003), is important for the prevention of many lifestyle-related diseases in epidemiological (Laukkanen et al., 2010) observational (Lee et al., 2014; Steell et al., 2019; Sui et al., 2017) and randomized studies (Nordby et al., 2012); moreover, some studies (Tarp et al., 2021; Farrell et al., 2010) indicate that higher levels of cardiorespiratory fitness are associated with lower risks for poorer health. Kokkinos pointed out in another study of 20,950 American veterans that each 1-MET increment in CRF confers an 15% decrease in mortal up to 10 METs beyond which the additional survivor benefits largely plateau (Kokkinos et al., 2017).

ACSM's Guidelines for Exercise Testing and Prescription clearly demonstrate that exercise of the intensity, duration, and frequency recommended results in improvements in VO_{2max} , it is important to beg the question of what the effect of exercise training on cardiorespiratory fitness is. In recent years, studies appear to provide conflicting recommendations regarding the relationship between exercise amount and intensity on increases in VO_{2max} . Current guidelines suggest that changes in cardiorespiratory fitness are similar in high and moderate intensity interventions of longer duration if the energy cost of exercise is similar. O'Donovan reported that among 63,591 adult liability participants, those who performed less than 150 minutes of moderate physical activity per week or less than 75 minutes of heavy physical activity per week had a similar risk of cardiovascular disease reduction compared with those who performed more than 150 minutes of moderate physical activity per week or at least 75 minutes of heavy physical activity per week (O'Donovan et al., 2017). In contrast, vigorous exercise provides greater CVD benefits than moderate PA with equal energy expenditure (Franklin et al., 2023). Min concluded that individuals who performed vigorous PA had a significantly lower risk of all-cause and cause-specific death compared with patients who performed only mild/moderate PA (Zhao et al., 2019). Briefly, data regarding the specific quantity and quality of exercise for the attainment of the VO_{2max} are less clear.

In accordance with a derivation of the Fick equation (Yamabe et al., 1997), VO_{2max} is typically due to both maximal cardiac output (Q_{max}) and the maximal arterial-venous oxygen difference ($a-vO_{2diff}$). However, there is limited data available on the parameters of proportion contributions of Q_{max} and $a-vO_{2diff}$ underlying the increases in VO_{2max} in different dose of exercise, while some studies (Murias et al., 2010; Dogra et al.) have demonstrated the proportion contributions in different ages. For instance, Murias JM investigated the time-course and mechanisms of adaptation of cardiorespiratory fitness in older and young men with a short-term (12wk) endurance training, the results showed that the majority of the increase in VO_{2max} was attributed to an increased Q_{max} (~69%) with the remaining ~31% to a widened $a-vO_{2diff}$ in older men; and 56% of the increase in VO_{2max} explained by a greater Q_{max} and 44% by a widened $a-vO_{2diff}$ in young. Thus, there is clear need for a randomized, controlled trial that address the mechanisms of adaptations in different amounts and intensities of exercise training. The mainly purpose of this study was to investigate which parameters, central or peripheral, are responsible for greater VO_{2max} in a short-term (12wk) different dose of volume and intensity exercise. We hypothesized that 1) the intensity of exercise would be more important than volume for improving VO_{2max} ; 2) A greater VO_{2max} is majority due to a higher Q_{max} compared to peripheral widened $a-vO_{2diff}$.

METHODS

Study design

A complete description of the STRRIDE study design has been published elsewhere (Kraus et al., 2001). The research protocol was reviewed and approved by the relevant institutional review boards, and all subjects provided written, informed consent.

Subjects

Sedentary male volunteers (n = 67), aged 40-49 yr were recruited from the local community to participate in this study. A letter was sent to male soliciting their interest in taking part in a 12-wk study of the mechanisms of adaptations in cardiorespiratory fitness with different dose of amount and intensity exercise training. This letter stated that eligible men were nonsmokers or ex-smokers with at least 2 yr of abstinence. A history of recreational drugs or had significant chronic medical problems were screened with an International Physical Activity Questionnaire (IPAQ) (<https://www.academia.edu/5346814>), and volunteers were excluded if the questionnaire revealed any participation in very hard activities or exercise for >30min/day on two or more occasions per week. Volunteers were examined by a cardiologist and were excluded if there was evidence of cardiovascular disease.

Exercise training protocols

After screening, subjects were randomized via computer program into one of four groups differing in exercise intensity and amount. The 12 weeks exercise training programs were as follows: 1) low-volume/moderate intensity, LVMI, the caloric equivalent of working approximately 19 km/wk, 1,200 kcal/wk at 40-55% VO_{2max} ; 2) low-volume/vigorous intensity, LVVI, jogging approximately 19 km/wk, 1,200 kcal/wk at 65-80% VO_{2max} ; 3) high-volume/vigorous intensity, HVVI, jogging approximately 32 km/wk, 2,000 kcal/wk at 65-80% VO_{2max} ; 4) a non-exercising control group. The specific training regimens were chosen to compare different dose/volume of exercise (1,200 vs.2,000 kcal/wk) in groups exposed to the same intensities of training (65-80% VO_{2max}) and different dose/intensities (40-55 vs. 65-80% VO_{2max}) in groups with the same exercise volume (1,200 kcal/wk). The exercise volume (1,200 and 2,000 kcal/wk) were consistent with recommendations of the Surgeon General's report (US Department of Health & Human Services Centers for Disease Control (CDC) 200 Independence Avenue, 1996). The 65-80% VO_{2max} level was chosen because this is the traditional exercise intensity prescribed for cardiovascular fitness benefits (American College of Sports Medicine). The lower training intensity (40-55% VO_{2max}) approximated brisk walking or moderate-intensity exercise as advised in health guidelines (Pate et al.1995). Once the exercise volume (kcal/kg/wk) was calculated, subjects selected, with the assistance of an exercise physiologist, an appropriate exercise frequency and duration to achieve their weekly dose.

Exercise training monitor

All exercise sessions were verified by direct supervision and use of a heart rate monitor (Polar Electro, RS600, Finland) and tri-axial RT3 accelerometer (Stayhealthy, Inc., Monrovia, CA) that provided recorded data. Subjects were instructed to wear the device during the exercise time as described in a previous study (Hollowell et al., 2009), physical activity energy expenditure (PAEE) determined via the RT3 accelerometer has been shown to consistent with the Prescribed volume (kcal/wk). Adherence was calculated weekly as a percent, equal to the actual number of exercise minutes completed each week at the appropriate intensity, divided by the total number of minutes prescribed. Subjects were counselled to maintain baseline body weight and the goal of the intervention was not weight loss.

All of groups were provides with the IPAQ to record in arbitrary units any additional physical activity or exercise that was above the prescribed program. On entering the study participants were asked to complete a typical retrospective week of the same questionnaire. This was to ensure that all individuals from groups participated in similar amounts of physical activity or exercise at baseline. The control group was offered the intervention at the end of the trial.

Cardiorespiratory fitness measurements

Cardiorespiratory fitness (CRF) was indexed by VO_{2max} using a graded maximal bicycle ergometer test. Briefly, an initial test was performed to screen for underlying cardiovascular disease and to acclimate the

subject. If no evidence for cardiovascular disease was detected, a second test was conducted to determine the pretraining VO_{2max} . Additional VO_{2max} test were performed after the ramp period and periodically during training in order to modify the exercise workload to maintain the weekly caloric expenditure prescription. Finally, VO_{2max} was also determined after the final week of training.

The initial workload of 25W was increased every 2-min by 25W until volitional exhaustion. Participants were required to meet three of the four following criteria for having achieved VO_{2max} : heart rate \geq age-predicted maximum heart rate [$220 - \text{age (yr)}$], respiratory exchange ratio ≥ 1.15 , rating of perceived exertion ≥ 19 , or an increment in $VO_2 \leq 2$ ml/kg/min in response to an increased gradient. During the test, HR was measured by electrocardiographically at the same times, while blood pressure was measured by auscultation. Respiratory data through breath-by-breath analysis were continuously measured (Cortex MetaMax II; Cortex, Leipzig, Germany). These measurements were corrected to standard conditions and used to determine VO_2 at 20-s intervals throughout the test. VO_{2max} was determined by averaging values over the final minute of testing.

Maximal cardiac output measurements

Participants performed a standard echocardiographic assessment system (Vivid 7, GE Vingmed, Horten, Norway) for Maximal cardiac output (Q_{max}) determination during the ramp incremental exercise to volitional fatigue. That is, when the participant indicated that they felt they could only sustain exercise for one more minute, the Q_{max} measures were initiated. Peak blood velocity across the mitral valve (E-wave) was measured by pulse wave Doppler echocardiography from an apical four-chamber view at the tips of open mitral valve leaflets using a 2.5-MHz transducer. Myocardial longitudinal velocities at the lateral aspect of the mitral valve annulus were recorded by pulse wave tissue Doppler image using the same transducer in the apical four-chamber view. This protocol was performed to not only confirm the attainment of VO_{2max} and for determination of Q_{max} , but also to be highly reliable (T. Rowland & Whatley Blum, 2000). Further, this method compares well to other techniques and provides values that reliable at maximum exercise (T. W. Rowland & Willers, 2010).

Subjects pedalled to exhaustion in the upright sitting position at a cadence of 60 revolutions per minute on a mechanically braked cycle ergometer (Monark model 818, Varberg, Sweden). During data acquisition, the transducer beam was aligned as closely as possible with the cardiac longitudinal axis. These measurements were performed by one operator adjusting and fixing the transducer position on the subject's chest while the other researcher operated the echocardiographic controls. Subjects were asked to limit body motion, what is avoid exaggerated swinging or leaning forward over the handlebars but were not otherwise constrained. All echocardiographic measures were obtained during spontaneous breathing.

Q_{max} was calculated as the product of stroke volume and HR, Q_{max} and stroke volume were both indexed to body surface area (BSA). Arterial venous oxygen difference ($a-vO_{2diff}$) was calculated from the Fick equation as: $a-vO_{2diff}$ (ml O_2 /100 ml blood) = VO_2 (l/min)/Q (l/min) \times 100.

Statistical analysis

All tabular data are presented as means \pm SD, and all data in Figure 1 are presented as mean \pm SE. Analysis of variance with Bonferroni *post hoc* testing was used to test for demographic difference between groups. Paired *t* tests were used to compare intragroup differences between baseline and after training. Analysis of variance with Bonferroni *post hoc* testing was used to test relative (percentage) change scores between groups. To determine whether there were significant differences between groups, data were analysed using one-way ANOVA by SPSS version 12.0 (SPSS, Chicago, IL). Statistical significance was denoted at the $p < .05$ level.

RESULTS

Subjects

Initially, 67 subjects were randomly assigned to one of four groups; data are presented from the 58 subjects who completed the training/testing (randomized/completed: control group, 16/15; low-volume/moderate intensity group, 16/14; low-volume/vigorous intensity group, 18/16; high-volume/vigorous intensity group, 17/13). Dropout was similar in all of exercise groups, the main reasons discontinued intervention were moved away, especially on a business trip, and change physical activity. There were no within-group differences observed between dropouts and men who finished the intervention.

Exercise training

Characteristics for subjects that completed the exercise training were presented in Table 1. There were no significant differences between the groups in age, height and Weight. The rate of adherence was significantly ($p < .05$) lower in the HVVI group compared with the LVVI group. As expected, all of the exercise groups achieve the prescribed volume (1155.8 ± 204.3 , 1196.2 ± 281.5 vs 2034.9 ± 445.4 kcal/wk, respectively), and HVVI group exercise for significantly greater volume (km/wk) and time (min/wk) than the low volume groups. The actual exercise time was approximately 2.5 h/wk for the low volume groups and 3 h/wk for the HVVI group. Weekly training volume averaged ~ 16 km/wk or ~ 134 min/wk in LVVI group; this volume was obtained with three or four exercise sessions per week of ~ 5 km or ~ 40 -min duration in contrast to the LVMI group, which consisted of ~ 4 km or ~ 40 -min duration. Caloric intake (calculated by IPAQ) measured before and after intervention, did not change significantly in any exercise group or in the control group (data not shown). The exercise frequency chosen to attain 3-4 time/wk dosage was not significantly among any exercise groups.

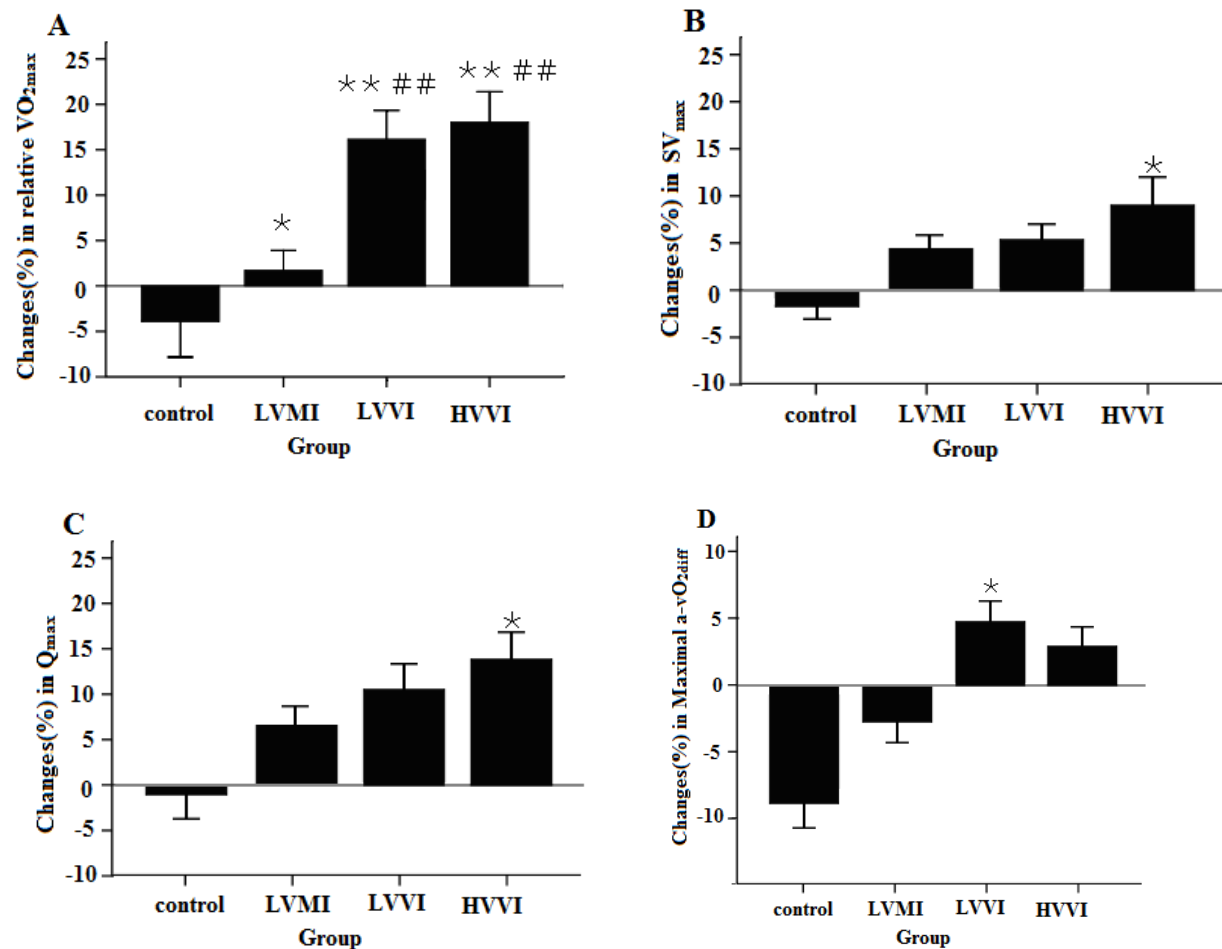
Table 1. Baseline characteristics of the subjects who completed post-training testing.

	Control	LVMI	LVVI	HVVI
Variable	(n = 15)	(n = 14)	(n = 16)	(n = 13)
Age, yr	44.3 \pm 3.4	43.8 \pm 4.0	45.4 \pm 2.1	45.3 \pm 4.8
Height, cm	171.2 \pm 5.4	171.2 \pm 5.7	169.6 \pm 4.0	173.5 \pm 3.1
Weight, kg	75.3 \pm 10.4	73.9 \pm 8.6	71.5 \pm 11.9	73.4 \pm 5.2
Exercise prescription				
Prescribed intensity, %VO _{2max}	/	40-50	65-80	65-80
Prescribed volume, kcal/wk	/	1200	1200	2000
Prescribed volume, km/wk [#]	/	19	19	32
Prescribed time, min/wk	/	173.5 \pm 55.3	140.5 \pm 40.4	208.8 \pm 57.4
Actual exercise dose				
Adherence %	/	88.2 \pm 8.6	93.7 \pm 11.3	84.6 \pm 12.8@
Actual volume, kcal/wk	/	1155.8 \pm 204.3	1196.2 \pm 281.5	2034.9 \pm 445.4
Actual volume, km/wk	/	14.8 \pm 4.4	16.3 \pm 4.9	20.5 \pm 4.0&
Actual time, min/wk [§]	/	148.9 \pm 57.3	133.5 \pm 47.8	182.5 \pm 70.3*
Frequency, sessions/wk	/	3.7 \pm 0.9	3.4 \pm 0.5	4.2 \pm 1.4

Note. Values are presented as mean \pm SD, # values are the approximate number of km per week that are calorie equivalent to the prescribed 14 kcal/kg/wk for the moderate intensity group and 23 kcal/kg/wk for the vigorous intensity groups. Adherence was calculated as a percent by dividing the time spent exercising by the time needed the defined exercise prescription. § Values are the prescribed time multiplied by the rate of adherence for each subject. @Significantly different ($p < .05$) from the low-volume/vigorous intensity group; & Significantly different ($p < .05$) from the low-volume/moderate intensity group; *Significantly different ($p < .05$) from low-volume groups.

Cardiorespiratory fitness

Table 2 depicts the within-group changes of absolute maximal oxygen uptake, relative maximal oxygen uptake, peak power output, maximal heart rate and exercise time to exhaustion between groups following exercise training. After 12 weeks, there were only differing slightly changes for absolute VO_{2max} in control and LVMI groups, but the changes in vigorous intensity groups were higher compared to the control group ($p < .05$), which increased by 0.2 ± 0.3 L/min in the LVVI group and 0.3 ± 0.2 L/min in the HVVI group, respectively (Table 3). When expressed relative to body weight, relative VO_{2max} increased to a greater extent in the vigorous intensity groups than in the control and moderate intensity groups ($p < .01$), which increased by 4.6 ± 3.0 mL/kg/min in the LVVI group and 5.4 ± 2.7 mL/kg/min in the HVVI group (both $p < .01$ vs. control and LVMI groups). More interestingly, peak power output and exercise time to exhaustion, as measured for a surrogate marker of aerobic fitness, were similar to relative VO_{2max} , increased significantly in both of vigorous intensity groups ($p < .01$). There was no difference change within-group for maximal heart rate following exercise training. The percent change in VO_{2max} from baseline was similar to both vigorous intensity groups (LVVI, $16.3 \pm 3.1\%$ vs. HVVI, $17.8 \pm 2.8\%$; $p < .01$) respectively (Figure 1A).



A: relative VO_{2max} (** $p < .01$, control vs LVVI and HVVI, ## $p < .01$, LVMI vs LVVI and HVVI). B: SV_{max} (* $p < .05$, control vs HVVI). C: Q_{max} (* $p < .05$, control vs HVVI). D: Maximal $a-vO_{2diff}$ (* $p < .05$, control vs LVVI).

Figure 1. Percentage changes between groups from before exercise to after training (mean \pm SE).

Table 2. Effects of the volume and intensity of exercise on cardiorespiratory fitness.

Variable	Control (n = 15)		LVMI (n = 16)	
	Baseline	12 wk	Baseline	12 wk
VO _{2max} (L/min)	2.2 ± 0.4	2.0 ± 0.3	2.4 ± 0.5	2.4 ± 0.4
VO _{2max} (mL/kg/min)	28.5 ± 3.7	27.0 ± 2.8	28.8 ± 3.5	29.0 ± 3.0
PO _{peak} (W)	168 ± 31	155 ± 23	155 ± 19	168 ± 23 [※]
HR _{max} (bpm)	157 ± 19	158 ± 16	157 ± 17	163 ± 13
TTE (s)	738 ± 144	697 ± 115	713 ± 101	765 ± 104

Variable	LVVI (n = 14)		HVVI (n = 13)	
	Baseline	12 wk	Baseline	12 wk
VO _{2max} (L/min)	2.1 ± 0.3	2.4 ± 0.4 [※]	2.1 ± 0.3	2.4 ± 0.4 [※]
VO _{2max} (mL/kg/min)	29.3 ± 3.4	34.0 ± 3.7 ^{※※}	29.3 ± 3.4	34.0 ± 3.7 ^{※※}
PO _{peak} (W)	157 ± 25	180 ± 15 ^{※※}	157 ± 25	180 ± 15 ^{※※}
HR _{max} (bpm)	165 ± 14	175 ± 10	165 ± 14	175 ± 10
TTE (s)	675 ± 109	793 ± 72 ^{※※}	675 ± 109	793 ± 72 ^{※※}

Note. Values are presented as mean ± SD, VO_{2max}, maximal oxygen uptake; HR_{max}, maximal heart rate; PO_{peak}, peak power output; TTE, exercise time to exhaustion; Within-group change is significantly different from baseline, ※ p < .05, ※※ p < .01.

Table 3. Change from baseline in cardiorespiratory fitness characteristics of each group.

Variable	Control (n = 15)	LVMI (n = 16)	LVVI (n = 14)	HVVI (n = 13)
VO _{2max} (l/min)	-0.1 ± 0.3	0.0 ± 0.3	0.2 ± 0.3	0.3 ± 0.2
VO _{2max} (ml/kg/min)	-1.5 ± 2.0	0.2 ± 2.0	4.6 ± 3.0 ^{###}	5.4 ± 2.7 ^{###}
PO _{peak} (W)	-12.5 ± 17.7	13.6 ± 17.2 ^{**}	22.7 ± 20.8 ^{**}	25.0 ± 15.8 ^{**}
HR _{max} (bpm)	1.2 ± 7.8	6.6 ± 10.3	8.1 ± 8.9 [*]	6.2 ± 10.1
TTE (s)	-41 ± 76	52 ± 83 [*]	117 ± 75 ^{* *}	119 ± 110 ^{**}

Note. Groups compared using one-way ANOVA, values are presented as mean ± SD, VO_{2max}, maximal oxygen uptake; HR_{max}, maximal heart rate; PO_{peak}, peak power output; TTE, exercise time to exhaustion; Change from baseline is significantly different from control group, * p < .05, ** p < .01; Change from baseline is significantly different from low-volume/moderate intensity group, #p < .05, ## p < .01.

Maximal cardiac output

Table 4 summarizes the values which maximal SV_{max}, Q_{max}, and maximal a-vO_{2diff} in response to training from pre to post-training. SV_{max} and Q_{max} increased from baseline to post-training in each exercise group, a higher SV_{max} and Q_{max} were observed in HVVI group after 12 weeks (p < .05) when compared with the baseline. However, the maximal a-vO_{2diff} from baseline to after 12 weeks was did not significantly affect by training in any exercise group. A similar SV_{max} change was observed in the same exercise volume groups (LVMI, 4.8 ± 8.5 mL/beat vs LVVI, 5 ± 8.1 mL/beat,); more interestingly, with further increases in SV_{max} (8.4 ± 9.6 mL/beat, p < .01) and Q_{max} (2.2 ± 1.1 L/min, p < .05) seen in the high-volume exercise group when compared with control group (Table 5).

As observed in Figure 1B, the percent changes in SV_{max} were 4.8 ± 1.7, 5.1 ± 1.9, and 9.0 ± 2.2% (p < .01) for the LVMI, LVVI, and HVVI groups, respectively; Which in Q_{max} in response to training improve constantly, values were 6.1 ± 2.3, 10.8 ± 3.3, and 14.6 ± 3.7% (p < .01) (Figure 1C). Although the maximal a-vO_{2diff}

increases in the vigorous intensity groups, only the LVVI group remained significantly increase ($4.8 \pm 1.3\%$, $p < .05$), HVVI group widened slightly ($3.0 \pm 1.0\%$, $p > .05$) (Figure 1D).

Table 4. Effects of the volume and intensity of exercise on cardiac output.

Variable	Control (n = 15)		LVVI (n = 16)	
	Baseline	12 wk	Baseline	12 wk
SV _{max} (ml/beat)	90 ± 20.3	88 ± 24.4	93.6 ± 11.5	97.4 ± 17.6
Q _{max} (l/min)	14.1 ± 1.1	13.9 ± 4.6	14.7 ± 1.5	15.6 ± 2.9
Maximal a-vO _{2diff} (ml O ₂ /100ml blood)	21.4 ± 1.3	19.5 ± 4.0	19.1 ± 2.4	18.6 ± 3.9
Variable	LVVI (n = 14)		HVVI (n = 13)	
	Baseline	12 wk	Baseline	12 wk
SV _{max} (ml/beat)	94.8 ± 17.4	98.8 ± 16.5	94.8 ± 17.4	98.8 ± 16.5
Q _{max} (l/min)	15.8 ± 2.7	17.5 ± 3.3*	15.8 ± 2.7	17.5 ± 3.3*
Maximal a-vO _{2diff} (ml O ₂ /100ml blood)	18.6 ± 5.0	19.5 ± 4.4	18.6 ± 5.0	19.5 ± 4.4

Note. Values are presented as mean ± SD. SV_{max}, maximal stroke volume; Q_{max}, maximal cardiac output; Maximal a-vO_{2diff}, maximal arterial-venous O₂ difference; Within-group change is significantly different from baseline, * $p < .05$.

Table 5. Change from baseline in cardiac output characteristics of each group.

Variable	Control (n = 15)	LVVI (n = 16)	LVVI (n = 14)	HVVI (n = 13)
SV _{max} (ml/beat)	-2 ± 10.6	4.8 ± 8.5	5 ± 8.1	8.4 ± 9.6**
Q _{max} (l/min)	-0.2 ± 2.9	1 ± 1.8	1.7 ± 2.5	2.2 ± 1.1*
Maximal a-vO _{2diff} (ml O ₂ /100ml blood)	-2 ± 1.9	-0.6 ± 1.3	1 ± 4.3*	0.6 ± 1.5

Note. Groups compared using one-way ANOVA, values are presented as mean ± SD. SV_{max}, maximal stroke volume; Q_{max}, maximal cardiac output; Maximal a-vO_{2diff}, maximal arterial-venous O₂ difference; Change from baseline is significantly different from control group, * $p < .05$, ** $p < .01$.

In order to describe the relative contribution of Q_{max} and maximal a-vO_{2diff} to the increase in VO_{2max}, the percentage was calculated as the percent change in Q_{max} (or maximal a-vO_{2diff}) divided by the total percent change in VO_{2max}. In LVVI group, ~66% of the change in VO_{2max} from pre-training to post-training was explained by the increase in Q_{max}, whereas the remaining ~34% was explained by an improved maximal a-vO_{2diff}. In HVVI group, ~82% of the improvement in VO_{2max} was attributed to a higher Q_{max}, and only ~18% was attributed to a widened maximal a-vO_{2diff}. Collectively, the contribution percentage reflected the remainder of the change in VO_{2max} mostly reliance on Q_{max} in contrast to maximal a-vO_{2diff} in different dose of exercise training.

DISCUSSION AND CONCLUSIONS

This study examined the central and peripheral mechanisms contributing to adaptations in cardiorespiratory fitness in response to a 12 weeks endurance training program in difference dose of exercise. The primary findings were as follows: (1) the percent change in VO_{2max} was similar to the both vigorous intensity groups, while 12 weeks of low-volume/ vigorous-intensity exercise, at a volume calorically equivalent to walking approximately 16 km over an average of 134 minutes per week, will be enough to improve VO_{2max} significantly. (2) A trend toward both a separate and combined effect of exercise volume and intensity on increasing VO_{2max} does exist, while the intensity of exercise appears to be more effective in increasing VO_{2max} than volume; this conclusion is drawn from our data showing that increasing the volume from 1200 to 2000

kcal/week (with the same intensity of 65-80% VO_{2max}) did not significantly improve VO_{2max} ; however, increasing the intensity from 40-55% to 65-80 % VO_{2max} (with the same exercise volume of 1200 kcal/week) did improve VO_{2max} significantly. (3) The central and peripheral mechanisms contributed to increase VO_{2max} were differences in vigorous intensity groups. The majority of the improvement of VO_{2max} was attributed to significantly higher Q_{max} (~82% of the improvement) with a widened a- vO_{2diff} (~18%) in high-volume/vigorous-intensity group; whereas in low-volume/vigorous-intensity group, Q_{max} (~66%) together with maximal a- vO_{2diff} (~34%) contributed to the greater VO_{2max} .

The duration of the exercise prescriptions keeping only 12 weeks, which different from the 24 weeks designed by the Studies of Targeted Risk Reduction Interventions through Defined Exercise (STRRIDE), was consisted with the 12 wk endurance training program (Lee et al., 2014). In this study, 16.3% and 17.8% increasing in VO_{2max} in both of vigorous intensity groups, which agreement with those of Gossard D (Gossard et al., 1986), VO_{2max} increased by 8% in the low intensity group (42-60% VO_{2max}) and by 17% in the high intensity group (63-81% VO_{2max}) after 12 weeks. Moreover, the vigorous intensity groups had similar increases in VO_{2max} when compared to the 6-mo intervention (16.3% and 17.8% vs 16.7% and 17.8%) (Kraus William E. et al., 2002). Thus, it concluded that in the short term, higher intensity exercise training is more beneficial than moderate intensity exercise training, while in the long term high or moderate intensity exercise training is equally effective (Van Ryckeghem et al., 2022). Hansen et al. (Hansen et al., 2009) reported that there was a significant interaction effect (exercise training \times intensity) for the changes in VO_{2max} after 2 months of exercise training, which increased to a greater extent in the high intensity (75% VO_{2max}) group than in the group following the moderate intensity (55% VO_{2max}) ($16 \pm 2\%$ vs $9 \pm 2\%$, respectively; $p < .05$); More interestingly, there were no interactions about the percent change of VO_{2max} observed within from 2- to 6-mo ($16 \pm 4\%$). It is applying that 12 weeks exercise project enough to improve VO_{2max} , continuous exercise training does not further augment VO_{2max} . It is noteworthy that the values of VO_{2max} during the 12 wk exercise would be no further improvement whereas an additional 12 wk of progressive exercises training. This study contributes to a growing body of evidence concerning the beneficial effects of short-term (12wk) improvements in VO_{2max} .

The beneficial effects of regular exercise on cardiorespiratory fitness are well documented (Sagelv et al., 2019; Tari et al., 2019). However, the previous studies did not include detailed information on the preferred exercise modalities that should be implemented to maximize the VO_{2max} . In the present study, common components of exercise prescriptions which improve in VO_{2max} were volume and intensity. In our date, the LVVI group (expended 1200 kcal/wk at 40-55% of VO_{2max}) and HVVI group (expended 2000 kcal/wk at 65-80% of VO_{2max}) had similar increases in VO_{2max} (16.3% and 17.8%, both $p < .001$ vs controls), without further changes in VO_{2max} despite the progressive increase in training volume, which indicated that increasing the volume from 1200 kcal/week to 2000 kcal/week, at a controlled intensity of 65 to 80% VO_{2max} , is not a strong stimulus to significantly improve VO_{2max} . However, the additional intensity of exercise (40-55% vs 65-80% VO_{2max}) prescribed in the LVMI and LVVI groups with the same volume of exercise did result in a significant increase in VO_{2max} . It suggests that the intensity of exercise is more important than the volume of exercise in terms of increasing the level of VO_{2max} . Talsnes (Talsnes et al., 2022) argues that even though both low and high intensity improve maximal oxygen uptake capacity of exercise, high intensity training is more sufficient to elicit better maximal oxygen uptake adaptations, which is consistent with our view. Although it is often suggested that the genetic component of physical fitness undermines its prognostic power, genetic differences explain only 25-47% of the individual variation in VO_{2max} (Bouchard et al., 1999). However, there were high and low responders, vigorous exercise (75% of VO_{2max}) has been shown to increase cardiorespiratory fitness by 20% in sedentary individuals, regardless of age, gender, race, and initial fitness level (Skinner et al., 2001). Storen (Støren et al., 2017) reported an increase in VO_{2max} of approximately 9%-

13% in adults between the ages of 20 and 80 years after completion of post-8 HIIT, which was a significant inverse relationship between baseline fitness (expressed as a percentage of mean maximal aerobic capacity at pre-training age) and the percentage increase in “maximal aerobic capacity” ($r = -0.66$). In conclusion, these findings taken together suggest that exercise intensity may be a critical factor to consider when designing exercise prescriptions to optimize the persistence of the training-induced improvement in VO_{2max} .

The concept that cardiorespiratory fitness, a physiological characteristic that quantifies the ability of the body to transport and use oxygen at the working muscle and is dependent primarily on maximal cardiac output, maximal arterial-venous oxygen difference, and efficient shunting of blood to working skeletal muscle. In the resting state, the body's O_2 uptake (VO_{2max}) is $3.5\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, with only a small fraction consumed by skeletal muscle. However, during incremental exercise, lung VO_2 increases progressively and, depending on gender, age, body weight, genetics, training status, and fitness, reaches approximately $90\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ maximum (VO_{2max}) (Joyner & Casey, 2015; Bouchard et al., 2011). An early study by Murias JM et al. assessed the interplay of central vs. peripheral mechanisms explaining the adaptations involving improvements in VO_{2max} in older (68 ± 7 yr) and young (23 ± 5 yr) with the training protocol performed on a cycle ergometer three times per week for 45 min ($135\text{min}/\text{wk}$) at $\sim 70\%$ VO_{2max} . This study demonstrated that in older, 69% of the increase in VO_{2max} was explained by an increased Q_{max} with the remaining 31% explained by a widened $a-vO_{2diff}$, while 56% attributed to a greater Q_{max} and 44% to a widened $a-vO_{2diff}$ in young Ekblom et al (Ekblom et al., 1968). found that 16 wk of physical training increased VO_{2max} from 3.15 to 3.68 L/min. this improvement in VO_{2max} resulted from an 8.0% increase in cardiac output (from 22.4 to 24.2 L/min) and a 3.6% increase in $a-vO_{2diff}$ (from 138 to 143 mL/L). These findings are in keeping with the present study, given that $\sim 66\%$ of the increase in VO_{2max} was attributed to larger Q_{max} and $\sim 34\%$ to a widened maximal $a-vO_{2diff}$ in LVVI group for adult. However, in HVVI group, the majority of the increment in VO_{2max} was relied on larger Q_{max} ($\sim 82\%$) whereas widened $a-vO_{2diff}$ ($\sim 18\%$). It is wonder why VO_{2max} increase similarly in those groups but with different changed in Q_{max} and maximal $a-vO_{2diff}$; moreover, with the additional increases in exercise volume, the proportion of Q_{max} contributed more important than maximal $a-vO_{2diff}$. Increase in VO_{2max} after short-term, high-intensity interval training may be due to central haemodynamic (Gibala & MacInnis, 2022). Mandić studied a 10-minute exercise programme in which participants were healthy men and women who would perform all-out cycle sprints of 30s three times a week. Q_{max} , measured after training using the inert gas rebreathing method (Bostad et al., 2021), was found to increase Q_{max} by 9 per cent, with similarities to a 10 per cent increase in VO_{2max} . The authors also reported training-induced increases in plasma volume (8%), blood volume (7%) and haemoglobin volume (6%) (Mandić et al., 2022). Considering that the overall HR_{max} response was changed not significantly from baseline to 12 weeks. Thus, the majority of the improvement in Q_{max} was a consequence of a larger SV_{max} which indicate that volume of exercise is an important marker for improving SV_{max} (Nottin et al., 2012). it is possible that when increase volume in the vigorous intensity, metabolic style would change from aerobic to anaerobic, the function of body's ability to deliver and extract oxygen to meet the metabolic demands of vigorous exercise is limited (Gordon et al., 2015), which induce the relative O_2 extraction at vigorous intensity exercise was smaller and diminish oxidative capacity. Taken together, the majority of the increase in VO_{2max} observed in this study was explained by central adaptations.

In conclusion, we demonstrated that the training-induced improvement in VO_{2max} is dependent on the nature of the original exercise intensity with VO_{2max} improvements similar to both vigorous intensity groups. However, the central and peripheral mechanisms contributed to increase VO_{2max} were differences in vigorous intensity groups. In low-volume/vigorous-intensity group, Q_{max} ($\sim 66\%$) together with maximal $a-vO_{2diff}$ ($\sim 34\%$ of the improvement) contributed to the greater VO_{2max} . However, in high-volume/vigorous-intensity group, the majority of the increment in VO_{2max} was relied on larger Q_{max} ($\sim 82\%$) whereas widened $a-vO_{2diff}$ ($\sim 18\%$). It

was a trend toward that higher volume exercise might confer additional benefit for Q_{max} , but the “ceiling effect” would be expected with further research such as long-term endurance training.

AUTHOR CONTRIBUTIONS

LJ and HQ designed the study, wrote the initial draft, and made revisions, managed data, conducted surveys, formulated methods, created visualizations, supervised, and managed the project. ZX participated in software, data curation, formal analysis, visualization, and manuscript revision. ZA and LP conducted formal analysis, supervision, validation and revision. All authors have contributed to the manuscript, approved the final version for submission, and consent to its publication in JHSE.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

ETHICS STATEMENT

The studies involving humans were approved by Ethics Committee of Jimei University. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material and further inquiries can be directed to the corresponding author.

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Unfolding the aggression and locus of control paradigm in sportspersons and non-sportspersons

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ABSTRACT

The present study investigated Aggression and Locus of Control on Combat Sports Persons, Non-Combat Sports Persons, and Non-Sports Persons. In this study, a sample of 240 individuals (80 Combat sports, 80 Non-Combat Sports & 80 Non-Sportspersons) was used through purposive sampling. The tools administered were the Buss and Perry Aggression Questionnaire by Arnold H. Buss and Mark Perry and Rotter's Locus of Control Scale by Julian Rotter respectively. The objective of the study was to investigate Aggression and Locus of Control in males and females from Combat, Non-Combat, and Non-Sports persons. This research also aims to explore the relationship between Aggression and Locus of Control. Mean, t-test, F-value (ANOVA), and correlation have been computed over SPSS-16. Results suggest that males from Combat have higher Aggression than people from non-sports and non-combat sports. There is also a significant difference between non-sports persons and sports people over the Locus of Control, sports persons showed internal locus of control compared to non-sports persons who were higher on external locus of control. The result also indicates a significant relationship between the anger dimension of the Aggression and Locus of Control.

Keywords: Sports psychology, Physical education, Anger, Combat sports, Non-combat sports.

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INTRODUCTION

As sports blend enjoyment with competitiveness, they are seen as essential components of life. Sports have long played a significant role in culture and society. It is significant for maintaining physical fitness, and there is now mounting evidence that it is beneficial for mental health. Any number of sports involve some level of aggressiveness, which can take many different forms, from physical to verbal. Experts and researchers have long disagreed on the significance of violence in sports. Some contend that an athlete's performance can be improved by positively directing their aggression. It may be possible for an athlete to harness their aggressive instincts to push himself to the edge and achieve greater success. Some contend that aggressive behaviour in sports might have adverse effects both on and off the pitch. Excessive hostility on the pitch can result in injuries, violence, and unsportsmanlike behaviour. The term "*aggression*" is used in sports in numerous different ways. Gill, Williams, and Reifsteck (2017) claim that the word seems to trigger automatic associations as well as positive or negative emotional reactions and value judgments. Many sports psychologists (e.g., Widmeyer, Dorsch, Bray, & McGuire, 2002) define assertive behaviours as playing within the rules with high intensity and emotion but without intent to cause harm. This includes what many refer to as instances of good aggression in sports, such as driving hard to the basket in basketball. Husman & Silva (1984) further distinguish between assertiveness and aggression. To be assertive, one must act in a way that may appear antagonistic to an opponent but does not truly injure them. Strong physical play is often characterized by coaches as aggressive, but in reality, it is assertive; it is played under the rules and is done with no malicious intent. The purpose to cause harm distinguishes aggression from assertion. When an athlete uses legal tactics to accomplish their aims without intending to hurt them, their behaviour is assertive rather than aggressive. The goal of assertiveness is not to hurt the other person; rather, it is to establish power. Athletes who are pushed to be extremely aggressive off the pitch can be more prone to use violence in their personal lives. Various studies have demonstrated that males who play organized sports behave more aggressively than men who do not, in both athletic and non-athletic circumstances. These actions consist of physical hostility, sexual assault, and bullying (Forbes, Adams-Curtis, Pakalka, & White, 2006). One possible explanation for their heightened hostility and inclination towards violence could be the masculine social norms associated with sports teams (Coulomb-Cabagno & Rasclé, 2006; Koss, 1993; Sonderlund et al., 2014; Steinfeldt et al., 2012).

The degree to which people think they influence the things that happen in their lives is known as their locus of control. In his theory of social learning, Julian Rotter was the first to suggest the idea of locus of control, or LOC. According to Rutkowska and Gierczuk (2014), human action is influenced by both the objective accounts of occurrences and the subjective interpretations placed on them. The personality dimension that is on the spectrum between internal and external control over behaviour is known as LOC, as defined by Rotter. LOC is a person's perception of their degree of control over the results of their behaviour (Holden, Forester, Williford, and Reilly, 2019). The features of an individual's personality dictate the source of control, which can be either internal or external (Theberge, 2008). The fundamental component of understanding how people live in the world is their conviction that they have control over the events that affect them (Shapiro, Schwartz, & Austin, 1996).

To find out if playing sports has any effect on this psychological aspect, the locus of control was examined. Individual's LOC can be conceptualized as either internal or external (Onu, Osogwa, Obetta, 2013). Athletes who have an internal locus of control think that their efforts and actions are what make them successful or unsuccessful in sports. Athletes can have a greater sense of internal locus of control by their coaches and sports psychologists highlighting the value of practice, effort, and accepting accountability for their performance. Additionally, they can teach athletes to pay more attention to the things they can control, such

as their preparation and technique, than to outside influences. All things considered, athletes may benefit from cultivating a stronger internal locus of control since it can increase their drive, resiliency, and optimistic outlook. There was no discernible difference in LOC between athletes who participated in combat and non-combat sports, according to Kishore's 2016 research. The locus of control is also influenced by the kind of sport and the type of event (team or single). A higher external locus of control was demonstrated by athletes who competed in team events (Cartel, Kozak, 2017, Yesilyaprak, 2004). The present study explored the overall aggression & Locus of control of sportspersons and non-sportspersons. It further divided the sports group into two, combat and non-combat sports to study whether the level of physical contact and nature of the game have any impact of the variables chosen. Both of the groups are further compared with non-sports persons to find whether participation in sports has any impact on aggression and locus of control. This study also examined the gender difference between the two variables and the relationship between Aggression and its dimension with Locus of control.

Rationale

The present study can deepen our awareness of the intricate interactions between aggressiveness and locus of control by examining these concepts through the lenses of gender and sport. This will ultimately improve our understanding of human behaviour in sports and other contexts. Many sports contain some degree of aggression, which can manifest in a variety of ways, comprising verbal as well as physical. Regarding the relevance of aggression in sports, experts and researchers have long debated. Some contend that properly channelling animosity toward an opponent might enhance an athlete's performance. Athletes who learn to control their aggression may be able to push themselves to the limit and perform at a higher level. Some claim that aggressive attitudes in sports could have negative consequences off the pitch as much as on it. The degree to which people think they influence the things that happen in their lives is known as their locus of control. When it comes to sports, an athlete's locus of control can greatly impact their thinking and strategy. To find out if playing sports has any effect on this psychological aspect, locus of control was explored. Athletes who have an internal locus of control think that their acts and efforts decide whether they succeed or fail in sports. They are more inclined to accept accountability for their actions and think that practice and dedication will help them become better. Athletes can have a greater sense of internal locus of control by their coaches and sports psychologists highlighting the value of practice, effort, and accepting accountability for their performance. They can also teach athletes to train their attention to be directed towards the things they can control, including their own preparation and technique, as opposed to outside influences. All things considered, athletes may benefit from cultivating a stronger internal locus of control since it can increase their drive, resiliency, and optimistic outlook. In the present study, the sports persons were divided into two groups comprising, combat and non-combat sports to study whether the level of physical contact and nature of the game have any impact on the variables chosen. Both groups are further compared with non-sports persons to find whether participation in sports has any impact on aggression and locus of control. Understanding aggression and locus of control in sports contexts can inform coaching strategies, sports psychology interventions, and policies to promote positive behaviour and reduce aggression in sports.

The present research was exploratory thus it was determined to drop the research hypotheses in this study. Since there aren't many publications on combat sports, it was anticipated that the analyses will greatly expand the body of knowledge already available on the topic (Harwood et al., 2017; Basiaga-Pasternak et al., 2020). It should be noted that, particularly in the past, the topic of aggressiveness and its connection to locus of control has hardly ever been brought up. Without a doubt, all the elements served as motivation to undertake the present study.

Research questions

The research study has its basis on a few research questions which served as steppingstones for the basic idea of this exploratory study:

- Is there a significant difference in aggression levels and locus of control between males and females?
- Does the type of sports (combat sports, non-combat sports, and non-sportsperson) have any significant difference in aggression and locus of control?
- Do sportspersons in general exhibit higher levels of aggression compared to sportspersons?
- Do sportspersons and non-sportspersons exhibit significant differences in locus of control?
- Is there a link between aggression (its 4 dimensions) and locus of control?

Objectives

- To investigate overall aggression and Locus of control among combat, non-combat, & non-sports persons.
- To examine Aggression and Locus of control between male and female persons.
- To study Overall Aggression and Locus of Control between male combat & female combat sports; male & female non-combat sportspersons and male & female non-sportspersons.
- To investigate the Overall Aggression and Locus of Control between male combat, Male non-combat, and male non-sports persons.
- To investigate the Overall Aggression and Locus of Control between female combat, female non-combat, and female non-sports persons.
- To investigate the relationship between Aggression and its dimensions and locus of control.

Sample

The sample size consisted of 240 individuals out of which 160 belonged to the sports category further divided into 80 Combat, 80 Non-Combat, and 80 Non-Sports people were chosen. All the 3 categories have the same proportion of males and females i.e. 40 belonging to the age group of 16-30 years old.

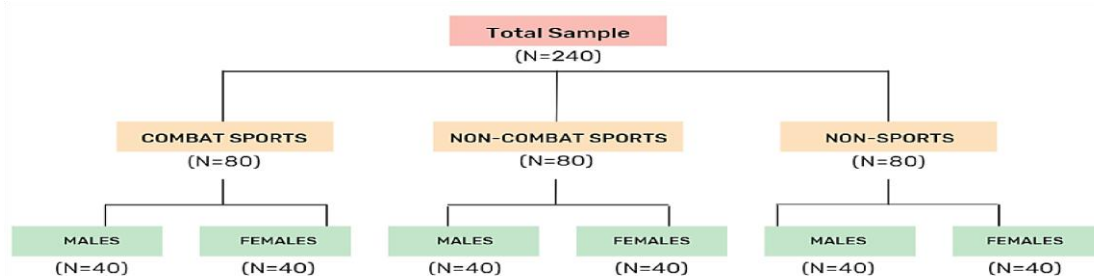


Figure 1. Description of the sample.

Tools

The Buss-Perry Aggression Questionnaire (BPAQ)

Developed by Arnold Buss & Robert Perry, 1992 is composed of 29 items, each rated on a 5-point Likert-type scale. The BPAQ has a score range of 29 to 145. Higher scores suggest more aggressive behaviour. The BPAQ is divided into four subscales: hostility, anger, verbal aggression, and physical aggressiveness.

The Rotter's locus of control scale

Created by Julian Rotter in 1966 measures a person's locus of control, Rotter's locus of control scale (Hindi Version) was developed by Dr. Anand Kumar and Dr. S.N. Srivastava. This forced-choice test consists of 29

pairs of statements, 23 of which are scored. The scale's possible scores fall between 0 and 23. The split-half reliability of the scale is between 0.65 and 0.79. Estimates for reliability via the split-half method correlated by the Spearman-Brown formula are equal to 0.73 and test-retest samples six weeks apart are equal to 0.67. The test reported good discriminant validity. Internal consistency: The scale has high internal consistency, with Cronbach's alpha coefficients ranging from 0.60 to 0.80 in various studies. The association between an individual's locus of control and numerous outcomes, such as academic success, work happiness, and mental health, has been extensively researched using Rotter's locus of control measure.

Procedure

For the study, demographic information(comprising age, gender , sports, training experience, rank level, etc.), the Buss and Perry Aggression Questionnaire, and Locus of Control were administered to combat, non-combat, and non-sportspersons. The form had two sections, which measured the demographics and consent, and the scores for Overall Aggression and Locus of Control. After obtaining permission and support from the coach, or organization representatives, researchers approached athletes. Informed consent was obtained, and participation was voluntary. The form also comprised information for the sportspersons were further divided into combat & non-combat sportspersons. Combat sports, which were considered are Boxing, Wrestling, MMA, Jitsu, Taekwondo, and karate. Non-combat sports comprised Basketball, Cricket, Volleyball, Table Tennis, and badminton. Owing to the above-mentioned inclusion criteria and conditions, and lack of complete documentation, results obtained from 240 respondents underwent final analysis. Data were organized, gathered, and categorically separated after data gathering was complete. The analysis was carried out on SPSS -16.

RESULTS

The present study investigates overall Aggression and locus of control of 240 individuals belonging to combat, non-combat, and non-sports persons. Once the data was collected, analysis was carried out through descriptive (Mean & SD) as well as inferential statistics, F (ANOVA) to find out if there was any significant difference among the three groups, post hoc (Tuckey) test was analysed to further find out which groups were showing a significant difference in Overall Aggression and Locus of control. Student t-test was carried out to see the gender differences among the groups on Overall Aggression & Locus of Control. Table 1 depicts the demographic details of the participants.

Table 1. Demographic details of the sample.

Variable		Frequency (N)	Percentage
Age	16-20	92	38.3 %
	21-25	82	34.16 %
	26-30	66	27.5 %
Total		240	
Combat Sports	Boxing	10	12.5 %
	MMA	40	50 %
	Wrestling	4	5 %
	Taekwondo	8	10 %
	Jitsu	4	5 %
	Karate	14	17.5 %
Total		80	
Non - Combat Sports	Basketball	6	7.5 %
	Cricket	9	11.25 %
	Volleyball	7	8.75 %
	Table tennis	11	13.75 %

	Badminton	16	20 %
	Football	13	16.25 %
	Calisthenics	12	15 %
	Archery	6	7.5 %
Total		80	
Level in sports (Combat sports)	District /High school/Univ	26	32.5 %
	State	23	28.75 %
	National	23	28.75 %
	International	8	10 %
Total		80	
Level in sports (Non - Combat sports)	District /High school/Univ	41	51.25 %
	State	14	17.50 %
	National	21	26.25 %
	International	4	5 %
Total		80	

Table 2. Mean, SD, & F-Value on overall aggression & locus of control among combat, non-combat, & non-sports persons.

Dimensions	Combat sports N = 80		Non-combat sports N = 80		Non-sports N = 80		F-value (N = 240) df = 237, 2	Post hoc (Tuckey)
	Mean	SD	Mean	SD	Mean	SD		
Overall aggression	82	14.93	79.04	15.33	79.75	13.49	0.896	
Locus of control	11.40	3.40	11.24	2.94	12.79	2.58	6.493**	C > B C > A

Note. * $p < .05$, ** $p < .01$. A- Combat sports, B - Non-Combat sports, C- Non-Sports persons.

Overall aggression has no significant difference on combat, non-combat and non-sport persons. Whereas locus of control shows significant difference at .001 level among non-combat and non-sport persons.

Table 3. Mean, SD, and t-value of males & females on overall aggression and locus of control.

Dimensions	Males (N = 120)		Females (N = 120)		t-value
	Mean	SD	Mean	SD	
Overall aggression	83	12.2	77.6	16.2	2.8*
Locus of control	11.62	3.11	12	3	0.92

Note. * $p < .05$, ** $p < .01$.

Table 4. Mean, SD, & t-value on overall aggression & locus of control b/w males & females in combat sports.

Dimensions	Males (combat sports) N = 40		Females (combat sports) N = 40		t-value
	Mean	SD	Mean	SD	
Overall aggression	88.05	13.7	75.95	13.76	3.94***
Locus of control	11.30	3.5	11.50	3.3	0.26

Note. * $p < .05$, ** $p < .01$.

From the Table 3, it can be inferred that overall aggression is significantly higher in males than in females. Whereas locus of control is non-significant at .01 and .05 level when compared between male and female.

Results in Table 4 indicate a significant difference in overall aggression in males than in females of combat sports. Whereas locus of control is non-significant at .01 and .05 level between genders, male and female of combat sports. It is also inferred that both males and females acquire an internal locus of control as the scores lie in the range of less than or equal to 12.

Table 5a. Mean, SD, and t-value on overall aggression and locus of control among males and females in non-combat sports.

Dimensions	Males (non-combat) N = 40		Females (non-combat) N = 40		t-value
	Mean	SD	Mean	SD	
Overall aggression	78	11.8	80	18.3	0.60
Locus of control	10.85	3.1	11.62	2.65	1.17

Note. * $p < .05$, ** $p < .01$.

Results indicate that male & female of noncombat sportspersons' is non-significant on overall aggression and locus of control.

Table 5b. Mean, SD & t-value of male & female non-sports person on overall aggression & locus of control.

Dimensions	Males N = 40		Females N = 40		t-value
	Mean	SD	Mean	SD	
Overall aggression	82.75	9	76.75	16.4	2.02
Locus of control	11.72	2.25	11.85	3	0.21

Note. * $p < .05$, ** $p < .01$.

Results indicate a significant difference at .01 level between males & females on overall aggression & locus of control.

Table 6. Mean, SD, and F-Value of aggression & locus of control among males from combat, non-combat, and non-sports persons.

Dimensions	Combat sports Male (N = 40)		Non-combat male sports (N = 40)		Non-sports male (N = 40)		F-value	Post hoc (Tuckey)
	Mean	SD	Mean	SD	Mean	SD		
Overall aggression	88.05	13.689	78	11.797	82.75	8.96	7.45**	A > B
Locus of control	11.30	3.51	10.85	3.19	12.72	2.25	4.15	

Note. * $p < .05$, ** $p < .01$. A- Combat sports, B - Non-Combat sports, C- Non-Sports persons.

Results indicate a significant difference at a .01 level in Overall Aggression among males of combat, non-combat, & non-sports persons. Post hoc test indicates on overall aggression significant difference is observed between the two groups at .01 level.

Table 7. Mean, SD, and F-Value on overall aggression and locus among females from combat, non-combat, and non-sports persons.

Dimensions	Combat sports (female) N = 40		Non-combat sports (female) N = 40		Non-sports (female) N = 40		F-value
	Mean	SD	Mean	SD	Mean	SD	
Overall aggression	75.95	13.769	80.08	18.300	76.75	16.439	0.723
Locus of control	11.50	3.28	11.62	2.65	12.85	2.90	2.53

Note. * $p < .05$, ** $p < .01$.

From the Table 7, it can be inferred on overall aggression & Locus of control non-significant difference was observed in females of combat, non-combat, and non-sports persons.

Table 8. Relationship between aggression and locus of control.

	Locus of control	Physical aggression	Verbal aggression	Anger	Hostility	Total aggression
Locus of control	1	.093	.021	.191**	.083	.119

Note. * $p < .05$, ** $p < .01$.

It is evident from the Table 8 that there exists a positive relationship between the dimension of Aggression i.e., anger at .01 level. This means that higher the scores in locus of control scale indicating higher the external locus of control higher will be the anger and vice-versa. The other scores show that there is no relationship found between locus of control and the other dimension of Aggression i.e., physical aggression, verbal aggression, and hostility.

DISCUSSION

Both culturally and economically, sports continue to play a significant part today. Sports are a creative transformation of human nature as it exists inherently. The present study aims to investigate aggression among combat, non-combat, and non-sports persons. Sports may be the only activity where aggressiveness is not only permitted but encouraged and viewed as proper behaviour in the world we live in today. Combat sports are seen as being more violent and aggressive by society than their counterparts.

The first objective states to study Overall Aggression and Locus of Control among combat, non-combat, and non-sports persons. Table 2 results suggested there is no significant difference in overall aggression levels among the three categories of combat, non-combat, and non-sports. In a research Deva. A et al. (2022), found no statistically significant difference in aggression between national-level combat sports competitors and non-combat competitors. Results indicate however when compared to non-sportspeople, participants in combat sports exhibit marginally higher overall aggression. The finding is consistent with the findings of Trivedi, R., & Pinto, E. (2015) which show sportspersons had higher aggression than non-contact sportspersons, thus the higher level of aggression was attributed to the higher aggression required in contact sports as its nature. It is also indicated by the results that non-sports persons have higher hostile aggression than combat sports persons. Given that aggression is a complex concept that can be influenced by a wide range of factors, including individual differences and situational factors, there may be no discernible difference in aggression levels between combat, non-combat, and non-sportspeople. There is no significant difference in aggression levels between combat and non-combat sports due to similar levels of physical exertion and competitive performance. These findings are consistent with the findings of Barczak et al. (2020), which indicate similar results that there is no significant difference in aggression based on the type of sports, combat, or non-combat.

Furthermore, non-sports persons have shown significantly higher scores on locus of control indicating having an external locus of control when compared to Combat sports persons and non-combat sportspersons. Kushalappa, A. (2019) researched the locus of control comparatively among athletes and non-athletes. The conclusion indicated that significant differences exist between athletes and nonathletes in terms of locus of control. There are several potential reasons for individuals who are not involved in sports having higher external locus of control like Lack of experience with goal setting and achievement, leading to believe that outcomes are largely determined by external factors. In contrast, individuals who participate in sports often set goals for themselves and work towards them, which can lead to a greater sense of control over their outcomes. Individuals who do not participate in sports may not receive as much feedback on their performance. In contrast, sports provide a structured environment for receiving feedback and evaluating performance, which can help individuals develop a greater sense of personal agency. On the contrary individuals in sports have a higher internal locus of control due to their Experience with goal-setting and achievement, Regular feedback and performance evaluation, Emphasis on personal effort and achievement, Opportunity for personal growth and development, and Positive reinforcement.

The second objective states to investigate Aggression between male and female persons. Table 3 shows males having significantly higher aggression than females. Males possess significantly higher overall aggression than their female counterparts. In a study, Sarn .K. S & Bhambri. E ,(2018) explored gender differences in aggression and its relationship with sleep. The total participants were 80 (35 females and 45 males) who were administered the Buss and Perry Aggression Questionnaire and Pittsburgh Sleep Quality Index. Results indicated a significant difference in aggression and Males showed higher levels of aggression than females. Cultural and social norms may encourage or discourage aggression in different ways for men and women. Overall, it's likely that the higher levels of aggression in males are influenced by a complex interplay of genetic, hormonal, environmental, and cultural factors, and the precise causes may vary depending on the individual and the context in which the aggression occurs. Males typically have higher levels of testosterone than females, which may contribute to their greater tendency toward aggression. In many cultures, there are specific gender roles and expectations that dictate how men and women should behave, these expectations may contribute to differences in aggression between males and females. Whereas there is no significant difference between males and females when it comes to locus of control. Locus of control refers to an individual's belief about the extent to which they can control the events and outcomes in their life. There is no inherent reason why men and women should have different locus of control beliefs. Research has shown that both men and women can have an internal or external locus of control beliefs. A study conducted by Mohanty, A. (2021), on the gender comparison in Locus of Control reveals similar results.

The third objective investigates the Overall Aggression & Locus of Control between males and females in combat, non-combat & non-sportspersons. Table 4 indicates males possess significantly higher overall aggression than their female counterparts. The fact that men and women may have distinct reasons for participating in combat sports is one explanation for this. Females may be more prone to participate in combat sports for fitness or self-defence purposes, but males may be more likely to consider them as a method to display their authority or masculinity, this variation in motivation may result in variations in aggressiveness. Whereas both genders show no significant impact on the locus of control. The results are consistent with the earlier stated findings by Mohanty, A. (2021). Moreover, both genders participating in combat sports show an internal locus of control. Combat sports may attract individuals who already have a strong internal locus of control, as these sports require a great deal of discipline, perseverance, and mental toughness. Combat sports athletes must be able to take responsibility for their own training, conditioning, and performance, and they must be able to cope with setbacks and challenges along the way. In addition, combat sports athletes may develop an internal locus of control through their participation in these sports. By training and competing, they gain a greater sense of control over their physical and mental abilities, as well as their performance outcomes. This sense of control can lead to a greater sense of personal responsibility and confidence in one's abilities.

Table 5a shows on overall aggression no significant difference was observed in either of the genders involved in non-combat sports. One possible explanation for this is that non-combat sports may attract individuals who are more interested in cooperation, teamwork, and skill development rather than competition and aggression. The result suggests that gender differences in these factors are generally less pronounced in non-combat sports compared to combat sports. This helps us to devise similar intervention training programs as both genders display similar psychological concepts of aggression and locus of control. Likewise in combat sports, both the genders displayed playing noncombat sports shows internal locus of control.

Table 5b shows there is no significant difference between males and females in Overall aggression involved in non-sports. The findings are in line with those made earlier by Mohanty, A. (2021), concluding that there

is no appreciable difference between men and women in this area. Also, it can be inferred from the Table 5b that both the genders playing no sports have an external locus of control. Samaei, L. and Ramezani, Z. N.(2012) studied the relationship between locus of control between athletic and non-athletic girls, yields consistent results Suggesting involvement in sports can help develop and manage internal locus of control in individuals, one possible explanation for this relationship is that sports involvement provides individuals with a sense of control over their own physical and mental abilities, through training and practice. On the other hand, a lack of involvement in sports may be associated with an external locus of control, as individuals may not have as many opportunities to develop a sense of control over their physical and mental abilities. Without the feedback and structure provided by sports involvement, individuals may be more likely to attribute their outcomes to external factors such as luck or circumstance, rather than their own actions and decisions.

The fourth objective states to examine Aggression among males & females belonging to combat, non-combat, and non-sports. Table 6 shows significantly higher scores, indicating combat sportsmen have significantly higher aggression than non-combat sportsmen and non-sports males. Basumatary, S. J. (2019), and Trivedi, R., & Pinto, E. (2015) conducted research that revealed similar results. Combat sports are inherently aggressive, as they involve physical contact and competition to defeat an opponent. Whereas all three categories show no significant difference in the locus of control. Table 6 shows consistency with the previously stated fact that sportspersons have an internal locus of control whereas non-sports persons have an external locus of control. The result is supported by similar research findings of Samaei, L. and Ramezani, Z.N.(2012). Sports participation can aid in the development of an internal locus of control by giving participants the chance to define objectives, make choices, and accept accountability for their own actions.

The fifth objective furthermore states to examine Aggression and Locus of Control among females belonging to combat, non-combat, and non-sports. Table 7 shows that type of game, whether combat, non-combat, or non-sports has no significant difference in aggression and locus of control over females. Unlike men, women may not have received the same socialization to aggressive and competitive behaviour. Gender-based preconceptions and expectations may affect how women perceive and react to various circumstances. Females may be more prone to feel pressure to fit in with gender roles and expectations, which may have a special effect on their aggression and locus of control. The outcomes are in line with the research by Shambharkar, K., & Agashe, C. D. (2016).

The sixth objective states to examine the relationship between Aggression and Locus of Control. Table 8 shows there exists only a significant relationship between locus of control and anger. Other dimensions of aggression and locus of control does not have a significant relationship. Österman, K., Björkqvist, K., Lagerspetz, K. M. J., Charpentier, S., Caprara, G. V., & Pastorelli, C. (1999); Malipatil, R.P. and Patil, S.S. (2017), conducted research that yields similar results. Individuals with an external locus of control are more likely to experience anger and frustration because people with an external locus of control tend to blame outside factors for their problems and feel helpless to change their situation, as a result, they may become angry and resentful towards the perceived source of their problems. Another study by Annie Deming, over Relation of Locus of Control, Anger, and Impulsivity to Boys' Aggressive Behaviour indicated that anger and impulsivity were positively associated with aggression. This denotes higher the anger higher the score on the locus of control scale, i.e. external locus of control.

CONCLUSIONS

The present study investigated Overall Aggression and Locus of Control among combat sports persons, non-combat sports persons, and non-sports persons. The sample consisted of 240 participants in the age range

of 16-30 years old. Both descriptive and inferential statistics were examined in the analysis of the data from the participants. Findings indicate male Combat sports persons have significantly higher overall non-combat sports persons and non-sports persons. On the other hand, females show no such difference in aggression belonging to either of the three categories. There is also a significant difference between non-sports persons to sports persons over the locus of control. Non-sports persons, either male or female, acquire an external locus of control whereas sports persons (combat or non-combat, both males and females) have shown an Internal locus of control. Gender has no such relationship with the locus of control. Anger was also found to have significantly correlated with locus of control. Various reasons were discussed for these results along with support from past literature. The findings of the present study might assist in identifying suitable interventions or preventive measures. Overall, these suggestions may help strengthen the study and provide more comprehensive insights into the relationship between aggression and locus of control over sportspersons and non-sportspersons.

AUTHOR CONTRIBUTIONS

All authors contributed to all stages of the project including the writing of this manuscript. All authors have read and agreed to the published version of the manuscript. Ekta Bhambri Marwaha conceived, and designed the study, collected the data, analysed and interpreted the data, wrote the paper. Dr Ashima conceived, and designed the study, collected the data, interpreted the data, wrote the paper while data collection was done by Ms Khushi.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

ETHICAL APPROVAL

All the participants were informed about the study and required consent was taken from the participants. The participants in the study were volunteer, they could quit the study at any point they wanted. The primary and the only reason to collect the data is research that would in turn help students, academia and society as a whole in this section.

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The relationship of foot anthropometry with countermovement jump and squat jump performance among male university-level athletes

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ABSTRACT

This study assessed the relationship between foot anthropometry with countermovement jump (CMJ) and squat jump (SJ) performance among university-level male athletes. A total of 51 male athletes were selected from different sports. Various gross and acute anthropometric measurements were conducted. Each participant performed three CMJs and SJs each. Standing height has a moderate positive correlation with CMJ force ($\rho = .368, p = .008$) and power ($\rho = .326, p = .019$). Body mass demonstrated a high positive association with CMJ force ($\rho = .568, p = .001$) and a moderate positive correlation with power ($\rho = .446, p = .001$). The lower leg length was moderately positively correlated with CMJ flight time ($\rho = .316, p = .024$) ($\rho = .311, p = .026$), velocity ($\rho = .304, p = .030$), and power and showed a weak positive correlation with CMJ height ($\rho = .290, p = .039$). Foot length had a moderate positive correlation with CMJ force ($\rho = .419, p = .002$) and power ($\rho = .377, p = .002$). Conversely, a weak negative correlation was observed between foot arch height and both CMJ height ($\rho = -.286, p = .042$) and CMJ velocity ($\rho = -.285, p = .043$). These findings suggest the significant relationships between specific anthropometric characteristics with CMJ and SJ performance. However, the correlations showed moderate or lower strengths, underscoring the importance of further investigation.

Keywords: Performance analysis, Jump performance, Foot mechanics, Athletic performance, Muscular strength, Lower extremity.

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INTRODUCTION

Human feet are built uniquely to support the body's entire weight as permitted by foot anthropometry. The human foot is composed of around 100 muscles, ligaments, tendons, and 30 joints, in addition to 26 bones, which are the phalanges ($n = 14$), tarsal ($n = 7$), and metatarsal ($n = 5$). These anatomical components cooperate to stabilize the foot movement and balance in static and dynamic conditions, shock absorption, and transferring ground reaction forces (Hazari et al., 2021).

Vertical jump movements are crucial in many sporting events, such as basketball, football, badminton, and volleyball. Sometimes, jumping movements play a decisive role during a match. Whether it's a footballer jumping to score a header goal, a basketball player leaping to shoot a ball towards the basket, smashing the shuttlecock by a badminton player, or a volleyball player trying to spike the ball, this action can have an impact on the outcome of the match (Washif & Kok, 2022). Vertical jumps are widely used in athlete's training and testing (i.e., assessment). Vertical jump tests are commonly used to assess the lower limb power of athletes. Furthermore, jump training can also develop lower body strength and power and can contribute to enhanced neuromuscular control, landing mechanics, joint stability, and overall lower body strength (Markovic, 2007; Ramirez-Campillo et al., 2023; Thapa et al., 2024).

Two commonly used vertical jump assessments are the countermovement jump (CMJ) and squat jump (SJ) tests. CMJ is performed from the normal standing position with a quick downward movement and jumps vertically with the aim of achieving maximum height (Suchomel et al., 2016), where utilization of the stretch-shortening cycle (SSC) takes place. The SSC involves lengthening of the muscle (i.e., eccentric phase) followed by shortening of the muscle (i.e., concentric phase). In contrast, the squat jump starts from the squat position (i.e., ~3-5 seconds pause) and then jumps as high as possible. The pause during the squat position prevents the SSC from occurring and thus mainly focuses on the concentric phase of the muscle contraction (i.e., shortening of the muscles). Thus, such an assessment allows for measuring the concentric muscle power and force generation without elastic energy involvement (Petrigna et al., 2019).

The measurement of CMJ and SJ performance is plausible with a validated and reliable mobile-based video analysis software My Jump Lab (Şentürk et al., 2024). The application is an affordable alternative to expensive equipment (e.g., force platforms) (Bogataj et al., 2020). It uses the ability of the mobile to capture video in slow motion, which is then used for further analysis. For the evaluation of the flight time of CMJ and SJ the software uses the slow-motion video to estimate the participant's jump take-off and landing frames. An equation (Bosco et al., 1983) is then used to calculate the jump height using flight time from the recorded video. The equation used in the application is $h = t^2 \times 1.22625$, 'h' is the height in meters of the jump, and 't' denotes the flight time of the jump in seconds. It is a widely used method for calculating jump height from flight time (Balsalobre-Fernández et al., 2015). In addition, the application also uses a simple computational method using the body mass, push-off distance, and jump height to estimate force, velocity, and power during jumps, which has been validated and found reliable (Jiménez-Reyes et al., 2017).

Understanding the connection between foot structure and vertical jump has important implications. There is a gap in research on the effect of toe length, heel length, arch height, and the maximum range of motion on vertical jump performance. The relationship between the different parameters of foot anthropometry and vertical jumps, such as CMJ and SJ performance, needs to be established in the literature. The study hypothesizes that there is a significant correlation between the anthropometric measurement of the foot and an individual's vertical jump performance. A shorter foot length and heel length can produce a greater vertical

height, and a greater arch height, toe length, plantar flexion, and dorsiflexion will positively correlate with a higher vertical jump height.

MATERIAL AND METHODS

Participants

Fifty-one male athletes were recruited from Central University of Rajasthan. The age of the participants ranged between 18-26 years. The minimum requirement to be included in the study (i.e., inclusion criteria) was participation at the inter-university level competition in their respective games. Among the selected 51 participants, 14 participants played football, 9 participants played volleyball, 9 participants played cricket, 10 participants played basketball, 5 participants played badminton and 4 participants played. All the participants selected for the study had no history of musculoskeletal injury, history of lower limb surgery, or any other health condition during the data collection. All the participants provided their consent to participate in the study and signed informed forms after an explanation about the procedures and possible risks associated with the study.

Procedure

Familiarization session was conducted before the data collection to minimize the learning effect. During the familiarization session, the techniques of CMJ and SJ were explained and demonstrated. In addition, the explanation of the procedure for anthropometric measurements was also explained. Thereafter the experimental sessions included data collection for both the jumps and anthropometric measurement of the lower body and foot. All the assessments were conducted in an indoor hall of the university.

Anthropometric measurements

For the measurement of height, a stadiometer (Mediguard, JE Surgical Industries, India) was utilized. The standing height was measured with the participants standing erect without shoes in a stadiometer (Sørensen et al., 2020). In addition, a bioelectrical impedance machine (Charder Bioelectrical impedance, Taiwan) was used to measure the participant's body mass and BMI (Branco et al., 2023). A Gullick tape was used to measure the upper leg length, lower leg length, and calf muscle girth. Three measurements were taken for each, and the average was considered as the actual measurement for better accuracy (Rumbo-Rodríguez et al., 2021).

In the upper leg length measurement, the greater trochanter, the bony prominence on the lateral side of the upper thigh, nearer to the hip joint, was identified. The lateral knee joint line, which is the outermost point of the knee articulation where the tibia and femur bones meet, was located, and measurement was conducted (Schwab & Anighoro, 2022). Lower leg length was measured as the vertical distance from the head of the fibula to the most prominent part of the lateral malleolus. One end of the measuring tape was placed at the end of the lateral malleolus (Saeki et al., 2017). The Gulick tape was placed around the calf at the identified middle point in the largest circumference of the calf for the measurement (Kiss et al., 2024). The foot dorsiflexion and plantar flexion was measured using a goniometer (Patterson Medical Holdings Inc, China). The participant's leg was marked at the midpoint between the lateral and medial malleoli. This mark was the reference point during the measurement. Participants were instructed to perform the dorsiflexion of the foot (i.e., bringing the top of the foot of the subject towards the shin). A ruler was set up on the surface which was parallel to the participant's heel. The distance between the reference mark on the ruler is the point where the foot dorsum is elevated during the dorsiflexion, was measured and recorded. For the measurement of plantar flexion, participants were asked to perform plantar flexion of the foot (i.e., pointing the foot downwards as much as possible without feeling any discomfort). The gap between the reference mark on the foot and ruler

which is the point at where foot dorsum is at lower during the plantar flexion was measured and recorded (Pietrzak et al., 2022). All measurements were recorded in centimetres.

Foot anthropometric measurements

Three black marks were placed on the most visible part of the lateral malleolus, medial malleolus, and the first metatarsophalangeal joint. While sitting medial and lateral views of the right foot were digitally photographed using a high-resolution camera (Canon EOS 7D), where the foot was placed on a wooden block. On the side of the wooden block a millimetre-scale was placed for scaling. The tibia was aligned with respect to the reference box at a right angle. Each subject's right foot images were digitalized with a custom-designed MATLAB (The MathWorks, Inc., Natick, MA) code. The code measured the foot length, toe length, arch height, medial heel length, and lateral heel length by using the scaling provided by the millimetre scale in the images (Hawley, 2016).

Foot length is the horizontal distance between the most anterior part of the longest toe and the most posterior point of the calcaneus bone (Prasad & Rajasekhar, 2019). Toe length is the distance between the most distal portion of the big toe's proximal phalanx to the metatarsophalangeal joint big toe articulates with the corresponding metatarsal bone (Klein & Weil, 2020). Arch height is the vertical distance between the highest point of the longitudinal arch and the ground; navicular tuberosity is the midpoint of the arch. Lateral and medial heel length is the horizontal distance from the bottom of the heel and the most prominent part of the medial and lateral aspects of the malleolus, respectively. The average heel length was determined by summing the medial and lateral heel lengths, and the average heel length was used as the heel length (Hawley, 2016).

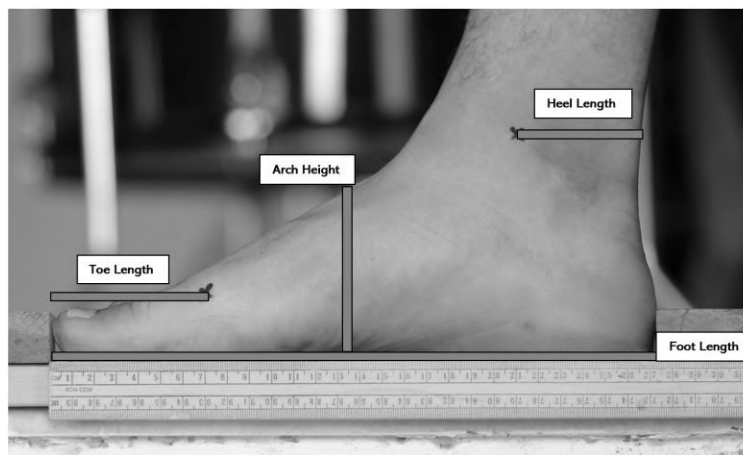


Figure 1. Medial foot anthropometric measures as determined by digital imaging.

Vertical jump measurements

The CMJ and SJ were recorded using an iPhone 12 mobile phone (Apple, India; HD 240 fps slow motion) and analysed with a validated and reliable mobile application (MyJump2). The video was recorded with the camera placed on a tripod at a height of ~40 cm from the ground surface and ~3 meters away from the participants. All videos were recorded from the sagittal plane and focused on capturing the take-off and landing phases of the jumps.

The participants performed a total of six jumps with no arm swing, 3 CMJs, and 3 SJs during the recording. The CMJs and SJs were performed in random order to reduce the risk of learning impact on performance.

Participants were instructed to jump as high as possible. Between the same type of jumps, subjects rested for 30 seconds. The subject rested for 3 minutes between differing jumps.

Statistical analysis

Data are presented as median and interquartile range (IQR). The normality of the data was assessed using the Shapiro-Wilk test. As data were non-normally distributed, Spearman's rank correlation coefficient test was used to verify the relationship between the anthropometric measurements and vertical jump performance. The magnitude of the correlation between test measures was interpreted as trivial (≤ 0.1), low (0.1–0.3), moderate (0.3–0.5), high (0.5–0.7), very high (0.7–0.9), and almost perfect (0.9–1.0) (Hopkins et al., 2009). All the statistical analyses were conducted using SPSS (version 26). For testing the hypothesis, the level of significance was set at $p \leq .05$.

RESULTS

Descriptive statistics, including the number of participants, median, and IQR of anthropometric variables, are presented in Table 1. Moreover, in Table 2, descriptive statistics, including the number of participants, median, and IQR of CMJ and SJ performance, are presented.

Table 1. Descriptive statistics of anthropometric variables.

n = 51	Median	IQR
Height (cm)	174.30	8.80
Body mass (kg)	64.70	14.80
Body mass index (kg/m ²)	21.50	3.40
Upper Leg Length (cm)	54.10	5.80
Lower leg Length (cm)	51.80	4.50
Calf Girth (cm)	35.20	3.70
Dorsiflexion(cm)	88.00	9.00
Plantar flexion(cm)	156.00	14.00
Foot Length(cm)	26.33	2.08
Toe Length(cm)	6.96	0.47
Heel Length(cm)	6.17	0.42
Arch Height(cm)	7.18	0.51

Table 2. Descriptive statistics of jump performance.

Countermovement jump performance (n = 51)		
	Median	IQR
Jump Height (cm)	33.67	8.30
Velocity(m/s)	1.28	0.15
Force (N)	1387.45	415.36
Flight Time(s)	518.0	66.00
Power(W)	1816.68	507.29
Squat jump performance (n = 51)		
	Median	IQR
Jump Height (cm)	32.52	7.49
Velocity(m/s)	1.26	0.15
Force (N)	1433.56	396.63
Flight Time(s)	512.00	61.0
Power(W)	1779.38	534.79

The Spearman correlation coefficients (ρ) and their corresponding p-values (p) between foot anthropometry and other anthropometric variables with performance metrics of CMJ are presented in Table 3. Height showed a significantly moderate positive association with CMJ force ($\rho = .368, p = .008$) and power ($\rho = .326, p = .019$). Body mass had a high positive correlation with CMJ force ($\rho = .568, p = .001$) and a moderate positive correlation with power ($\rho = .446, p = .001$). Body mass index had a moderate positive correlation with both CMJ force ($\rho = .423, p = .002$) and power ($\rho = .288, p = .041$). The upper leg length did not show any significant correlation with any of the CMJ performance metrics. Lower leg length had a moderate positive correlation with CMJ jump height ($\rho = .290, p = .039$), flight time ($\rho = .311, p = .026$), velocity ($\rho = .304, p = .030$), and power ($\rho = .316, p = .024$). Calf girth had a significant but weak correlation with CMJ force ($\rho = .304, p = .030$). No correlations were found with any of the parameters and either plantar flexion or dorsiflexion.

Table 3. Relationship between anthropometric measurements and countermovement jump performance.

Variables	Jump height		Flight time		Velocity		Force		Power	
	ρ	p-value	ρ	p-value	ρ	p-value	ρ	p-value	ρ	p-value
Height	.203	.153	.177	.214	.212	.136	.368*	.008	.326*	.019
Weight	-.076	.595	-.096	.502	-.060	.677	.568*	.001	.446*	.001
BMI	-.240	.089	-.259	.067	-.227	.110	.423*	.002	.288*	.041
ULL	-.086	.547	-.099	.489	-.050	.729	-.118	.408	-.197	.167
LLL	.290*	.039	.311*	.026	.304*	.030	.244	.084	.316*	.024
Calf Girth	-.135	.346	-.103	.471	-.116	.419	.304*	.030	.209	.141
Dorsiflexion	-.160	.261	-.126	.380	-.165	.246	.152	.287	.073	.610
Plantar flexion	.163	.252	.154	.281	.134	.350	.020	.888	.025	.860
Foot Length	.232	.101	.174	.223	.165	.247	.419*	.002	.377*	.006
Toe Length	-.001	.992	-.010	.945	-.052	.717	-.011	.937	-.009	.950
Heel Length	.160	.262	.143	.317	.119	.407	.118	.409	.135	.346
Arch Height	-.286*	.042	-.243	.085	-.285*	.043	.145	.311	.001	.993

Note. BMI- Body Mass Index, ULL- Upper Leg Length, LLL- Lower Leg Length. * Correlation is significant at the .05 level.

Table 4. Relationship between anthropometric measures and squat jump performance.

Variables	Jump height		Flight time		Velocity		Force		Power	
	ρ	p-value	ρ	p-value	ρ	p-value	ρ	p-value	ρ	p-value
Height	.188	.187	.177	.213	.201	.158	.209	.140	.252	.074
Weight	-.100	.484	-.195	.171	-.198	.164	.447*	.001	.304*	.030
BMI	-.226	.111	.257	.069	-.277*	.049	.399*	.004	.230	.104
ULL	.001	.995	.072	.613	.120	.401	-.106	.458	-.049	.732
LLL	.327*	.019	.249	.078	.263	.062	.011	.940	.132	.357
Calf Girth	-.127	.375	-.167	.242	-.191	.178	.202	.255	.096	.504
Dorsiflexion	-.150	.294	-.106	.457	-.124	.388	.172	.226	.079	.581
Plantar flexion	.184	.197	.091	.527	.062	.665	-.021	.883	.014	.920
Foot Length	.145	.311	.104	.468	.104	.469	.228	.108	.234	.098
Toe Length	.102	.477	.147	.303	.138	.334	.003	.986	.054	.706
Heel Length	.206	.147	.210	.139	.186	.192	.074	.607	.138	.333
Arch Height	-.164	.251	-.133	.353	-.153	.283	.104	.469	.000	.999

Note. BMI- Body Mass Index, ULL- Upper Leg Length, LLL- Lower Leg Length. * Correlation is significant at the .05 level.

There was a significant moderate positive association between foot length and CMJ power ($\rho = .377, p = .002$) and force ($\rho = .419, p = .002$). There was a notable weak negative correlation between arch height and CMJ height ($\rho = -.286, p = .042$), which indicates that subjects with higher arch height have the tendency for

lower heights. For arch height and velocity, a weak negative correlation was found ($\rho = -.285$, $p = .043$), which indicates that higher arch height has a tendency for lower jump velocity during CMJ.

The Spearman correlation coefficients (ρ) and their corresponding p-values (p) between foot anthropometry and other anthropometric variables with performance metrics of SJ are presented in Table 4.

Body mass showed a significant moderate positive correlation with both SJ force ($\rho = .447$, $p = .001$) and power ($\rho = .304$, $p = .030$). BMI showed a moderate positive correlation with SJ force ($\rho = .399$, $p = .004$); a weak negative correlation was also found between BMI and SJ velocity ($\rho = -.277$, $p = .049$). Upper leg length was not associated with any of the SJ parameters. Lower leg length positively correlated with SJ jump height ($\rho = .327$, $p = .019$). Calf girth, dorsiflexion, plantar flexion, foot length, toe length, heel length, and arch height did not significantly correlate with any SJ performance parameters.

DISCUSSION

The study aimed to examine the foot anthropometric and other anthropometric variables that are related to the foot with CMJ and SJ performance parameters such as jump height, jump flight time, jump velocity, jump force, and jump power measured through a video-based mobile application. The Spearman correlation analysis was used to identify the relationship between the anthropometric variables and vertical jump performance. Our findings showed height had a moderate positive correlation with CMJ jump force and power. In addition, body mass showed a high positive association with force and a moderate positive association with power during the CMJ. Moreover, body mass showed a positive moderate correlation with both force and power during SJ performance. Of note, the lower leg length had a moderate positive correlation with flight time, velocity, and power and a weak positive correlation with the jump height during the CMJ. In addition, a moderate positive correlation was observed between foot length and force and power during CMJ, and there was a weak positive correlation with lower leg length and SJ height. A weak negative correlation was also observed between foot arch height and jump height and velocity during CMJ.

The moderate correlation between standing height and force and power during CMJ may be attributed to the interconnection between these variables. For example, previous studies have stated that taller individuals may produce more power during jumps due to their longer limbs and quantity of muscle (Nishioka & Okada, 2022). However, although taller individuals may have the biomechanical advantages of longer limbs, this advantage will not always correspond to higher CMJ performance (Marshall & Moran, 2015; McErlain-Naylor et al., 2014). The key determinants of CMJ height are muscle strength, power, and technique instead of standing height alone (Thomas et al., 2022). This is also reflected in our current findings, as the standing height was not correlated with the jump height during the CMJ. Indeed, as previously stated the jump force and power were significantly correlated to the jump height in our current study. In addition, the maximum strength and rate of force development are two important factors that influence jump height (Van Hooren et al., 2022). Although, we did not include maximal strength measurements or the rate of force development, it is possible that these factors contributed to the jump height.

Another finding from our study was a high positive correlation between the body mass and CMJ force and a moderate positive correlation with SJ force and both SJ and CMJ power. This may be possible because the body mass affects the jump forces and power during CMJ and SJ performance. For example, individuals with heavier body mass should produce higher absolute force to overcome the gravitational pull to achieve a similar jump height when compared to an individual with a lighter body mass. The variations in power and force output can be reduced, and more accurate comparisons between individuals with different body mass

can be made when these forces are normalized to the body mass (i.e., using the relative values) (Thomas et al., 2022). The current study findings related to the force and power during vertical jumps with body mass reinforce these conclusions. Similar to those mentioned above, the BMI includes both the body mass and standing height of an individual for its calculation, and thus, the results (i.e., moderate positive correlation between body mass index with CMJ, SJ force, and power) may be influenced by both variables.

Furthermore, there was a weak positive correlation between lower leg length and CMJ height and a moderate positive correlation between lower leg length and SJ height. Lower leg length has been shown to impact jump height for both CMJ and SJ directly. The complicated interaction between muscle power, the angle of joints, and the length of the limbs are all components of the biomechanics of jumping (O'Brien et al., 2009; Sharma, 2017). It may be possible that jump performance can be enhanced by longer lower legs that provide a greater advantage and more effective force transfer during the jump phases (Anicic et al., 2023). This advantage might have improved the jump performance and helped to reach a high vertical jump performance (Anicic et al., 2023). In addition, the CMJ consists of a preparatory downward movement (i.e., the eccentric phase), which uses the stretch-shortening cycle action to increase the muscle power output (Turner & Jeffreys, 2010). Previous studies have reported that individuals who have longer lower leg lengths can produce a greater amount of ground reaction forces (Pereira et al., 2006), enabling the individual to jump higher and longer legs contribute to enhanced jumping performance by increasing higher power output (Risnawati & Jusrianto, 2020). This is because more production of force and torque during the push off phase is possible with longer lever arms (i.e., longer lower leg length) (Tomita et al., 2020). Longer lower legs can increase the moment arm, which allows for increased torque production and the greater torque can result in higher take off velocities (Chen et al., 2022). However, for the SJ, the starting position is from the squatting position, where the SSC is not applicable and thus assesses only the concentric muscle power (Markovic et al., 2004). Similar to the CMJ, the individuals with longer lower leg length may have a mechanical advantage during the push off phase as compared to those who have short lower limbs (Hornsby et al., 2017; Panoutsakopoulos & Bassa, 2023). This might be one of the possible reasons why both jump clearly showed a direct correlation between lower leg length and jump height (Hornsby et al., 2017). It is also possible that the aforementioned reasons are responsible for the positive correlation between the lower leg length and CMJ flight time.

Lastly, a positive moderate correlation was reported between the calf girth and force during CMJ. An increased muscle mass at the calf may increase the force production capability thus improving the jump height (Cengizel et al., 2021). In addition, various factors can affect the vertical jump performance, including the size of the body and the mechanics of the limb. These factors indicate that foot length might play a key role in the overall movement of the body during the jump performance. The interaction between different aspects such as strength of the muscle, joint angle, and movement techniques are the determinants of CMJ power (Nuzzo et al., 2008; Sheppard et al., 2008). Our study also reported a moderate positive correlation between foot length and CMJ force and power. Foot length might have impact on how force is interchanged during CMJ take-off and landing phases, affecting how well the individual is performing the jumps (Ho et al., 2019). In addition, our study also reported a weak negative correlation between foot arch height and CMJ height and CMJ velocity (i.e., as arch height decreases there is a tendency to achieve more jump height). Previous studies have found that the use of foot orthoses affects lower limb mechanics and vertical jump performance in basketball players with different foot arch types. Specifically, individuals with flat feet, which are characterized by a shorter arch height, exhibited a significant difference in counter movement jump (CMJ) performance compared to those with normal arch height. (Ho et al., 2019). In contrast, other studies have reported that a lower arch height is usually linked with flat feet, which can cause a reduction in the jump height and velocity of CMJ due to less effective force generation. This is because the arch height acts like a

spring during the vertical jump performance, providing more cushioning to the foot, reducing sudden impact, and helping to reach greater jump heights during CMJ (Carlock et al., 2004; Gathercole et al., 2015).

There are a few limitations in our study that should be acknowledged. Firstly, the study included only male university-level athletes. Hence, the findings generated from this study should not be extrapolated to female or higher-level athletes. Secondly, the CMJ and SJ assessments were conducted using video-based software. Although video-based software is valid and reliable, using a gold-standard force platform would be suggested for future research studies. Thirdly, the study lacked information about the subjects' training history and proficiency in functional movement techniques, which are crucial for optimal performance in the CMJ and SJ. Lastly, the samples included participants from various sports backgrounds, which may have affected the findings. The current research may be used as a proof-of-concept study for future research focusing on athletes from a particular sport.

CONCLUSION

In conclusion, our study revealed that significant correlation between the anthropometry of the foot and lower limb with the performance of CMJ and SJ. However, the magnitude of the correlation ranged from low to moderate. While the study offers guidance for coaches working with athletes, further research is needed to explore the correlations found.

AUTHOR CONTRIBUTIONS

Conceptualization, T.S.B. and R.K.T.; methodology, T.S.B. and R.K.T.; software, T.S.B.; formal analysis, T.S.B.; investigation, T.S.B.; resources, T.S.B.; data curation, T.S.B.; writing—original draft preparation, T.S.B.; writing—review and editing, R.K.T.; project administration, T.S.B. Both authors have read and agreed to the published version of the manuscript.

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The effects of chat GPT generated exercise program in healthy overweight young adults: A pilot study

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ABSTRACT

Overweight is an increasing public health issue worldwide. Physical activity may reduce the risks of consequences from overweight. Chat GPT is a potential tool in healthcare projects. This study aimed to evaluate if the chat GPT generated exercise program group (ChatGPT) was effective in overweight persons. This was an intervention study with a randomized controlled fashion. The inclusion criteria were students aged of 18 years or more, male sex, healthy, and had body mass index of 23-24.99 kg/m². Eligible participants were randomly assigned into two groups by a simple random sampling: control group or ChatGPT group. The intervention was performed for eight weeks and three times/week. The outcomes included weight, cardiovascular endurance, percent fat, percent muscle, flexibility, and lung capacity. There were 9 participants in the study; ChatGPT for 6 persons and control group for 3 persons. At baseline, there was no significant difference of studied variables between both groups. At the end of study, there were three studied variables significantly different between the ChatGPT group and the control group including body mass index, heart rate after standing and knee lifting for three minutes and sit and stand in 30 seconds. The body mass index of the ChatGPT group was significantly lower than the control group (22.99 vs 24.46 kg/m²; $p = .020$). Chat GPT generated exercise program is feasible for overweight, young adults to lose weight and improve their cardiovascular fitness, muscle fitness, and fat loss. However, further studies are required to confirm the results of this study.

Keywords: Sport medicine, Health, Body mass index, Heart rate, Agility, Artificial intelligence.

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INTRODUCTION

Overweight, defined as a body mass index between 23 and 24.99 kg/m² in Asian populations (Tham et al., 2023), has an increasing trend. Data from a national survey in the US found that the prevalence of overweight in adults with an age of 20 years or older was 73.8% or adjusted odds ratio of 1.08 (95% confidence interval of 1.04, 1.13) (Li et al., 2022). While, a report from South Asia found that the prevalence of overweight was highest at 52.4% (Awasthi et al., 2023). Additionally, the survey in the US found that the percentage of inactive physical inactivity dramatically increased from 5.6% in 2003 to 21.2% in 2018. Physical inactivity may lead to obesity and several diseases such as obstructive sleep apnoea and cardiovascular diseases (Khamsai et al., 2021; Sanlung et al., 2020; Soontornrungsun et al., 2020).

Several studies have shown that physical activity is a crucial factor in overweight people (Huang et al., 2024; Zhang & Liu, 2024; Zhao et al., 2024). A national database study from China found that being insufficiently active had significantly higher risk for cardiovascular diseases and mortality at 1.24 and 1.32 times, respectively (Zhang & Liu, 2024). Physical activity in adults with type 2 diabetes and overweight or obesity lower risk of cardiovascular outcomes with hazard ratio of 0.39 with a *p*-value of .01 (Huang et al., 2024). A systematic also found that active video games was an intervention to increase physical activity in overweight and obese college students.

Chat GPT, a language model in natural language processing, is a potential tool in healthcare projects (Arslan, 2023; Ismail, 2023). Chat GPT may be useful in obesity treatment in regards of nutrition plan, exercise program, or psychological support (Arslan, 2023). However, there is limited study on using Chat GPT to create the exercise program. This study aimed to evaluate if the chat GPT generated exercise program group was effective in overweight persons.

METHODS

This was an intervention study with a randomized controlled fashion conducted at Nakhon Ratchasima Rajabhat University, Nakhon Ratchasima, Thailand. The inclusion criteria were students aged of 18 years or more, male sex, healthy, and had body mass index of 23-24.99 kg/m². The exclusion criteria were those who were unable to perform exercise, had comorbidities contraindicated for exercise such as osteoarthritis, severe hypertension, or chronic obstructive airway disease, or had an injury during the exercise program.

Eligible participants were randomly assigned into two groups by a simple random sampling: control group or chat GPT generated exercise program group (Appendix 1). The control group did not receive any intervention and continued their daily life, while the chat GPT generated exercise program group received the intervention. The chat GPT generated exercise program was generated by the chat GPT version 4.0 by including exercises which were effective in weight reduction. The program comprised of warm-up for 5-10 minutes, physical fitness exercise (aerobic exercise, resistance training, flexibility training) for 45-60 minutes, and cool-down for 5-10 minutes. Details of the chat GPT generated exercise program were summarized in appendix 2. Participants in this group practiced the exercise program for eight weeks and three times/week.

At baseline and at the end of study, participants were evaluated for the studied outcomes including age, height, body weight (kg), body mass index (kg/m²), percent of fat (%), level of visceral fat (%), body age (years), basal metabolic rate (kg/body weight), percent of skeletal muscle at trunk, arms, legs, and whole body (%), percent of subcutaneous fat at trunk, arms, legs, and whole body (%), heart rate after standing and knee lifting for 3 minutes (bpm), hand grip strength (kg), sit and stand in 30 seconds (times), flexibility (cm),

and lung capacity (ml). Hand grip strength was measured by the hand grip dynamometer, while lung capacity was measured by spirometry.

Statistical analyses

Descriptive statistics were used to calculate median (range) of the studied variables both at baseline and at the end of study. The Wilcoxon rank sum test was used to compare differences of medians between both study groups at baseline and at the end of study, while Wilcoxon signed rank test was used to compare differences of median between at baseline and at the end of study. All statistical analyses were performed by STATA software, version 18.0 (College Station, Texas, USA).

RESULTS

There were 9 participants in the study; chat GPT generated exercise program for 6 persons and control group for 3 persons. At baseline, all participants had an age of 19 years and the median height between both groups were comparable ($p = .667$). The chat GPT generated exercise program had median height of 171 cm (range 166-180 cm), while the control group had median height of 172 cm (range 166-173).

Table 1. Studied variables between the control and chat GPT generated exercise program in young obese adolescents at the baseline.

Factors	Control group n = 3	Intervention group n = 6	p-value
Body weight, kg	71.2 (65.0-72.5)	70.1 (66.3-75.3)	.517
Body mass index, kg/m ²	24.07 (23.59-24.22)	23.76 (23.04-24.40)	.517
Fat, %	20.4 (12.1-22.6)	20.1 (19.0-21.6)	.796
Level of visceral fat, %	7.5 (7.0-9.0)	7.5 (6.5-8.5)	.892
Body age, years	32 (24-33)	33 (29-38)	.435
Basal metabolic rate, kg/bw	1774 (1657-1795)	1748 (1675-1868)	.517
Skeletal muscle			
Trunk, %	27.3 (26.2-32.6)	27.4 (24.5-28.7)	.897
Arms, %	39.3 (39.2-41.7)	36.6 (32.3-29.8)	.197
Legs, %	51.0 (50.2-54.5)	50.9 (48.0-52.3)	.606
Whole body, %	33.8 (33.2-37.4)	33.4 (32.2-34.7)	.437
Subcutaneous fat			
Trunk, %	13.4 (7.8-14.3)	12.4 (11.5-13.5)	.697
Arms, %	20.9 (12.5-23.5)	20.1 (18.6-21.5)	.795
Legs, %	20.4 (11.2-23.1)	20.6 (19.3-22.5)	.897
Whole body, %	14.8 (12.0-15.9)	14.4 (13.4-16.0)	.999
Heart rate after standing and knee lifting for 3 minutes, beats/min.	144 (140-148)	142 (125-152)	.791
Hand grip strength, kg.	42 (39-43)	40 (35-41)	.362
Sit and stand in 30 sec, times.	30 (29-34)	34 (28-35)	.452
Flexibility, cm.	13 (2-15)	11 (-9, 18)	.999
Lung capacity, ml.	3100 (2900-3200)	2850 (2600-3350)	.362

At baseline (Table 1), there was no significant difference of studied variables between both groups. At the end of study (Table 2), there were three studied variables significantly different between the chat GPT generated exercise program group and the control group including body mass index, heart rate after standing and knee lifting for three minutes and sit and stand in 30 seconds. The body mass index of the chat GPT generated exercise program group was significantly lower than the control group (22.99 vs 24.46 kg/m²; $p =$

.020) as well as heart rate after standing and knee lifting for three minutes (128 vs 152 bpm; $p = .019$) and sit and stand in 30 seconds (37 vs 32; $p = .019$).

Table 2. Outcomes of the study between the control and between the control and ChatGPT generated exercise program in young obese adolescents at the end of study.

Factors	Control group n = 3	Intervention group n = 6	p-value
Body weight, kg	73.0 (66.0-73.2)	68.1 (64.5-74.0)	.300
Body mass index, kg/m ²	24.46 (23.95-24.68)	22.99 (22.41-23.72)	.020
Fat, %	21.6 (12.8-23.0)	19.4 (17.4-20.3)	.437
Level of visceral fat, %	8.0 (7.5-9.5)	6.5 (5.5-8.0)	.067
Body age, years	36 (24-39)	30 (25-34)	.439
Basal metabolic rate	1797 (1671-1805)	1724 (1652-1851)	.606
Skeletal muscle			
Trunk, %	26.0 (25.2-31.5)	28.1 (25.1-29.4)	.796
Arms, %	38.4 (28.5-40.2)	37.6 (33.2-40.6)	.796
Legs, %	49.5 (49.4-53.0)	51.7 (49.2-53.0)	.897
Whole body, %	32.2 (31.0-36.2)	34.3 (33.3-35.4)	.439
Subcutaneous fat			
Trunk, %	14.5 (9.0-15.5)	11.9 (10.5-12.9)	.439
Arms, %	22.0 (13.7-24.6)	19.1 (17.3-20.7)	.439
Legs, %	21.4 (13.1-25.0)	19.2 (17.9-20.9)	.439
Whole body, %	15.8 (13.5-16.4)	13.7 (12.2-14.9)	.154
Heart rate after standing and knee lifting for 3 minutes, beats/min.	152 (148-152)	128 (105-132)	.019
Hand grip strength, kg.	41.0 (36.5-41.5)	42.3 (40-48)	.153
Sit and stand in 30 sec, times.	32 (30-32)	37 (35-40)	.019
Flexibility, cm.	10 (-3, 13)	9 (-2, 20)	.606
Lung capacity, ml.	2950 (2850-3000)	3200 (2800-3500)	.154

Table 3. Outcomes of the control group in young obese adolescents at baseline compared with at the end of the study (n = 3).

Factors	Baseline	End of study	p value
Body weight, kg	71.2 (65.0-72.5)	73.0 (66.0-73.2)	.109
Body mass index, kg/m ²	24.07 (23.59-24.22)	24.46 (23.95-24.68)	.109
Fat, %	20.4 (12.1-22.6)	21.6 (12.8-23.0)	.109
Level of visceral fat, %	7.5 (7.0-9.0)	8.0 (7.5-9.5)	.083
Body age, years	32 (24-33)	36 (24-39)	.166
Basal metabolic rate	1774 (1657-1795)	1797 (1671-1805)	.109
Skeletal muscle			
Trunk, %	27.3 (26.2-32.6)	26.0 (25.2-31.5)	.109
Arms, %	39.3 (39.2-41.7)	38.4 (28.5-40.2)	.109
Legs, %	51.0 (50.2-54.5)	49.5 (49.4-53.0)	.103
Whole body, %	33.8 (33.2-37.4)	32.2 (31.0-36.2)	.109
Subcutaneous fat			
Trunk, %	13.4 (7.8-14.3)	14.5 (9.0-15.5)	.103
Arms, %	20.9 (12.5-23.5)	22.0 (13.7-24.6)	.103
Legs, %	20.4 (11.2-23.1)	21.4 (13.1-25.0)	.109
Whole body, %	14.8 (12.0-15.9)	15.8 (13.5-16.4)	.109
Heart rate after standing and knee lifting for 3 minutes, beats/min.	144 (140-148)	152 (148-152)	.103

Hand grip strength, kg.	42 (39-43)	41.0 (36.5-41.5)	.109
Sit and stand in 30 sec, times.	30 (29-34)	32 (30-32)	.786
Flexibility, cm.	13 (2-15)	10 (-3, 13)	.109
Lung capacity, ml.	3100 (2900-3200)	2950 (2850-3000)	.109

For a pre-post intervention comparison, the control group had non-significant studied outcomes for all variables such as increasing of body mass index from 24.07 to 24.47 kg/m² ($p = .109$), or percent of fat (20.4 to 21.6%, $p = .109$) as shown in Table 3. In contrast, the chat GPT generated exercise program group had significantly improved of the studied outcomes except the flexibility such as body weight (70.1 to 68.1 kg; $p = .028$), body mass index (23.76 to 22.99 kg/m²; $p = .028$), body age (33 to 30 years; $p = .024$). However, percent skeletal muscle at trunk, arms, legs, and whole body were significantly increased at the end of study than at baseline as shown in Table 4.

Table 4. Outcomes of the ChatGPT generated exercise program in young obese adolescents at baseline compared with at the end of the study (n = 6).

Factors	Baseline	End of study	p-value
Body weight, kg	70.1 (66.3-75.3)	68.1 (64.5-74.0)	.028
Body mass index, kg/m ²	23.76 (23.04-24.40)	22.99 (22.41-23.72)	.028
Fat, %	20.1 (19.0-21.6)	19.4 (17.4-20.3)	.028
Level of visceral fat, %	7.5 (6.5-8.5)	6.5 (5.5-8.0)	.024
Body age, years	33 (29-38)	30 (25-34)	.024
Basal metabolic rate	1748 (1675-1868)	1724 (1652-1851)	.028
Skeletal muscle			
Trunk, %	27.4 (24.5-28.7)	28.1 (25.1-29.4)	.028
Arms, %	36.6 (32.3-29.8)	37.6 (33.2-40.6)	.028
Legs, %	50.9 (48.0-52.3)	51.7 (49.2-53.0)	.027
Whole body, %	33.4 (32.2-34.7)	34.3 (33.3-35.4)	.028
Subcutaneous fat			
Trunk, %	12.4 (11.5-13.5)	11.9 (10.5-12.9)	.027
Arms, %	20.1 (18.6-21.5)	19.1 (17.3-20.7)	.028
Legs, %	20.6 (19.3-22.5)	19.2 (17.9-20.9)	.027
Whole body, %	14.4 (13.4-16.0)	13.7 (12.2-14.9)	.027
Heart rate after standing and knee lifting for 3 minutes, beats/min.	142 (125-152)	128 (105-132)	.026
Hand grip strength, kg.	40 (35-41)	42.3 (40-48)	.027
Sit and stand in 30 sec, times.	34 (28-35)	37 (35-40)	.027
Flexibility, cm.	11 (-9, 18)	9 (-2, 20)	.344
Lung capacity, ml.	2850 (2600-3350)	3200 (2800-3500)	.027

DISCUSSION

This may be the first study using chat GPT generated exercise program. Here, the eight-week chat GPT generated exercise program was effective compared with the control group in terms of body mass index, heart rate after exercise, and agility.

The chat GPT generated exercise program in this study comprised of aerobic exercise, resistance training, and flexibility training for 45-60 minutes per session. As recommended by the American College of Sports Medicine, moderate aerobic exercise for 150 minutes per week can reduce body weight (Donnelly et al., 2009). Weight loss of 4.9 kg and 5.2 kg was found in the 400 and 600 kcal/session aerobic exercise in

overweight or obese individuals (Donnelly et al., 2013). These may be due to several factors including body fat loss, improvement of insulin resistance, or improvement of oxygen consumption (Chiu et al., 2017; Oda et al., 2014; O'Hagan et al., 2013). This study found that body weight was decreasing by 0.77 kg in the chat GPT generated exercise group (Table 4). Weight loss in this program may be also an additional effect of the resistance exercise which may increase muscle mass and fat oxidation (Donnelly et al., 2009).

Several studies found that aerobic exercise can reduce resting heart rate (Kang et al., 2016; Oh et al., 2016; Riebe et al., 2015). Marathon runners had significant lower resting heart rate than control group (58.80 vs 74.47; $p < .001$) (Oh et al., 2016). Similarly, heart rate of the intervention group after the standing and knee lifting for 3 minutes was significantly lower than the control group (128 vs 152 bpm; $p = .019$) as shown in table 2. These findings may be due to the lower resting heart rate in the chat GPT generated exercise program group. Finally, the improvement of the number of sit and stand in 30 seconds may indicate better agility and leg strength. The leg strength was improved by the program as the parameters of skeletal muscle in the whole body were significantly improved as shown in Table 4.

Even though the intervention program comprised of flexibility training, flexibility outcome was not different between both groups. These findings may be explained by several factors were associated with flexibility including joint, muscle, or spine (Almansoof et al., 2023). Additionally, flexibility exercises were initiated in week 5 and 6 (Appendix 2). These may imply that flexibility may need more than two weeks to be improved. Taken together, significant changes in body weight, muscle fitness, cardiovascular fitness, fat reduction but not flexibility were found in the chat GPT generated exercise program group (Table 4).

CONCLUSION

Chat GPT generated exercise program is feasible for overweight, young adults to lose weight and improve their cardiovascular fitness, muscle fitness, and fat loss. However, further studies are required to confirm the results of this study.

AUTHOR CONTRIBUTIONS

Pakpoom Philuek and Austtasit Chainarong: preparation and research design, data collection, statistical analysis, result interpretation, manuscript writing, supervision of the study, and review of the final version. Sarawut Kusump, Thanakan Sathianpoonsook, and Charee Jansupom: data collection, result interpreter, and reviewed the manuscript. Pongtawat Sawanyawisuth, and Kittisak Sawanyawisuth: statistical analysis, and review of the final version.

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APPENDIX 1. Details of exercise generated by chat GPT.

You
Design training schedule for weight loss males aged 18-24 years
Please write in English language.

ChatGPT
Designing a training schedule for weight loss, specifically for males aged 18-24 years, involves considering both exercise and dietary strategies to create an effective program. The goal should be to create a sustainable and balanced approach that combines cardiovascular exercise, strength training, and flexibility exercises, while also paying attention to nutrition and recovery. Here's a comprehensive weekly training schedule, considering the target demographic's potential physical capabilities and recovery needs:

You
Monday, Wednesday, Friday
Please write in English language.

ChatGPT
To adapt the training schedule for weight loss in males aged 18-24 years to focus on Monday, Wednesday, and Friday workouts, we'll create a condensed version that still covers all essential aspects: cardiovascular exercise, resistance training, and flexibility exercises. This approach ensures adequate recovery time while promoting weight loss and muscle tone.

Week 1-2: Foundation and Endurance Building

- Monday (Full Body Strength Training)**
 - Warm-up: 10 minutes of light cardio (jogging or cycling)
 - Circuit (3 sets, 10-12 reps): Squats, bench presses, deadlifts, overhead presses, and planks.
 - Cool Down: 10 minutes of stretching focusing on major muscle groups.
- Wednesday (Cardiovascular Exercise)**
 - Warm-up: 5 minutes of dynamic stretching
 - Cardio: 45 minutes of moderate-intensity cardiovascular exercise (running, cycling, or swimming).
 - Cool Down: 5-10 minutes of stretching.
- Friday (Strength Training & Core Focus)**
 - Warm-up: 10 minutes of light cardio
 - Circuit 1 (Upper Body, 3 sets, 8-12 reps): Bench press, bent-over rows, shoulder press, bicep curls, tricep dips.
 - Circuit 2 (Core, 3 sets): Planks (1 min), side planks (30 sec per side), Russian twists (20 reps), leg raises (12 reps).
 - Cool Down: 10 minutes of full-body stretching.

Week 7-8: Peak Performance and Tapering

- Monday (Peak Strength Training)**
 - Focus on lifting the heaviest weights of the program with good form. Concentrate on compound movements like squats, deadlifts, and bench press.
- Wednesday (Peak Intensity Cardio)**
 - A challenging cardio session, such as a longer-duration HIIT or a tempo run, to push cardiovascular limits.
- Friday (Full Body Circuit & Core)**
 - A high-intensity circuit that combines strength, cardio, and core exercises. Aim for minimal rest between sets to keep the heart rate up.

Notes:

- Nutrition:** A balanced diet is crucial for weight loss. Consider consulting a dietitian for personalized advice.
- Hydration:** Stay well-hydrated, especially on workout days.
- Recovery:** Prioritize sleep and consider active recovery or yoga on rest days to improve flexibility and reduce muscle soreness.
- Adjustments:** Listen to your body and adjust the intensity or volume as needed to avoid overtraining and injuries.

Notes:

- Nutrition:** A balanced diet is crucial for weight loss. Consider consulting a dietitian for personalized advice.
- Hydration:** Stay well-hydrated, especially on workout days.
- Recovery:** Prioritize sleep and consider active recovery or yoga on rest days to improve flexibility and reduce muscle soreness.
- Adjustments:** Listen to your body and adjust the intensity or volume as needed to avoid overtraining and injuries.

This condensed schedule aims to balance workout intensity with recovery, ensuring progressive overload for muscle growth and fat loss while avoiding overtraining.

Week 3-4: Intensity and Volume Increase

- Monday (Upper Body Strength)**
 - Increase the weight or resistance from weeks 1-2.
 - Exercises: Include variations like incline bench press, pull-ups, and dumbbell flies for upper body. Add more sets or reduce rest time to increase intensity.
- Wednesday (HIIT Cardio)**
 - Warm-up: 5 minutes of dynamic stretching.
 - HIIT Session: 20-30 minutes, alternating between high-intensity exercises (e.g., sprints, burpees) and low-intensity recovery periods.
 - Cool Down: 5-10 minutes of stretching.
- Friday (Lower Body Strength & Core)**
 - Focus on lower body strength with exercises like squats, lunges, and deadlifts. Increase the intensity by adding weights or changing to more challenging variations.
 - Core: Incorporate exercises like planks, bicycle crunches, and mountain climbers for a comprehensive core workout.

Week 5-6: Skill Development and Functional Training

- Monday (Functional Strength Training)**
 - Incorporate exercises that improve daily movement patterns, such as kettlebell swings, box jumps, and medicine ball throws.
- Wednesday (Mixed Cardio)**
 - Combine steady-state cardio with intervals for a 45-minute session. For example, alternate 5 minutes of jogging with 2 minutes of sprinting.
- Friday (Full Body Strength with Plyometrics)**
 - Integrate plyometric exercises (e.g., jump squats, burpees) with traditional strength training to enhance power and burn more calories.



APPENDIX 2. Details of exercise generated by chat GPT.

The chat GPT generated exercise for overweight individuals (Foundation and Endurance Building), week 1st and 2nd.

Day	Warm-up	exercise	Cool Down
Monday (Full Body Strength Training)	10 minutes of light cardio (jogging or cycling)	Circuit (3 sets, 10-12 reps): Squats, bench presses, deadlifts, overhead presses, and planks.	Cool Down: 10 minutes of stretching focusing on major muscle groups.
Wednesday (Cardiovascular Exercise)	5 minutes of dynamic stretching	Cardio: 45 minutes of moderate-intensity cardiovascular exercise (running, cycling, or swimming).	Cool Down: 5-10 minutes of stretching.
Friday (Strength Training & Core Focus)	10 minutes of light cardio	1.Circuit 1 (Upper Body, 3 sets, 8-12 reps): Bench press, bent-over rows, shoulder press, bicep curls, triceps dips. 2.Circuit 2 (Core, 3 sets): Planks (1 min), side planks (30 sec per side), Russian twists (20 reps), leg raises (12 reps).	10 minutes of full-body stretching.

The chat GPT generated exercise for overweight individuals (Intensity and Volume Increase), week 3rd and 4th.

Day	Warm-up	exercise	Cool Down
Monday (Upper Body Strength)	10 minutes of light cardio (jogging or cycling)	- Increase the weight or resistance from weeks 1-2. - Exercises: Include variations like incline bench press, pull-ups, and dumbbell flyers for upper body. Add more sets or reduce rest time to increase intensity.	Cool Down: 10 minutes of stretching focusing on major muscle groups.
Wednesday (HIIT Cardio)	5 minutes of dynamic stretching.	HIIT Session: 20-30 minutes, alternating between high-intensity exercises (e.g., sprints, burpees) and low-intensity recovery periods.	Cool Down: 5-10 minutes of stretching.
Friday (Lower Body Strength & Core)	10 minutes of light cardio	- Focus on lower body strength with exercises like squats, lunges, and deadlifts. Increase the intensity by adding weights or changing to more challenging variations. - Core: Incorporate exercises like planks, bicycle crunches, and mountain climbers for a comprehensive core workout.	10 minutes of full-body stretching.

The chat GPT generated exercise for overweight individuals (Skill Development and Functional Training), week 5th and 6th.

Day	Warm-up	exercise	Cool Down
Monday (Functional Strength Training)	10 minutes of light cardio (jogging or cycling)	Incorporate exercises that improve daily movement patterns, such as kettlebell swings, box jumps, and medicine ball throws.	Cool Down: 10 minutes of stretching focusing on major muscle groups.
Wednesday (Mixed Cardio)	5 minutes of dynamic stretching	Combine steady-state cardio with intervals for a 45-minute session. For example, alternate 5 minutes of jogging with 2 minutes of sprinting.	Cool Down: 5-10 minutes of stretching.
Friday (Full Body Strength with Plyometrics)	10 minutes of light cardio	Integrate plyometric exercises (e.g., jump squats, burpees) with traditional strength training to enhance power and burn more calories.	10 minutes of full-body stretching.

The chat GPT generated exercise for overweight individuals (Peak Performance and Tapering) week 7th and 8th.

Day	Warm-up	exercise	Cool Down
Monday (Peak Strength Training)	10 minutes of light cardio (jogging or cycling)	Focus on lifting the heaviest weights of the program with good form. Concentrate on compound movements like squats, deadlifts, and bench press.	Cool Down: 10 minutes of stretching focusing on major muscle groups.
Wednesday (Peak Intensity Cardio)	5 minutes of dynamic stretching	A challenging cardio session, such as a longer-duration HIIT or a tempo run, to push cardiovascular limits.	Cool Down: 5-10 minutes of stretching.

Friday (Full Body Circuit & Core)	10 minutes of light cardio	A high-intensity circuit that combines strength, cardio, and core exercises. Aim for minimal rest between sets to keep the heart rate up.	10 minutes of full-body stretching.
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Notes:

- Nutrition: A balanced diet is crucial for weight loss. Consider consulting a dietitian for personalized advice.
- Hydration: Stay well-hydrated, especially on workout days.
- Recovery: Prioritize sleep and consider active recovery or yoga on rest days to improve flexibility and reduce muscle soreness.
- Adjustments: Listen to your body and adjust the intensity or volume as needed to avoid overtraining and injuries.
- This condensed schedule aims to balance workout intensity with recovery, ensuring progressive overload for muscle growth and fat loss while avoiding overtraining.



A comparative analysis of volleyball skills in balanced sets for men and women in Asian competitions

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ABSTRACT

The study investigates volleyball performance indicators that distinguish winning and losing sets in men's and women's Asian competitions. It focuses on balanced sets, defined as those with a score difference of ≤ 5 points for men and ≤ 7 points for women, to avoid bias from lopsided sets. Data from the 2023 Men's and Women's AVC Challenge Cup was analysed. A six-level scale evaluated serve, reception, attack after reception and after defence, block and setting. Stepwise discriminant analysis identified the most significant performance indicators for winning a set in each gender. For men's teams, attack win percentage and serve win percentage were the most important factors. Teams with attack win percentages above 50% and serve win percentages above 7.5% exhibited a greater likelihood of winning. For women's teams, the analysis was not statistically significant, but attack win percentage after reception percentage showed the strongest influence. The study underscores the pivotal role of attack effectiveness in differentiating winning and losing sets, particularly for men's teams. Serve win percentage also plays a significant role for men. While the analysis for women's teams was inconclusive, attack success appears to be crucial. Future research could strengthen the findings for women's volleyball.

Keywords: Performance analysis, Volleyball, Sport analysis, Skills, Asian championship.

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INTRODUCTION

Volleyball is probably one of the most popular sports in the world. Therefore, numerous studies have investigated players' performance with the aim to determine the factors that will result in improving the performance and, consequently, competition (Silva et al., 2013).

This a sport that is inclusive of all genders, with separate tournaments. The decision to not have men compete against women or in mixed teams is based on differences in physical characteristics such as body composition, muscle mass, hormonal levels, and oxygen consumption. Technical skills are common to both genders, while the hierarchical structure of the game requires similar tactics (Drikos et al., 2018).

Volleyball skills depend on many external and unexpected factors, which the coaching process attempts to modify to achieve success. Great emphasis has been attributed to the coach's capacity to observe events that may become relevant to training and competition (Borrie et al., 2002). However, researchers have questioned the validity and reliability of subjective observations and suggest that a performance evaluation using game-related statistics may be very helpful in achieving better accuracy in coaching decisions (Sampaio et al., 2004). Literature on volleyball commonly focuses on the study of game-related and its effect on players and the team's performance. Also, some studies have focused on analyzing samples of high-level performance, especially in men's volleyball (Fatahi et al., 2022; Marcelino et al., 2008). For example, Palao, Santos, and Ureña studied the game-related team level for men and women derived from volleyball tournaments. Analysis yielded significant differences by the men's team level play on spike and block, while the women teams' levels were discriminated only on attack skills, and specifically, the spike (Palao et al., 2004). Examining the same tournament, Palao, Santos, and Ureña (2005) concluded that men's attack is more balanced than women's for the setter position (Palao et al., 2005).

Kountouris and colleagues found significant differences between men and women in terms of the effectiveness of five volleyball skills during the last four consecutive Olympics (2000–2016)(Kountouris et al., 2015). Their results indicated that at an elite level, serve and attack abilities are completely distinct between the genders. Bergeles et al. investigated the relationship between attack performance and setting performance, showing that higher setter performance directly correlates with better attacker performance in both men and women (Nikos et al., 2009). Palao et al.'s study based on performance data from the Sydney 2000 Olympics revealed notable discrepancies between male teams in attacking and blocking abilities, and among female teams in attacking prowess (Fatahi et al., 2022; Palao et al., 2009). Additionally, in a 2009 study, Palao et al. analyzed games from the Mediterranean Games of Almeria and determined that female players exhibited a more effective serving performance compared to males, whereas males excelled in serve reception, and attack effectiveness remained similar for both genders (Palao et al., 2009). Jo~ao et al., in their 2010 study, scrutinized games from various 2007 World Championships to discern statistical indicators that distinguish performance based on gender. Their focus lay on serve errors, attack proficiency, and reception skills (JoãTo et al., 2010).

Also, in volleyball Match Analysis research, significant focus has been on how contextual factors impacting the quality of the opposition affect technical and team performance. The competitive level of teams or the stage of the competition has been considered in various studies to ensure a homogeneous research sample, often choosing key moments like matches in the Olympic Games, the third phase of the World Championships, or the World League (Martínez et al., 2023).

However, studies were conducted in the male European Championship, without considering the differentiating effect of the competition analyzed, and the gender of the participants (Sánchez-Moreno et al., 2017). Comparing sets in which the competition load is similar could be highly important. It seems that the differences in points in the scoreboard in each set are related to significant indicators of technical performance so that the indicators are reduced, as the difference in points per set becomes equal (Martínez et al., 2023), although the performance of the finishing attack becomes more decisive (Drikos & Vagenas, 2011). Also, the technical-tactical behaviors of the teams could be altered, either due to the competition load of the set (Drikos & Vagenas, 2011), as well as the state of the scoreboard or the critical moment in the set. Thus, it seems that teams take on more risks when the scoreboard or sets are unbalanced, either when having an advantage or disadvantage in the scoreboard (Drikos & Vagenas, 2011; Marcelino et al., 2011); while the critical moments of the set and a scoreboard without little differences in scores, are associated with simpler blocking strategies and a lower level of risk related with the serve (Marcelino et al., 2011; Marcelino et al., 2012).

Hence A review of some studies showed that comparing sets in which the competition load is similar could be highly important. It seems that the differences in points in the scoreboard in each set is related with significant indicators of technical performance. Thus, it seems that teams take on more risks when the scoreboard or sets are unbalanced, either when having an advantage or disadvantage in the scoreboard (Drikos & Vagenas, 2011; Marcelino et al., 2011); while the critical moments of the set and a scoreboard without little differences in scores, are associated with simpler blocking strategies and a lower level of risk related with the serve (Marcelino et al., 2011; Marcelino et al., 2012). As for the state of the match, Ramos et al. with a high-level female sample, did not find differences in the tactical performance as a function of the state of the match (Ramos et al., 2017). In addition, Marcelino et al., with a sample of male World League teams, did not find significant differences that would allow them to establish a correlation between the final result of the set, and the following one (Marcelino et al., 2009). As the main goal of the study, we aimed to analyze the distinguishing abilities for balanced sets, categorizing them by gender in male and female competitions in Asia for this sport.

MATERIALS AND METHODS

Sample and variables

The study focused on the Men's and Women's Asian Volleyball Confederation (A.V.C.) Challenge Cup 2023, which was held in Indonesia for Women and Chinese Taipei for Men. In the A.V.C/ Challenge Cup 13 male and 11 female teams competed. To avoid bias from sets with clear score differences, a k-means cluster analysis was used to categorize balanced sets for each gender. A total of 61 sets for men with a score difference of ≤ 5 points and 21 sets for women with a score difference of ≤ 7 points were sampled and data were collected (N = 61 for men and N = 21 for women).

A six-level ordinal scale was employed for the evaluation of each skill, with the value of "one" indicating a poorly executed skill and the value of "six" indicating an excellent executed skill (Drikos & Tsoukos, 2018). Set statistics included variables of efficacy (the number of the categorized events divided by the total number of the skill and multiplied by 100) for the following eleven (11) key performance indicators (KPI): 1) Serve win (Swin%) 2) Serve Over (Sover%) 3) Serve Error (Serr%), 4) Reception precise % [Rec perfect + Rec excellent] (RPrC), 5) Attack 1 win (A1Win%), 6) Attack 1 blocked (A1BI%), 7) Attack 1 Error (A1Err%), 8) Attack 2 win (A2Win%), 9) Attack 2 blocked (A2BI%), 10) Attack 2 Error (A2Err%), 11) Setting error (StErr%).

Procedures

The data were recorded and processed by a volleyball expert scout man using Data Volley software (Drikos, 2018). To examine the intra-observer's reliability, a test-retest procedure of 20% of the total sample (12 sets from men and 5 sets from women randomly selected) following a four-week interval to avoid any possible adverse learning effects was established. Inter-observer reliability was examined by a second independent volleyball expert who was asked to evaluate the same selected 19 sets. The weighted kappa values for both procedures, intra-observer = 0.92, 0.84, 0.88, 0.91 and inter-observer = 0.92, 0.82, 0.89, and 0.95 for serve, reception, attack, block and setting, respectively showed very good values (Altman, 1990). Ethical approval was provided by the institutional university ethics committee, which was conducted following the 2013 Helsinki Declaration.

Statistical analysis

A stepwise discriminate analysis (DA) was performed to identify the contribution of each KPI to the win of a single set per gender. The DAs were planned to determine three items: which variables were best predictors for the teams' success in the classification of performance level, the discriminate function that best separates the two group means and the accuracy of the equation that best discriminates teams' level. The comment of the obtained discriminant functions depended on examination of the structure coefficients greater than |0.30|. It inferred that variables with higher absolute values have a greater contribution to discriminating between groups (Tabakhnick & Fidell, 2007). In more detail, loadings over .71 are considered excellent, .63 very good, .55 good, .45 fair and .32 poor (Comrey & Lee, 2013). To decrease the bias entered in the classification, jack-knifed classification was used. The statistical analysis was performed using SPSS 29.0 software and significances were tested at $p < .05$.

RESULTS

Male

Table 1 summarizes all the variables employed in this study for male teams' performance-related statistics.

Table 1. Descriptive statistics of the performance indicators for male teams.

Type of result	Lost		Win		Total	
	Mean	SD	Mean	SD	Mean	SD
SWin%	2.86%	3.53%	5.29%	4.69%	4.08%	4.31%
SOver%	2.81%	4.13%	4.12%	4.33%	3.47%	4.27%
SErr%	14.40%	8.32%	15.46%	7.22%	14.93%	7.77%
RPr%	55.21%	14.03%	60.24%	11.09%	57.73%	12.85%
A1Win%	48.52%	10.12%	56.94%	10.41%	52.73%	11.06%
A1Blk%	10.61%	7.92%	8.09%	6.59%	9.35%	7.37%
A1Wrr%	7.41%	5.81%	6.48%	5.92%	6.94%	5.86%
A2Win%	43.39%	16.38%	46.22%	18.87%	44.81%	17.65%
A2Blk%	8.93%	10.88%	6.07%	7.46%	7.50%	9.40%
A2Err%	10.40%	9.37%	7.40%	9.15%	8.90%	9.34%
StErr%	1.50%	2.89%	1.89%	3.68%	1.69%	3.30%
N	61		61		122	

The test of equality of the two group means for "type of result" was significant for the KPIs SWin ($p = .002$), RPr ($p = .030$) and A1Win ($p < .001$).

The eigenvalues, the canonical correlations, the chi-square values, the respective significances as well the correct classifications of the discriminant functions are presented in Table 2. The discriminate function was statistically significant ($p < .001$) and the canonical correlation coefficient ($=.577$), namely the measure of association between the discriminate function and the outcome variable, is moderate. Consequently, the squared canonical correlation ($=.333$) is the amount of variance accounted for by the discriminant function.

Table 2. Eigenvalue, test of the significance and classification table for the discriminant function for male teams.

Type of result	Male
Eigenvalue	0.498
Canonical Correlation	.577
Wilks' Lambda	.668
Chi-square	46.275
Df	11
p	<.001
Correct Classification	75.4% (77.0% for original cases)

To infer the meaning of the discriminant function and to assess the relative contribution of each performance indicator in maximizing the multivariate difference for type of result (win or lose) for each gender, the discriminant structure coefficients (SC) and the standardized canonical discriminant function coefficients (SCC) were examined (Table 3, *in italics* and underlined). Structure coefficients $>|.30|$ are meaningful and indicate the substantial contribution of the respective independent variables in the separation between the levels of the dependent variable (Pedhazur, 1997). Only two performance indicators A1win (.587) and Swin (.418) possessed a meaningful structure coefficient (SC) with regards to the multivariate separation between the two groups of "type of result". The squared SC values indicated that 35% and 18% respectively of the variance in these two variables is accounted for by the discriminant function. Their combination leads to the substantial explanation that the main difference between the two groups of sets (win-lose) reflects mainly the status of win attack and serve points. The negative sign of the SCC index in the variables indicates the negative effect on the team's performance.

Table 3. Test of significance (p -values, in bold $<.05$) for the equality of group means (EQ), structure coefficients (SC, in bold $>|.3|$) and Standardized Canonical Coefficients (SCC) for male teams.

Performance indicators	Male		
	EQ	SC	SCC
SWin%	.002	.418	<u>.661</u>
SOver%	.089	.222	<u>.327</u>
SErr%	.452	.098	<u>.081</u>
RPr%	.030	.284	<u>.302</u>
A1Win%	<.001	.587	<u>.640</u>
A1Bl%	.058	-.247	<u>-.088</u>
A1Err%	.382	-.114	<u>.107</u>
A2Win%	.378	.114	<u>-.065</u>
A2Bl%	.093	-.219	<u>-.380</u>
A2Err%	.076	-.232	<u>-.319</u>
StErr%	.523	.083	<u>.276</u>

Cross-validation results showed that the discriminant function was correctly classified for male teams 47 wins and 45 lost out of the 61 sets (predictive accuracy: 75.4%).

The importance of the two variables A1win % and Swin % in the accuracy of the discriminant function is presented in the scatter plot (Figure 1) with values of the two variables in the X and Y axis and labels the predicted groups for all the sets. Examination of the scatter plot reveals benchmark values of 50% for A1 Win and 7.5% for Swin (corresponding roughly to two aces for every 25 serves). A data point positioned above these reference values in both A1Win and Swin dimensions suggests a possible win per set for the team under investigation. It is important to note that aces are not an absolute prerequisite for winning a set. The scatter plot demonstrates numerous winning sets with a zero percentage of aces yet achieving a noteworthy A1Win ratio.

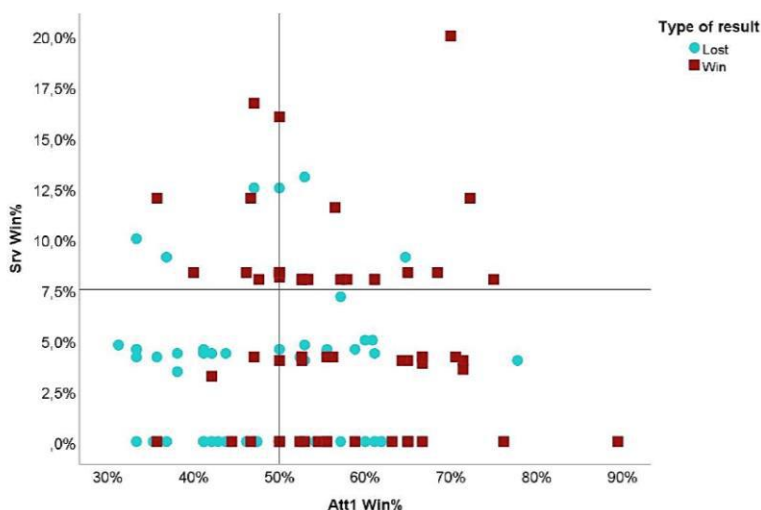


Figure 1. Scatter plot with values of the variables Att2Win% and Att1 Win% and labels for the predicted groups for the sets of male teams.

Female

Table 4 summarizes all the variables employed in this study for male teams' performance-related statistics.

Table 4. Descriptive statistics of the performance indicators for female teams.

Type of result	Lost		Win		Total	
	Mean	Sd	Mean	Sd	Mean	Sd
SWin%	2.96%	3.48%	3.79%	5.12%	3.38%	4.34%
SOver%	3.75%	5.13%	3.25%	2.69%	3.50%	4.05%
SErr%	6.99%	5.52%	6.42%	5.14%	6.70%	5.28%
RPr%	53.50%	10.15%	56.11%	10.40%	54.80%	10.24%
A1Win%	40.34%	8.42%	49.16%	14.22%	44.75%	12.38%
A1Blk%	5.37%	4.47%	4.06%	5.72%	4.72%	5.11%
A1Wrr%	4.34%	3.91%	3.78%	4.53%	4.06%	4.19%
A2Win%	36.36%	13.31%	40.41%	11.01%	38.38%	12.23%
A2Blk%	5.67%	6.21%	4.59%	6.03%	5.13%	6.07%
A2Err%	6.96%	7.22%	6.08%	4.96%	6.52%	6.13%
StErr%	2.44%	3.09%	2.17%	3.80%	2.31%	3.42%
N	21		21		42	

The test of equality of the two group means for “*type of result*” was significant for the KPI A1Win ($p = .019$).

The eigenvalues, the canonical correlations, the chi-square values, the respective significances as well the correct classifications of the discriminant functions are presented in Table 5. The discriminate function was not statistically significant ($p = .500$) and the canonical correlation coefficient ($=.509$), namely the measure of association between the discriminate function and the outcome variable, is moderate. Consequently, the squared canonical correlation ($=.259$) is the amount of variance accounted for by the discriminant function.

Table 5. Eigenvalue, test of the significance and classification table for the discriminant function for female teams.

Type of result	Female
Eigenvalue	0.350
Canonical Correlation	.509
Wilks' Lambda	.741
Chi-square	10.345
Df	11
p	.500
Correct Classification	47.6% (69.0 %for original cases)

To infer the meaning of the discriminant function and to assess the relative contribution of each performance indicator in maximizing the multivariate difference for type of result (win or lose) for each gender, the discriminant structure coefficients (SC) and the standardized canonical discriminant function coefficients (SCC) were examined (Table 6, *in italics* and underlined). Only performance indicators A1win ($-.654$) possessed a meaningful structure coefficient (SC) with regards to the multivariate separation between the two groups of “*type of result*” following by the A2win ($-.287$). The squared SC values indicated that 43% of the variance in this variable is accounted for by the discriminant function, leads to the substantial explanation that the main difference between the two groups of sets (win-lose) reflects mainly the status of win attack after reception. The negative sign of the SCC index in the variables indicates the negative effect on the team's performance.

Table 6. Test of significance (p -values, in bold $<.05$) for the equality of group means (EQ), structure coefficients (SC, in bold $>|.3|$) and Standardized Canonical Coefficients (SCC) for female teams.

Performance indicators	Female		
	EQ	SC	SCC
SWin%	.542	-.165	-.242
SOver%	.698	.105	.358
SErr%	.734	.092	.299
RPr%	.415	-.220	-.331
A1Win%	.019	-.654	-.642
A1Blk%	.414	.221	.377
A1Err%	.669	.115	.265
A2Win%	.289	-.287	-.722
A2Blk%	.569	.154	.347
A2Err%	.648	.123	.110
StErr%	.799	.068	.213

Cross-validation results showed that the discriminant function was correctly classified for female teams with 10 wins and 12 lost out of the 21 sets (predictive accuracy: 47.6%). The predictive accuracy of the original cases is 69,0%, as discriminant function was correctly classified 15 wins and 14 lost out of the 21 sets.

The importance of the two variables A1win % and A2win % in the accuracy of the discriminant function is presented in the scatter plot (Figure 2) with values of the two variables in X and Y axis and labels the predicted groups for all the sets.

Examination of the scatter plot reveals benchmark values of 50% for A1 Win and 25% for A2 Win. A data point positioned above these reference values in both A1Win and A2 Win dimensions suggests a possible win per set for the team under investigation. It is important to note that the aces are not an absolute prerequisite for winning a set. An examination of the scatter plot reveals a preponderance of winning sets where the A2win ratio surpasses 25%. Conversely, there exists only a single instance where the team under investigation secured victory with an A2win performance below this threshold.

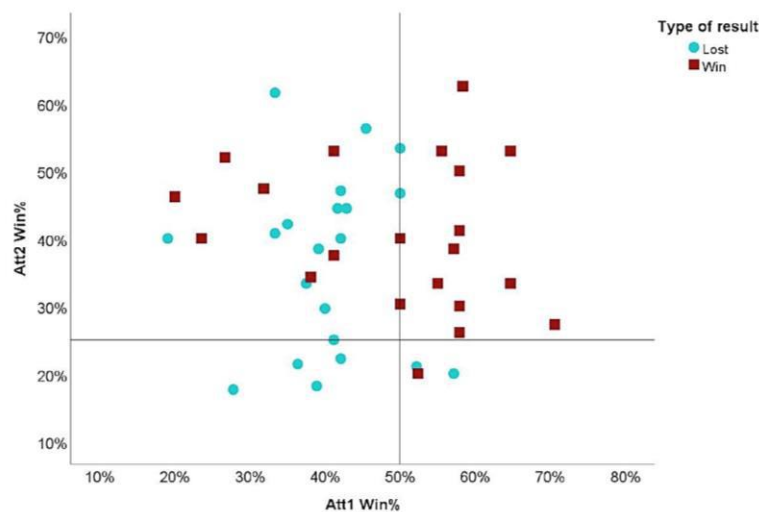


Figure 2. Scatter plot with values of the variables Att2Win% and Att1 Win% and labels for the predicted groups for the sets.

DISCUSSION

This study aimed to identify volleyball skills, analyse the distinguishing abilities for balanced sets, categorizing them by gender in male and female competitions in Asia for this sport. The data found that efficacy and importance of skills were different for males and females.

The aforementioned statistical analysis delves into the comparison of group means for the "type of result," focusing on key performance indicators (KPIs) in male and female cohorts. The study identifies significant differences in KPIs SWin, Pprc, and A1Win in males, along with a notable outcome in the KPI A1Win for females. This essay aims to dissect the implications of these findings, emphasizing the importance of gender-specific analysis in assessing performance metrics.

Research on discriminating skills for balanced sets in Asia Men's and Women's Volleyball presents an opportunity for further investigation. Studies have shown that in both men's and women's volleyball, the

effectiveness of attacks is a crucial performance indicator for all set types, emphasizing the significance of sustained training across all skills, including serve and block (Drikos et al., 2020; Giatsis, 2023; Giatsis et al., 2023). Additionally, the technical indicators between winning and losing teams in women's volleyball have highlighted the importance of block points in determining success, especially in 5-set matches (Giatsis, 2023). Analyzing volleyball skills that best discriminate between winning and losing in sets with minimal score differences can provide valuable insights into the key factors influencing match outcomes, suggesting a need for further research to enhance understanding and performance in Asia's volleyball scene. Research by Drikos et al. identified that in sets with a minimum score difference, the effectiveness of attacks 1 and 2 are the most important performance indicators (Drikos et al., 2020). Some results show that in male volleyball, attack 1 is essential for winning as receiving is easier than serving (Ferrante & Fonseca, 2014; Kovacs, 2009). Men's teams have higher attack 1 efficacy due to serving difficulty and precise receptions leading to fast tempo spikes (García-de-Alcaraz et al., 2015). This results in a higher percentage of attack 1 for males compared to females (53% vs. 39%) (García-de-Alcaraz et al., 2015). 7.5% difference between men and women, were found in a study by Ciemiński using data from European Volleyball Championships. Female volleyball shows lower attack 1 win values, leading to longer rallies and matches for women. Attack 1 is considered important based on its appearance as a discriminative variable with higher loading in discriminant functions for both genders (Ciemiński, 2018).

More analytically, with regard to serve skill in total sets, women tend to present higher values in serve aces and lower values to serve error than men. Thus, analysing the balance of serve errors and serve aces according to the serve efficiency ratio (SER) proposed by Drikos et al. (Drikos et al., 2009). Findings some study partly explain the different importance of the serve for each gender. Male teams more often risk at serve in order not to lose the rally directly (Drikos et al., 2019). This happens because of the overall performance in the skills of the complex 1 (side-out). Men present higher values than women in the quality of serve's pass (Palao et al., 2004) and, consequently, in the effectiveness of attack 1 (after serve's pass) (Ciemiński, 2018). Female teams served more conservatively comparing to male teams, as they lost fewer serves. The better SER is caused by the interaction between serve and reception because women receive serve in lower standards than men and thereafter attack 1 is not so efficient compared to men.

The statistical significance of the KPIs SWin, Pprc, and A1Win in males, with p-values of .002, .030, and <.001, respectively, underscores the distinct performance trends exhibited by this group. These findings suggest that males may excel in specific areas compared to their female counterparts, indicating potential discrepancies in skill sets or approaches towards achieving set targets. Moreover, the pronounced significance of A1Win ($p = .019$) in females hints at a noteworthy strength or advantage possessed by this group, warranting further investigation into the underlying factors contributing to this outcome.

The role of discriminant functions in differentiating between winning and losing outcomes for each gender is crucial in analysing performance indicators. In examining male performance, A1Win (SC = 0.587) and SWin (SC = 0.418) stand out with meaningful structure coefficients, signifying their significant roles in distinguishing between the two result categories. The squared SC values further reveal that 35% of the variance in A1Win and 18% in SWin is explained by the discriminant function. This underscores the importance of win attack and serve points in outcome differentiation among males.

Conversely, in the female category, it was observed that only A1Win (-0.654) and A2Win (-0.287) made significant contributions to the multivariate distinction between win and lose outcomes, with A1Win exerting the most substantial influence. The negative SCC index associated with these indicators implies a detrimental

impact on team performance. Evaluating these performance indicators in relation to the discriminant function sheds light on the factors that drive disparities in outcomes for male and female players.

The scatter plot highlights the importance of A1win % and A2win % in the accuracy of the discriminant function, with benchmark values of 50% for A1Win and 25% for A2Win. Data points above these values suggest a potential set win. Winning sets often have A2win ratios exceeding 25%, emphasizing its significance. Additionally, only one set was won with an A2win performance below 25%. This indicates the crucial role of A2win % in predicting set wins and underscores its importance in the analysis of the data.

The cross-validation analysis revealed a predictive accuracy of 75.4% in classifying male team outcomes, where they achieved 47 wins and 45 losses out of 61 sets. It is worth noting that although aces do contribute to winning sets, they are not always essential, as evident from some sets that secured notable A1Win ratios even with zero aces.

In contrast, the cross-validation results for female teams showed a lower predictive accuracy of 47.6%, correctly categorizing 10 wins and 12 losses out of 21 sets using the discriminant function. The original cases exhibited a slightly higher predictive accuracy of 69.0%, accurately identifying 15 wins and 14 losses out of the same 21 sets.

This study underscores the critical role of performance indicators in predicting outcomes and emphasizes the nuanced relationship between different variables and team success.

CONCLUSIONS

For men's teams, the analysis found that attack effectiveness and serving efficiency were the most important factors. Teams with attack effectiveness above 50% and serving efficiencies above 7.5% were more likely to win. For women's teams, the analysis did not produce statistically significant results, but attack effectiveness after reception showed the strongest influence. The study emphasizes the crucial importance of attack effectiveness in differentiating winning and losing sets, particularly for men's teams. Serving efficiency also plays a significant role for men's teams. While the analysis for women's teams was inconclusive, attack success appears to be important. Future research with a more extended sample could strengthen the findings for women's volleyball.

AUTHOR CONTRIBUTIONS

The concept was initially conceived by S.D., A.F, G.G. and SH. A. The introductory section of the paper was co-authored by R.M. S.D and A.F. SH.A. and G.G. provided support in the literature review, as well as contributing to the writing of the related works. The implementation was carried out by S.D., A. F. and R. M. Data was gathered by A.S. The Results and Analysis phase was conducted by S.D. and SH. A. The research work received proofreading and supervision from S.D, A.F. The final version of the manuscript was reviewed, edited, and approved by all authors.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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BMX: A scoping review of the literature

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ABSTRACT

Background: Bicycle Motocross (BMX) has evolved to cater to different styles of riders, including Flatland, Street, Park, and Dirt. BMX culture is characterised by a unique framework of regulations, guidelines, and principles of which a subculture has a pronounced anti-establishment sentiment and embraced do-it-yourself (DIY) practices, contributing to its distinctive identity within the realm of sport. Formal organisations have emerged, leading to the legitimisation of BMX through events such as the Olympics. To the author's knowledge, this is the first attempt to identify and synthesise all academic publications on BMX and describe the emergence of this research. **Methods:** After adopting the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines 940 studies were identified in the initial search and post screening 87 studies were included. Data was extracted to determine, among other things, the year of publication, methodology adopted, type of BMX and/or BMXers studied, discipline of the study, and focus of inquiry. No date limiter was applied to the search strategy. **Results:** We identified 87 BMX-related articles for analysis, published between 1982 to 2022. The majority of these studies were conducted within the disciplines of biomechanics and physiology/sports science with a primary focus on performance-enhancing techniques within BMX racing. Most studies have emerged from the UK, with both males and females as their gender sample, using quantitative methodology. **Conclusions:** This scoping review identified several trends in the history of BMX research. It also identified important gaps and possible avenues for future research to contribute to academic knowledge in this growing field.

Keywords: Bicycle motocross, Olympic sport, Bike riding, Racing, Freestyle.

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INTRODUCTION

For this scoping review, the researchers looked at a wide range of national and international articles regarding BMX bicycles and those who ride them. Literature included reportage of medical research, studies into bicycle mechanics, types of BMX, the evolution of BMX as a sport, rider performance, the culture of BMX riders, places, and spaces where BMX riding takes place, wellbeing of BMX riders, and creativity as expressed in the realm of BMX.

Bicycle Motocross (BMX) bicycles have evolved to cater to different styles of riders, including Flatland BMX for tricks on flat surfaces, Street BMX for urban stunts, Park BMX for skatepark infrastructure, and Dirt/trail riding for aerial stunts on dirt tracks. Freestyle began when BMX racers looked to fill in time between races by informally competing to perform tricks on their bikes and encourage the creation of new tricks (Edwards & Corte, 2009). Freestyle BMX shares similarities with mountain biking, with adaptations for handling loose substrate and performing jumps (Olsen, 2021). Over time, formal organisations have emerged, leading to the legitimisation of Freestyle BMX through events such as the X-Games and the Olympics. While Olympic inclusion may offer economic and cultural rewards for professional athletes in the BMX community. Nevertheless, Olympic exposure has inspired participation and acceptance, especially among women and families, in what has traditionally been a white male-dominated sport (Olsen, 2021; Ding, 2019).

BMX culture is characterised by a unique framework of regulations, guidelines, and principles that distinguish it from more established and regimented sports. Individuals with cultures such as BMX, *“carve out autonomous space for the development and maintenance of alternative forms of culture alongside, and in interaction with, dominant culture producers”* (Honea, 2014, p. 1272). This subculture has a pronounced anti-establishment sentiment and embraced do-it-yourself (DIY) practices, contributing to its distinctive identity within the realm of sport (Ellmer & Rynne, 2022).

The inclusion of BMX in the Olympics has no doubt changed some perceptions of BMX, including those who do not participate in the activity. Ding (2019) notes that for some riders, inclusion in the Olympics is a way to *“legitimise their sport, generate more public awareness, and create new career promises”* (Ding, 2019, p. 362). Further to this, it seems that the prestige associated with the Olympics *“eclipses the risk of participation. BMX status as an elite sport generates hope among the participants that the family may accept their career choice”* (Ding, 2019, p. 158). Conversely, for others, inclusion in the Olympics means that BMX’s core anti-mainstream values could be lost (Honea, 2014; Wheaton & Thorpe, 2018).

METHODS

A systematic scoping review of literature was conducted to obtain original and peer reviewed articles for appraisal. The current study was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement (Page et al., 2021).

A scoping review can be defined as a type of systematic and synthesised search strategy that can be used to *“map the literature on a particular topic or research area and provides an opportunity to identify key concepts; gaps in the research; and types and sources of evidence to inform practice, policymaking, and research”* (Daudt et al., 2013, p. 8). This review adopted Arksey and O’Malley’s six-stage methodological framework (2005) for conducting scoping reviews. These phases include: (i) identifying the research question; (ii) searching for relevant studies; (iii) selecting studies; (iv) charting the data; (v) collating,

summarising, and reporting results, and (vi) consulting with stakeholders to inform or validate study findings (optional) (Arksey & O'Malley, 2005).

During the first phase, preliminary scoping of literature consistently showed negligible results in attempting to pair BMX with various other constructs such as “*BMX and wellbeing*” or “*BMX and creativity*”. As a result, we broadened our research question considerably, to include an exploration of all academic peer-reviewed publications of BMX from any time, any discipline, and any focus.

The second phase of the framework involved seeking relevant studies; it was conducted via a comprehensive electronic search of five academic journal databases (EBSCOhost, ProQuest, Scopus, Dimensions, and PsycINFO). Once studies were identified, a further search of the reference lists in their corresponding articles was conducted. The literature search was based on as wide a range of concepts involving BMX as possible. The search syntax was endorsed by a liaison librarian at the authors' university and used important keywords in logical combinations. However, all terms were tailored to the thesaurus of each database. Key search terms used in the initial literature search included: “*BMX bikes*”, “*bicycle motocross*”, “*BMX events*”, “*BMX racing*”, “*BMX races*”, “*BMX riding*”, “*field-based bicycle*”, “*BMX riders*”, “*BMX activities*”, “*BMX trails*”, “*BMX street*”, “*BMX stunt*”, “*BMX flatland*”, “*dirt jumping*”, “*extreme sports*”, “*action sport*”, “*informal sport*”, “*street sport*”, “*lifestyle sport*”. For each concept a range of keywords and, where databases permitted, subject headings were used to increase the sensitivity and inclusiveness of the searches. The reviewers considered peer-reviewed articles containing these terms in the title and text.

The third phase involved selecting applicable studies, through designing quality eligibility criteria that were applied to assess the relevance to the research question, firstly to the title and abstract screening process and then to the full text screening stage. Research papers were included if: (i) they were published in an academic journal article; (ii) had undergone a peer review process; (iii) they reported on original research, and (iv) were written in English. Studies were excluded if: (i) they did not contain information on BMX; (ii) they were the wrong publication type e.g., an editorial, thesis, conference proceedings; (iii) they were not original research e.g., a literature review; or (iv) they were written in a language other than English. No publication date range was applied to the search. The eligibility criteria applied to the studies are shown in Table 1.

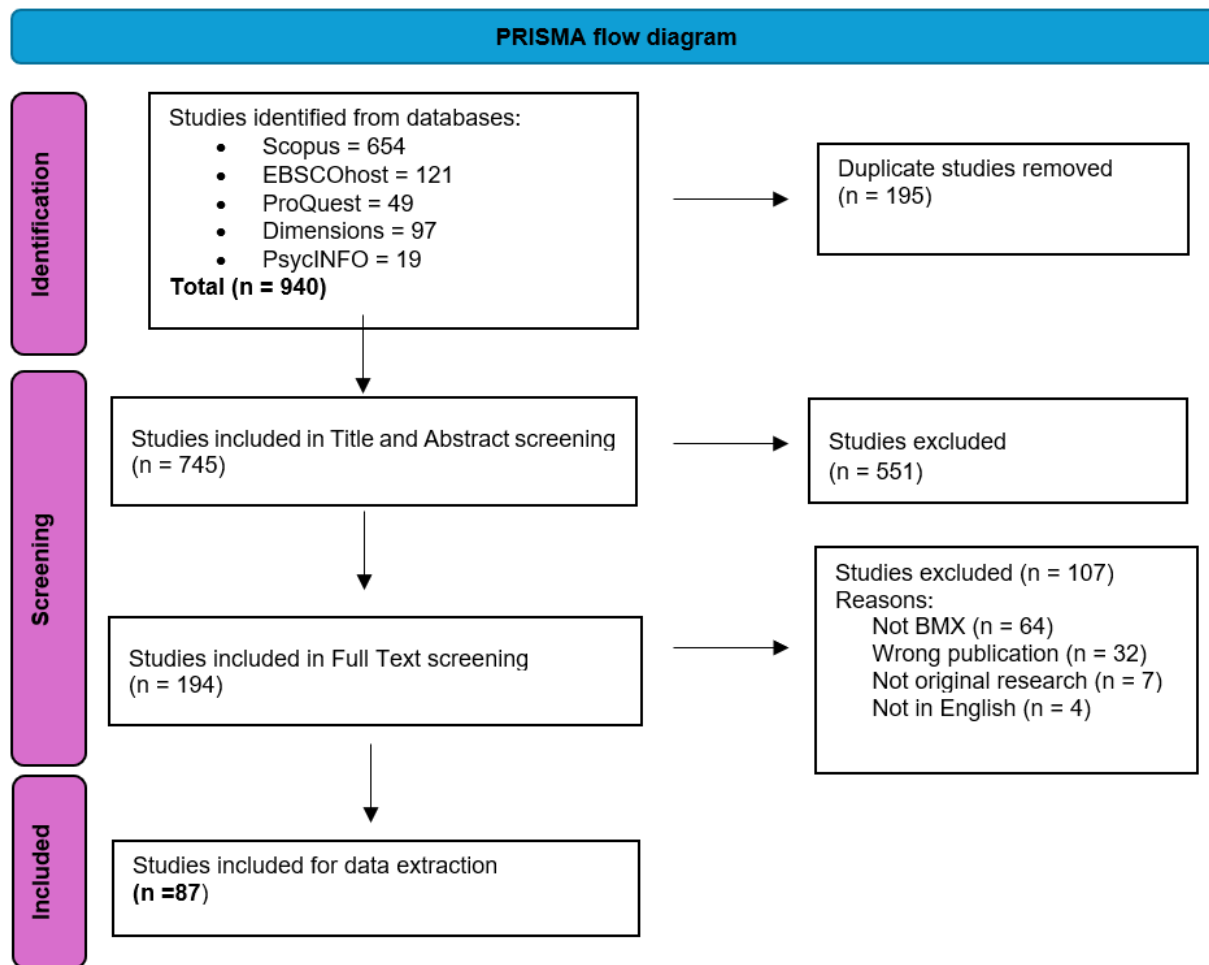
Table 1. Eligibility criteria applied to the research articles.

Eligible/Included	Ineligible/Excluded
About BMX ¹	Does not include BMX
An academic journal article	Not an academic article/paper e.g., editorial, conference proceedings, thesis
Original research	Not original research e.g., literature review
Has undergone a peer-review process	No peer-review is evident
Written in English	Written in a language other than English
Any time period	

Included articles were retrieved, imported, and stored within EndNote X9. Duplicate articles were identified and removed with the EndNote function, and then again manually by one of the review authors conducting a visual inspection to check and confirm duplicates before removal. Remaining articles were imported into the Covidence program, a screening and data extraction tool, where further duplicates were identified and removed.

¹The high initial count is due to research into an enzyme (*Cytoplasmic tyrosine-protein kinase BMX*) that in humans is encoded by the *BMX* gene.

Articles underwent a double-blind screening of title and abstract by six independent researchers. Conflicts were discussed and resolved. Subsequently, full text articles were retrieved to determine whether the eligibility criteria were observed. These articles underwent double-blind screening of the full text by the researchers, again with conflicts discussed and resolved. For both stages of screening, articles were allocated to reviewers randomly by Covidence software and each article was reviewed by two of the researchers. The full review process comprising the number of studies included at each phase is reported with a PRISMA flow chart (Page et al., 2021), (See Figure 1).



Note. Retrieved from: Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., et al. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*, 372, n71. <https://doi.org/10.1136/bmj.n71>

Figure 1. PRISMA flow chart.

Phase four involved charting the data whereby extraction and synthesis took place regarding pre-agreed data characteristics. Data were extracted from the final included articles using Covidence. Extracted data from articles included name of first author, year of publication, article title, journal, country study was conducted, aims, outcomes, study design, methodology, methods, survey instrument used, reliability/validity of instrument, sample, gender, sample size, setting, types of sport analysed, type of BMX analysed, focus of inquiry, discipline of inquiry, key findings, limitations. Data from each article was extracted blindly by two of the researchers and any conflicts were discussed until consensus was reached.

Phase five of Arksey and O'Malley's framework involves collating, summarising, and reporting results which is explained in the following "Results" section.

The sixth phase of Arksey and O'Malley's methodological framework, consulting with stakeholders to inform or validate study findings, is labelled as optional. This phase is designed to provide opportunities for consumer and stakeholder involvement to suggest additional references and provide insights beyond those in the literature. However, engaging consumers and stakeholders was beyond the scope of this review.

RESULTS

This scoping review identified 87 BMX-related articles for inclusion and analysis. The included articles in the scoping review were published between 1982 to 2022, with a significant concentration in the years 2012 and 2021. The majority of these articles were conducted within the disciplines of biomechanics and physiology/sports science. These studies primarily focused on performance-enhancing techniques within BMX racing, with the first emerging in 2008 (Zabala et al., 2008).

In the field of medicine, studies examined the injuries sustained by riders. Among the most common injuries studied were head injuries, abdominal injuries, urological complications such as urethral injuries and testicular calcifications, and musculoskeletal injuries. Over a period spanning 1982 to 1989, six articles were published, all with a focus on various aspects of injury.

The majority of studies regarding BMX have emerged from the United Kingdom (19), followed by the United States (14), Spain (12), Australia (11), France (10), and New Zealand (7). The number of BMX studies by country is depicted in Figure 2. It is important to note that the country refers to where the study took place, not the country of publication. Also of note, the numbers do not add to 100% as some studies took place in multiple countries.

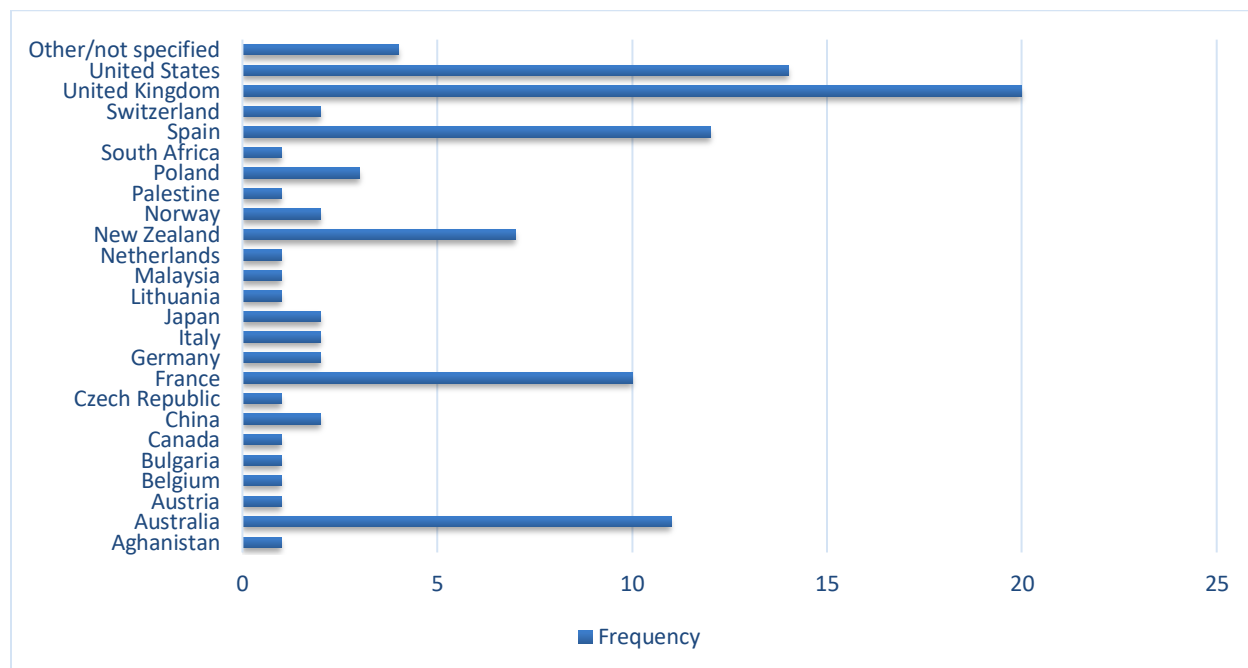


Figure 2. Frequencies of the country of BMX study.

The majority of studies published about BMX had both males and females as their gender sample (39), followed by males only (31), and one study with a focus of a female only sample. The large majority of the type of BMX riding studied was Racing (45), followed by Freestyle (18), with Racing and Freestyle combined (11), and then all other types (13). Table 2 shows the style of BMX studied by gender sample.

Table 2. Type of BMX style by gender sample.

	Type of BMX	Gender				Total
		Male	Female	Female and Male	Other	
	Freestyle	8	0	10	0	18
	Racing	22	1	18	4	45
	Freestyle and Racing	1	0	5	5	11
	Other	1	0	6	6	13
Total		32	1	39	15	87

Quantitative methodology was employed in the majority of BMX studies (48), followed by mixed methods (23), and then qualitative methodology (13), with three studies falling in the Other/Not specified category. The number of studies by methodology adopted is depicted in Figure 3.

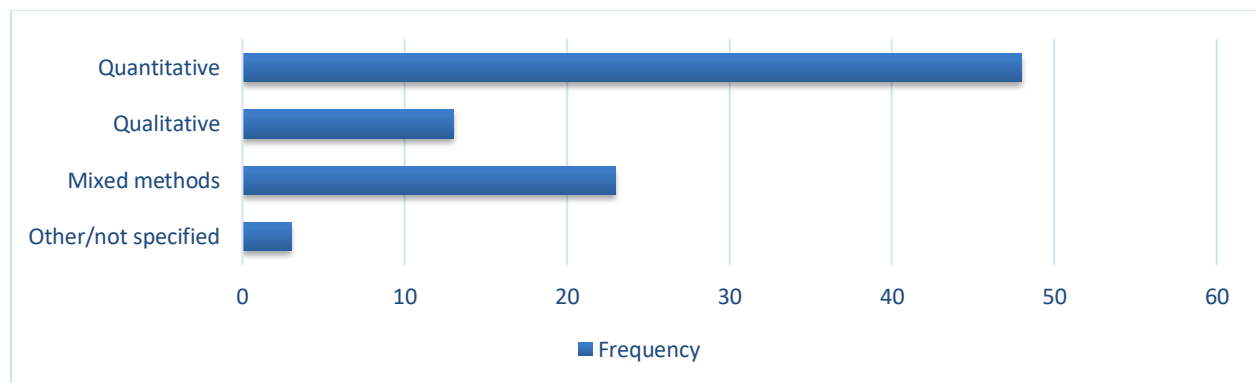


Figure 3. Number of studies by methodology.

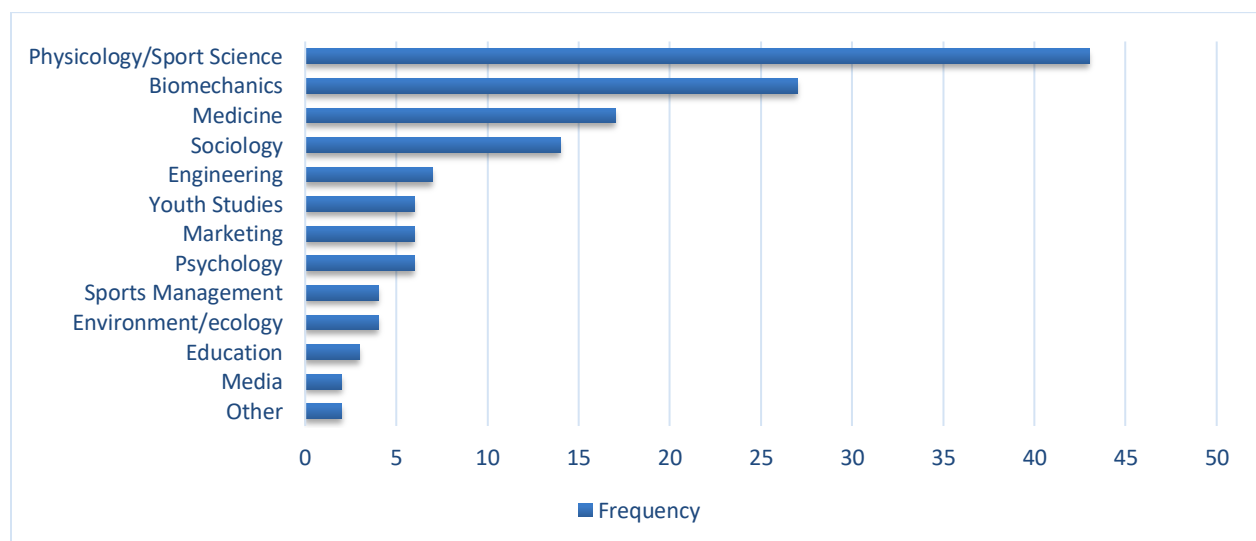


Figure 4. Number of studies by discipline.

From the scoping review it became apparent that BMX research has predominantly emerged from the discipline of physiology/sports science (43), followed by biomechanics (27), medicine (18), sociology (15), engineering (7), with psychology, marketing, and youth studies each producing 6 studies each. Other disciplines that have published BMX content include environment/ecology (4), education (4), sports management (4), and media (2). The number of studies by discipline is displayed in Figure 4. In the figure below the numbers do not add to 100% due to some studies belonging in more than one discipline.

Another key finding of the scoping review is that the focus of inquiry of BMX studies has largely centred around performance (49), followed by injuries (16), equipment such as bikes and helmets (13), risk taking (10), belonging (7), marketing/commercialisation (7) and wellbeing (6). Other focus areas have included tourism (5), creativity (3), media (3), and education (1). The number of BMX studies by focus of inquiry is displayed in Figure 5. In the figure below the numbers do not add to 100% due to some studies including more than one focus of inquiry.

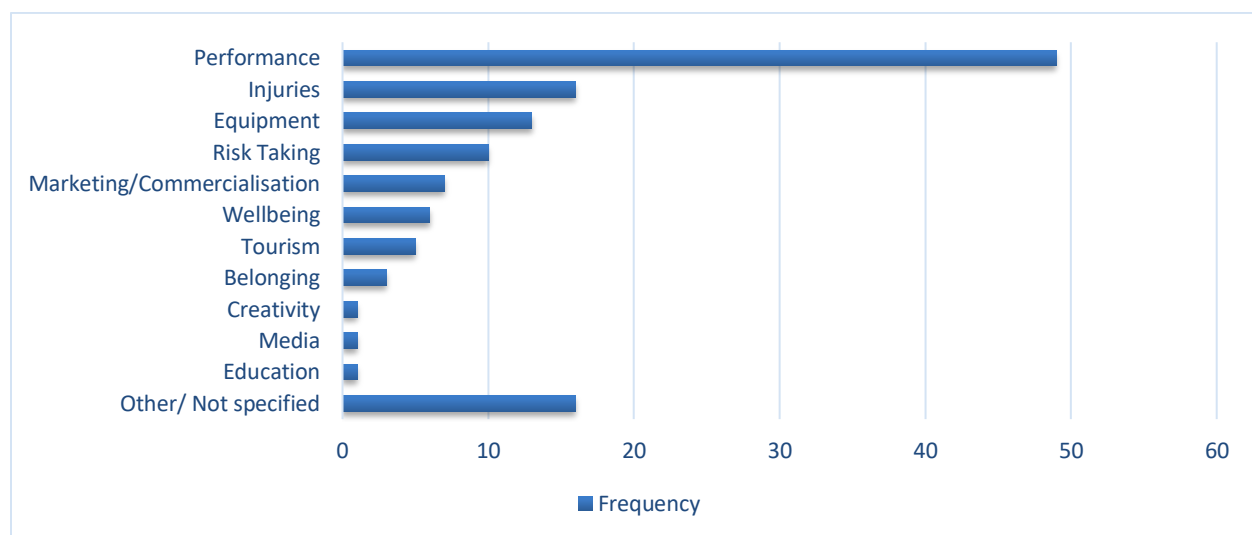


Figure 5. Frequency of focus of inquiry.

The majority of studies about BMX took place at race/test tracks (27), followed by laboratories (16), hospitals (11), specific events (6), and skate/sports parks (3) and [BMX] jumps (3). Other settings included simulations (2), and training sessions (2), with Other/Not specified (16). It is important to note that many settings were not specified in the articles. It should be noted that some studies were conducted in more than one type of setting.

DISCUSSION

To the authors' knowledge, this is the first attempt to identify and synthesise all published academic, peer-reviewed articles on BMX to date. The findings of this scoping review suggest that there has been a limited number of studies conducted over the past 25 years, with momentum increasing from 2008 onwards. The scoping review revealed to us 87 peer reviewed academic studies that have been published and met the criteria we established. For a full list of the 87 included articles, please refer to Supplementary Document 1.

Prior to 2005, BMX was barely studied but gained momentum around 2008. This timing reflects the overall increasing public interest in BMX with BMX racing events being included in the 2008 Beijing Olympics

(Wheaton & Thorpe, 2018). Figure 7 shows the type of BMX studied by year of publication. Later, freestyle was added to the 2021 Tokyo Olympics. Early research about BMX essentially focussed on injury within the BMX riding community, while Reinhart, (2002), was the first peer-reviewed research on BMX and grassroots trails (Rinehart & Grenfell, 2002).

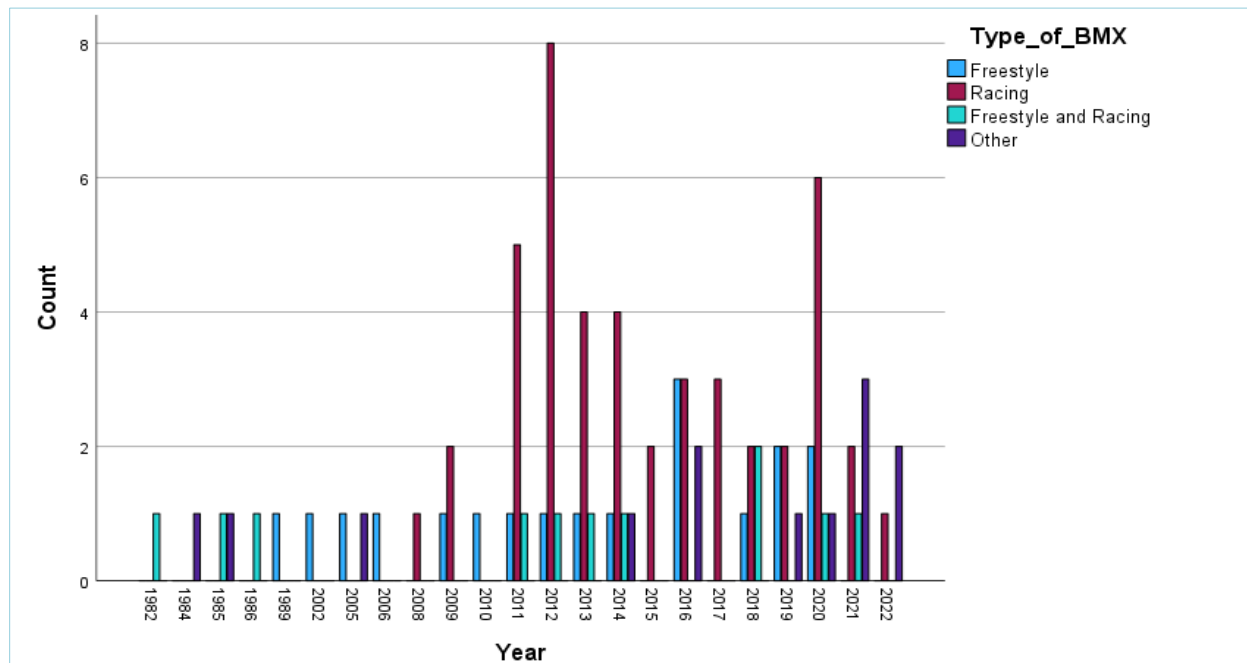


Figure 6: Type of BMX studied by year of publication.

The trends in the data extracted from the articles reveal there is a notable gender disparity in BMX research participation, with males being more represented compared to females and other genders. Wheaton & Thorpe (2018) argue against the suggestion that action sports have provided a more progressive gender equity space than more traditional sex-segregated sport. Instead, they believe this trend is possibly plateauing out as action sports become more institutionalised via Olympic inclusion. Additionally, we argue that this is possibly due to an increase in levels of competition. The exclusion of genders from sport places these groups at greater risk of social exclusion (Fernandez Gavira et al., 2017). As such, there is increasing debate and a growing body of literature around transgender people in competitive sport, particularly concerning any athletic advantages that testosterone levels may or may not give transgender women (Safer, 2022; Harper et al., 2021; Goldbach et al., 2022; Cooper, 2023). This has typically resulted in some transgender people feeling marginalised and having negative experiences when engaging in competitive sport (Jones et al., 2017).

We contend that gender equity in BMX research is important due to the emphasis placed on sport providing positive social outputs (Benitez Silva, 2018) and physical activities that foster a sense of belonging and health for people of all genders (Meredith et al., 2023). The lack of research on females and other genders in BMX highlights potential areas for further investigation into gender inclusivity and equity in BMX. Furthermore, the results underscore the intersectionality of gender identity and BMX participation, highlighting the need for inclusive approaches to promote diversity and equity within the BMX community. Understanding and addressing barriers to participation for underrepresented genders is crucial for fostering an inclusive and welcoming environment within the sport of BMX.

The importance placed on sport and international success may determine the amount of investment (e.g., financially, socially, and through physical infrastructure) a country makes in developing their athletes. For example, De Bosscher et al., (2016) discovered a link between a country's elite sport policy systems and success in international competitions involving social, cultural, and political factors. This includes outlay in financial resources, athletic and post-career support, training facilities, and coach development (De Bosscher et al., 2009). This investment leads to what Grix and Carmichael (2012) term a "virtuous cycle" where international success is rewarded with an increase in participation, which results in a larger pool of people from which to choose the champions of the future (Grix & Carmichael, 2012). Such findings are relevant to the sport of BMX.

Considering the locations of research conducted, the majority of BMX studies have emerged from the United Kingdom (19) and the United States (16), indicating a strong research presence in these countries. This trend likely reflects the historical development of BMX as a sport in these regions and the availability of research infrastructure and funding to support scholarly inquiry. Spain (12), Australia (11), and France (10), have also made substantial contributions to BMX research, suggesting active research communities and institutional support for studying the sport. Interestingly, Rylands & Roberts (2019) found that Europe had produced the highest amount of research on Racing in their scoping review on performance in BMX racing (Rylands & Roberts, 2019). Lastly, New Zealand (7) has contributed a moderate number of studies to the BMX research literature. While these numbers are lower compared to the leading countries, they indicate an engagement with BMX research within their respective academic communities.

The growing interest in BMX studies is evident since the inclusion of the sport in the Olympics. Correspondingly, this is marked by the increase in literature from 2008. With this, there has also been an increase in interest in other dimensions of BMX. With eight studies dedicated to investigating belonging and another eight focusing on wellbeing, and some research has been undertaken to understand the social and psychological aspects of BMX. Research has established the positive effects that various levels of participation in sport has on identity formation, social skills, and positive youth development (Bruner et al., 2017), as well as sense of belonging and subjective wellbeing in adults (Inoue et al., 2020) and general resilience (Soria et al., 2022). This marks a significant shift towards recognising the importance of factors like community cohesion and identity formation within the BMX community. Conversely, hostility towards participants of active sports, of which BMX is one, has been found to develop entrenched feelings of alienation. This generates a "disengagement threshold" whereupon individuals give up striving for acceptance and became disconnected (Brown, 2016). This often leads to creation of sub-cultures and a rejection of mainstream sports and society.

Concurrently, the emergence of seven studies centred on marketing and commercialisation highlights an awareness of BMX's position within the broader sports industry and the economic influences shaping its trajectory. The initial formation of businesses "by riders, for riders" saw enterprises created by grassroots riders in the production of bikes, equipment, and related merchandise. These companies traditionally re-invested back into the community by organising events including exhibitions and contests to build their base of rider customers (Edwards & Corte, 2009). According to Edwards and Corte (2010), the mass commercialisation of freestyle BMX took three forms: paraphernalia, movement, and mass market (Edwards & Corte, 2010), which some riders argue altered the once carefree and highly supportive ethos of early BMX in response to the raised economic stakes (Edwards & Corte, 2009). This train of thought claims that a strong overlay of mass-market commercialisation has decentralised grassroots informal social networks of local lifestyle-sport scenes (Edwards & Corte, 2010). Counter-marketing concerns are now focused on maintaining

the image of spontaneity, unsupervised, “*risky, free, individualistic, and non-conformist character that separates them from mainstream activities*” (Giannoulakis & Pursglove, 2016, p. 128).

There has been a consistent focus on performance since 2008, indicating a sustained interest in understanding and enhancing BMX athletes' performance levels (Ryland & Roberts, 2019). Inclusion into the Olympics has impacted the research agenda relating to BMX, perhaps at the expense of the grassroots level cultures. The predominant focus on performance, with 49 studies, indicates a significant interest in understanding the factors influencing BMX athletes' performance levels. This trend suggests a strong emphasis on factors such as training methods, skill development, and competition strategies and is similar in other extreme sports with a particular burgeoning of literature around mountain biking performance (Chidley et al., 2015; Inoue et al., 2021). Following performance, the focus on injuries (16 studies) highlights a substantial interest in injury prevention and management. This trend underscores a recognition of the physical risks associated with the sport and efforts to mitigate them through research and intervention. Reflecting a focus on safety and technology in BMX, 14 studies concentrated solely on equipment, including bikes and helmets. This trend suggests ongoing efforts to enhance equipment design and promote safety standards within the sport. Finally, research on risk-taking (11 studies) indicates an interest in understanding the psychological and behavioural aspects associated with extreme sports, including risk perception, decision-making, and risk management strategies (Martinkova & Parry, 2017; Willmott & Collins, 2015).

Interestingly, Boudreau et al. (2020) argued that adventure recreation has the potential to provide opportunities to experience flow. They found “*flow experiences can be influenced through immersion in nature and a desire to control and reduce risk*” (Boudreau et al., 2020, p. 1). Mitigating these risks has also become a focus in BMX research (Black et al., 2021).

While the number of studies on wellbeing and injuries fluctuates from year to year, there appears to be periodic spikes in interest, suggesting moments of heightened research activity around these topics. Studies focusing on marketing and commercialisation are present over recent years, reflecting a recognition of BMX's economic significance and the influence of marketing strategies on the sport's development. More broadly, there is growing body of literature sports entrepreneurs (Dobson & McLuskie, 2020) within the fitness sector, albeit BMX has not been a focus in these areas recently. Topics such as media have received relatively less attention compared to performance, equipment, wellbeing, and injuries. However, there are occasional spikes in research activity for these areas, indicating intermittent interest or emerging trends within the BMX research landscape. With the inclusion of BMX in the Olympics, this trend may change.

As reflected by its higher representation in the data, BMX research indicates a predominant focus on racing. This suggests that the majority of research has been directed towards competitive aspects of the sport, such as performance, training, and competition dynamics. The emphasis on performance implies a focus on the professionalisation of BMX, where participants may compete at a high level and have sponsorships or endorsements (Ellmer & Rynne, 2019). The results of this scoping review show limited exploration of grassroots and recreational participation in BMX riding outside of injury. We suggest that further research could include activities such as BMX street riding, park riding, or backyard ramp sessions, and trail riding which may not align with the structured formats of professional BMX competitions. The research emphasis on performance and competition possibly reflects the interests of researchers and funding priorities aimed at success at the Olympics.

The majority of BMX studies (48) have employed quantitative data collection and analysis methods. This reflects a strong preference for data-driven approaches, statistical analysis, and numerical measurements

within BMX research. Following quantitative methodology, mixed methods have been employed in a significant number of BMX studies (23), indicating a recognition of the value of combining qualitative and quantitative approaches to provide a more comprehensive and deeper understanding of BMX phenomena. Qualitative methods have been employed in a smaller but still substantial number of BMX studies (16). This indicates a need for more qualitative approaches to exploring the nuanced psychosocial aspects of BMX culture, identity formation, and social interactions. Based on the findings of systematic review of research on BMX Racing, Rylands and Roberts (2019) recommend “*ecological research designs which places an emphasis on the interactions of the rider in their natural environment where actions are viewed as interconnected rather than separate*” (Rylands & Roberts, 2019, p. 8). While they are referring to research on performance, the results of the current review also shows this need for more multidimensional studies investigating BMX.

This scoping review found that the predominant focus of research has been on aspects related to quantitative studies of performance within the BMX riding community. However, what has also emerged is that there has been relatively limited attention given to broader themes such as rider wellbeing, creativity, and participation at a grassroots level. Echoing Rylands & Roberts (2019) call to include psychological factors such as coping skills, confidence, determination, we suggest there is a gap in the existing research literature, highlighting the need for further exploration of these neglected areas to provide a more comprehensive understanding of the BMX culture and its impact on riders' overall experiences and outcomes.

Limitations

The following limitations of this scoping review need to be acknowledged. Only articles written in English were included. Thus, it is possible that important articles on BMX have been published in languages other than English. Only peer reviewed journal articles were in scope and so the findings contained within book chapters, opinion pieces or grey literature have not formed part of our findings.

CONCLUSION

In conclusion, this scoping review has provided a comprehensive overview of the existing literature on BMX, revealing key trends, gaps, and potential areas for future research. The review has highlighted a predominant focus on performance and competition, reflecting the sport's evolution and increasing institutionalisation with its inclusion in the Olympic games. However, it has also underscored the need for more research on underrepresented areas such as gender equity, social and psychological aspects, and the cultural and economic significance of BMX, particularly in relation to socio-cultural aspects of this new Olympic sport.

The review has further revealed a strong research presence in countries such as the United Kingdom and the United States, with emerging contributions from Spain, Australia, France, and New Zealand. The majority of studies have employed quantitative methodologies, indicating a preference for data-driven approaches. However, there is a growing recognition of the value of mixed methods and qualitative approaches for exploring the nuanced aspects of BMX culture and social interactions.

Moving forward, it is crucial to address the identified gaps and diversify research approaches to foster a more inclusive, equitable, and comprehensive understanding of BMX. This includes incorporating more research on female riders, informal BMX riding styles such as trails and freestyle, and social and behavioural aspects of BMX riding from Humanities based disciplines. There is also a need for more qualitative research to gain a deeper understanding of the lived experiences of BMX riders, this also applies to high level athletes.

Addressing these gaps will not only contribute to the academic discourse but also inform policy and practice, ultimately enhancing the sport's positive social outputs and the wellbeing of its diverse community of riders.

AUTHOR CONTRIBUTIONS

Camilleri, D., lead researcher – screening texts, drafting, writing. Williams, R., screening texts, drafting, writing. Sallis, R. J. T., screening texts, drafting, writing. Hyde, C. L., screening texts. Quach, J. L., screening texts.

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Machine learning analysis for predicting performance in female volleyball players in India: Implications for talent identification and player development strategies

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ABSTRACT

Talent identification and player development are crucial aspects of sports management, particularly in volleyball, where understanding players' performance predictors is essential. The primary objective is to investigate the relationships between players' demographic and physical attributes and their on-court performance, providing valuable insights for talent identification and player development strategies. The dataset comprises demographic and physical attributes alongside performance metrics of college-level female volleyball players in India. Data were meticulously collected from various institutions participating in volleyball tournaments across India. Three machine learning algorithms—linear regression, random forest regression, and XGBoost regression—were trained using the pre-processed dataset. Standard regression evaluation metrics such as mean squared error (MSE), root mean squared error (RMSE), and R-squared (R^2) score were used to assess model performance. Random forest regression emerged as the top-performing ML technique, achieving a prediction accuracy of 94.18%, followed by XGBoost regression with 92.76%. Height, muscle mass, and bone mass exhibited strong positive correlations with performance prediction, emphasizing their significance. This study highlights ML techniques' potential, particularly random forest regression, in improving talent identification and performance prediction in college-level female volleyball players in India.

Keywords: Performance analysis, Volleyball, Performance prediction, Machine learning, Physical attributes, Talent identification.

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INTRODUCTION

Volleyball has emerged as a sport of significant interest and participation worldwide, including in India, where it is particularly popular at the college level. Globally, volleyball is not only a recreational activity but also a competitive sport that fosters community and athletic excellence (Koley, 2011; Alvares et al., 2023). College-level tournaments serve as crucial breeding grounds for budding talent, providing young athletes with platforms to hone their skills and showcase their potential (Tiaprapong & Tiaprapong, 2022). Identifying and nurturing promising players is essential for the sustained growth and success of volleyball. However, traditional talent identification methods often rely on subjective evaluations, which can overlook hidden talents or misjudge player capabilities, leading to missed opportunities for player development and hindering the overall progress of the sport (Śliwa et al., 2021; Römer et al., 2023). The significance of effective talent identification extends beyond India and is a global concern in the sports community. Various authors have highlighted the limitations of conventional evaluation techniques across different sports, emphasizing the need for more objective, data-driven approaches to better assess and predict athletic performance. Inaccurate assessments can result in the loss of potential elite athletes and impede the development of the sport on a broader scale (Kapadia et al., 2022; Sumathi et al., 2023).

Machine learning (ML) techniques offer a promising solution by providing a data-driven approach to talent evaluation and performance prediction. By analysing historical data, ML models can make objective assessments of player capabilities, potentially revolutionizing talent identification processes. Despite the widespread use of ML in sports such as football, basketball, and cricket for talent identification and performance prediction, its application in volleyball remains relatively underexplored, especially at the college level (Bunker & Thabtah, 2019; Passi & Pandey, 2018). This study aims to address this gap by investigating the effectiveness of ML techniques in predicting the future performance of college-level female volleyball players globally, with a focus on India as a case study (Van Eetvelde et al., 2021; Baboota & Kaur, 2019). This research will explore the use of three main ML techniques: linear regression, random forest regression, and XGBoost regression. These techniques are chosen for their versatility, interpretability, and ability to manage both numerical and categorical data. By analysing past performance metrics, physical attributes, and other relevant factors, these ML models can provide valuable insights into the future potential of players (de Leeuw et al., 2022; Ju & Zhang, 2023). The primary objective of this research is to obtain new knowledge regarding the application of ML in volleyball talent identification and performance prediction (Śliwa et al., 2021; Abebe et al., 2020).

MATERIALS AND METHODS

Participants

The dataset for this study encompasses demographic and physical attributes of 174 college-level female volleyball players aged between 18 and 25 years in India, along with performance metrics recorded during matches or training sessions. The data were collected from various colleges and institutions participating in volleyball tournaments across different regions of India. Attributes such as age, height, weight, body fat percentage, fat mass, muscle mass, bone mass, BMI, and performance indicators were meticulously recorded for each player.

Procedures

The dataset underwent preprocessing to ensure data quality and consistency, including handling missing values, outliers, and data normalization for feature scaling (Figure 1). Categorical variables were encoded as numerical values if applicable. Three machine learning algorithms—linear regression, random forest

regression, and XGBoost regression—were implemented to predict the performance of college-level female volleyball players based on their demographic and physical attributes (Baboota & Kaur, 2019; Hu et al., 2022). Each algorithm was trained using the pre-processed dataset, with performance metrics serving as the target variable. Model evaluation was conducted using cross-validation techniques to assess predictive accuracy and generalization ability (Miguel-Ortega et al., 2023; Hudnurkar & Rayavarapu, 2022).

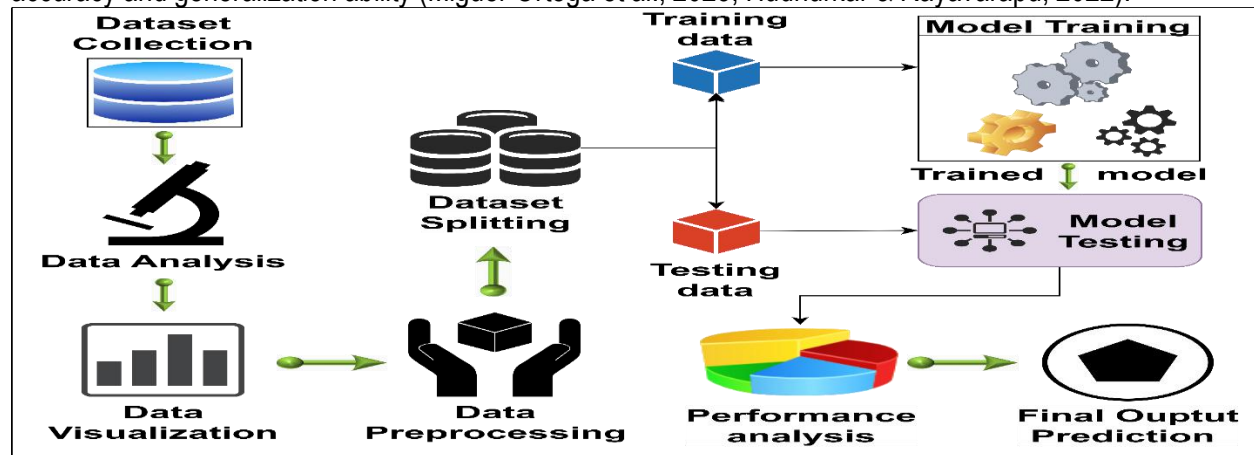


Figure 1. Diagram that represents the data processing architecture.

Statistical analysis

The performance of each model was evaluated using standard regression evaluation metrics such as mean squared error (MSE), root mean squared error (RMSE), mean absolute error (MAE), and R-squared. These metrics provide insights into the models' ability to accurately predict player performance based on the input features. Statistical tests, such as Pearson correlation analysis, were performed to examine the relationships between demographic and physical attributes and player performance (Lakshmi et al., 2024; Sanjaykumar et al., 2024). This analysis helps in identifying significant predictors and understanding the underlying patterns in the data.

RESULTS

Table 1 presents a sample dataset of college-level female volleyball players in India, showcasing their demographic and physical attributes, including age, height, weight, body fat percentage, fat mass, muscle mass, bone mass, BMI, and performance prediction (PP). These attributes provide insights into the characteristics of the participants in the study.

Table 1. Sample dataset of college-level female volleyball players in India.

Number of participants (n = 174)	Age (years)	Height (cm)	Weight (kg)	Fat (%)	Fat mass (kg)	Muscle mass (kg)	Bone mass (kg)	BMI (kg/m ²)	PP (%)
32	19	170	85.2	28.8	30.3	65.6	3.3	28.9	78
54	20	178	83.8	28.4	36.3	64.9	3.9	26.1	81
37	21	185	85.2	22.3	19	62.8	3.4	23.3	85
34	22	172	88	30.3	39	67.3	3.7	31.9	73
17	23	185	80.8	21.6	20.3	59	3.5	21.5	91

Note. cm = centimetre, kg = kilograms, % = percentage, m = meter.

Table 2. Performance comparison of machine learning algorithms for predicting volleyball player performance.

Algorithm	Mean Squared Error (MSE)	R-squared Score	Root Mean Squared Error (RMSE)
Linear Regression	30.3207	0.7531	5.5064
Random Forest	7.1505	0.9418	2.6740
XGBoost	8.8876	0.9276	2.9812

Performance prediction based on Linear Regression model

The linear regression model offers a reasonable approach to predicting the performance of college-level female volleyball players in India, with an achieved prediction accuracy of 75.31%. While the model provides a foundation for understanding the relationship between input features and player performance. With a moderate R-squared score of 0.7531, the model explains approximately 75.31% of the variability in player performance. However, the relatively high Mean Squared Error (MSE) of 30.3207 and Root Mean Squared Error (RMSE) of 5.5064 suggest notable prediction errors (Table 2). Despite its limitations, linear regression can still offer valuable insights into player performance, serving as a baseline for more sophisticated modelling techniques. Figure 2 illustrates the graphical representation of the linear regression model used to predict volleyball players' performance. The plot showcases the relationship between the players' demographic and physical attributes and their overall performance scores, providing insights into the predictive capability of the model.

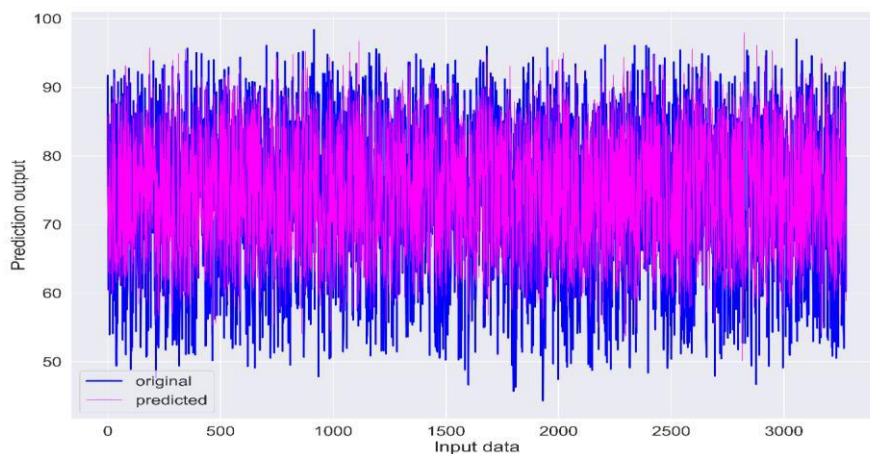


Figure 2. The linear regression model's graphical representation for predicting volleyball players' performance, the graph shows the model's predictions (pink) against input data (blue).

Performance prediction based on Random Forest Regression model

Random forest regression emerges as a highly effective approach for predicting the performance of college-level female volleyball players in India, boasting an impressive prediction accuracy of 94.18%. The model achieves a significantly lower Mean Squared Error (MSE) of 7.1505 and a high R-squared score of 0.9418, indicating its capability to explain approximately 94.18% of the variability in player performance. With a Root Mean Squared Error (RMSE) of 2.6740, the model's prediction errors are notably reduced compared to linear regression (Table 2). The ensemble nature of random forest regression, combining multiple decision trees, allows it to capture complex relationships within the data effectively. This robust performance makes random forest regression a valuable tool for talent identification and player development in the realm of volleyball. Figure 3 illustrates the graphical representation of the Random Forest Regression model used to predict

volleyball players' performance. The plot showcases the relationship between the players' demographic and physical attributes and their overall performance scores, providing insights into the predictive capability of the model.

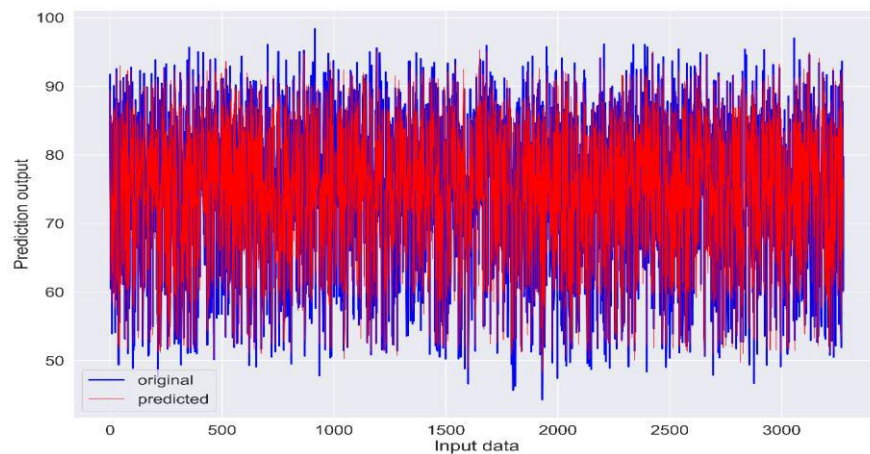


Figure 3. The random forest model's graphical representation for predicting volleyball players' performance, the graph shows the model's predictions (red) against input data (blue).

Performance prediction based on XGBoost Regression model

XGBoost regression emerges as a formidable contender in predicting the performance of college-level female volleyball players in India, achieving a prediction accuracy of 92.76%. With a relatively low Mean Squared Error (MSE) of 8.8876 and a high R-squared score of 0.9276, the model explains approximately 92.76% of the variability in player performance. The Root Mean Squared Error (RMSE) of 2.9812 indicates a reduced average prediction error compared to linear regression (Table 2). XGBoost's gradient boosting framework enables sequential learning, allowing the model to capture intricate patterns in the data and make accurate predictions. Despite slight differences in performance compared to random forest regression, XGBoost regression remains a powerful tool for talent identification and player development initiatives in volleyball. Figure 4 the graphical representation of the XGBoost Regression model for predicting volleyball players' performance. It highlights the relationship between players' attributes and performance scores, offering insights into the model's predictive capability.

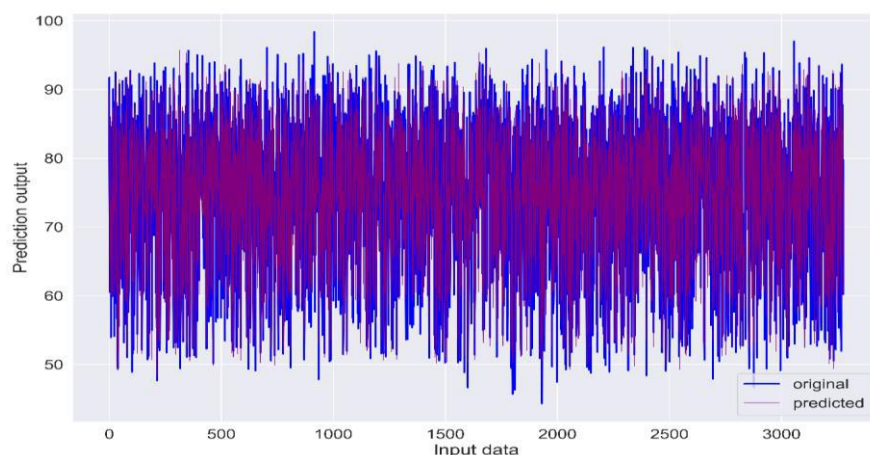


Figure 4. The XGBoost regression model's graphical representation for predicting volleyball players' performance, the graph shows the model's predictions (maroon) against input data (blue).

Table 3. Pearson correlation matrix for attributes and performance prediction.

Attribute	Age	Height	Weight	Fat	Fat mass	Muscle mass	Bone Mass	BMI	Performance Prediction
Age (year)	1	0.1151	0.4054	0.4759	0.4184	0.2644	0.2697	0.3881	0.2771
Height (cm)	0.1151	1	0.1245	-0.1091	-0.0381	0.5588	0.5332	-0.2217	0.8790
Weight (kg)	0.4054	0.1245	1	0.9358	0.9784	0.8052	0.8178	0.9383	0.3379
Fat (%)	0.4759	-0.1091	0.9358	1	0.9768	0.5778	0.5969	0.9627	0.1711
Fat mass (kg)	0.4184	-0.0381	0.9784	0.976	1	0.6650	0.6835	0.9737	0.1982
Muscle mass (kg)	0.2644	0.5588	0.8052	0.5778	0.6650	1	0.9920	0.5960	0.6525
Bone Mass (kg)	0.2697	0.5332	0.8178	0.5969	0.6835	0.9920	1	0.6166	0.6222
BMI (kg/m ²)	0.3881	-0.2217	0.9383	0.9627	0.9737	0.5960	0.6166	1	0.0416
Performance Prediction (%)	0.2771	0.8790	0.3379	0.1711	0.1982	0.6525	0.6222	0.0416	1

Note. cm = centimetres, kg = kilograms, % = percentage, BMI = Body Mass Index, kg/m² = kilograms/meters square.

The results indicate that several physical attributes are significantly correlated with performance prediction. Height shows a strong positive correlation (0.8790, $p < .001$) with performance prediction, suggesting that taller players tend to perform better. Muscle mass (0.6525, $p < .001$) and bone mass (0.6222, $p < .001$) also exhibit strong positive correlations with performance prediction, indicating their importance in evaluating player performance. Attributes such as age and BMI show weaker correlations with performance prediction, with BMI exhibiting a non-significant correlation (0.0416, $p = .5857$). This suggests that while BMI might not significantly impact performance prediction, other factors like height, muscle mass, and bone mass are crucial (Table 3).

DISCUSSION

The present study aimed to utilize machine learning (ML) algorithms to predict the performance of college-level female volleyball players in India by considering a range of demographic and physical attributes. The research question posited whether ML models could enhance the accuracy and objectivity of talent evaluations compared to traditional methods (Abebe et al., 2020; Borowiec et al., 2023).

The results indicate that all three ML models—linear regression, random forest regression, and XGBoost regression—demonstrate varying degrees of predictive efficacy. Specifically, random forest regression emerged as the top performer, achieving an impressive prediction accuracy of 94.18%, as evidenced by its high R-squared score of 0.9418 and low Mean Squared Error (MSE) of 7.1505. This model's ensemble nature, which combines multiple decision trees, effectively captures complex relationships within the data, making it particularly suited for predicting volleyball player performance (Bai & Bai, 2021). The hypothesis that ML models can significantly enhance the accuracy of talent evaluations is confirmed by these results. The random forest regression model, in particular, significantly outperforms linear regression, which achieved a moderate prediction accuracy of 75.31%, with a higher MSE of 30.3207 and an R-squared score of 0.7531. XGBoost regression also performed well, with a prediction accuracy of 92.76%, demonstrating its capacity to capture intricate data patterns, although slightly less effectively than random forest regression (Alvares et al., 2023). The Pearson correlation analysis provided valuable insights into the relationships between physical attributes and performance prediction. Height demonstrated a strong positive correlation (0.8790, $p < .001$) with performance prediction, indicating that taller players tend to perform better. This finding is consistent with the established understanding that height can be a critical factor in volleyball, affecting a player's ability to spike, block, and reach. Muscle mass (0.6525, $p < .001$) and bone mass (0.6222, $p < .001$) also showed strong positive correlations with performance prediction. These attributes are indicative of

physical strength and endurance, which are essential for powerful plays and sustained performance throughout a match. The strong correlations highlight the importance of these physical characteristics in evaluating volleyball players. On the other hand, attributes such as age and BMI exhibited weaker correlations with performance prediction. Specifically, BMI had a non-significant correlation (0.0416, $p = .5857$), suggesting it might not be a reliable predictor of performance. This may be due to BMI's inability to differentiate between muscle and fat mass, which are crucial in athletic performance contexts (Römer et al., 2023; Miguel-Ortega et al., 2023). However, it is crucial to acknowledge that these models focused solely on these attributes, potentially overlooking other critical factors such as skill level, experience, and psychological aspects, which could further enhance prediction accuracy. The study successfully demonstrates the potential of ML techniques in improving talent identification and performance prediction in volleyball. By providing a data-driven approach, ML models, particularly random forest regression, can offer valuable insights for coaches, scouts, and policymakers in the volleyball community. Future research should aim to incorporate a broader range of variables, including skill and psychological factors, and explore the applicability of these techniques across different demographics and levels of competition to generalize these findings further (Sanjaykumar et al., 2024; López-Serrano et al., 2024; Šuštaršič et al., 2022).

CONCLUSIONS

This study showcases the potential of machine learning techniques, particularly random forest regression, in enhancing talent identification and performance prediction in college-level female volleyball players in India. The results demonstrate that physical attributes such as height, muscle mass, and bone mass play significant roles in predicting player performance. While traditional methods rely on subjective evaluations, the application of data-driven approaches offers more accurate and objective insights. Future research should focus on incorporating additional variables, including skill level and psychological factors, to further refine predictive models and generalize findings across diverse demographics and competition levels, ultimately advancing talent development in volleyball.

AUTHOR CONTRIBUTIONS

Swamynathan Sanjaykumar: conceptualization, methodology, investigation, resources, writing-review & editing, supervision, writing-original draft and final approval the manuscript. Subhashree Natarajan: resources, formal analysis, data curation and collection, supervision and final approval the manuscript. Ponnusamy Yoga Lakshmi: methodology, formal analysis, data curation and collection, writing-review & editing and final approval the manuscript. Yuliya Kalmykova: writing-review & editing, validation, supervision and final approval the manuscript. Joseph Lobo: formal analysis, supervision and final approval the manuscript. Ratko Pavlović: writing-review & editing, formal analysis, and final approval the manuscript. Edi Setiawan: Validation, formal analysis, and final approval the manuscript.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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Optimizing performance with a 1-minute high-intensity re-warm up protocol in basketball substitutes

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ABSTRACT

The aim of the study was to investigate whether a 1-minute high-intensity Re-Warm Up (RWU) protocol on a cycle ergometer could attenuate the negative effects of passive rest on basketball players' performance. Twelve semi-professional players completed two trials on consecutive days in a counterbalanced, randomized design with repeated measures. Following a structured warm-up (WU), the trials included: a) 15 minutes of passive rest (CON) and b) 13 minutes of passive rest, followed by 1 minute of cycling at 80% VO_{2max} and 1 minute of rest (RWU80). Post-WU and post-RWU measurements included countermovement jump (CMJ), modified agility t-test (MAT), heart rate (HR), body temperature (BT), rating of perceived exertion (RPE), and perceived readiness rating (PRR). CON group showed significant decreases in all variables, while RWU80 attenuated these losses in HR ($p = .127$), RPE ($p = .058$) and PRR ($p = .236$). Between the two post-RWU measurements, the RWU80 showed significantly improved results in MAT ($p = .05$) and HR ($p < .001$) and higher RPE ($p = .002$). Although statistically significant differences did not appear in all variables, the RWU80 led to greater readiness of the substitute players to enter the game compared to the 15 minutes of passive rest.

Keywords: Performance analysis, Basketball, Re-warm up, Body temperature, Sport performance, Countermovement jump, Modified agility t-test.

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INTRODUCTION

Warm-up (WU) routines play a crucial role in enhancing subsequent performance in both training and athletic competitions (Sumartiningasih et al., 2022). These routines aim to raise muscle temperature which is associated with improved jump height (Krčmár et al., 2016), enhanced range of motion (Bleakley & Costello, 2013) and sprint performance (De Sousa et al., 2018). Basketball teams apply different warm-up routines to optimize the sport performance (De Sousa et al., 2018) and mitigate the risk of sport-related injuries (Ding et al., 2022) of the athletes. The performance boost resulting from WU is often attributed to temperature-related mechanisms (McGowan et al., 2015), which in general enhance neuromuscular function (Lovell et al., 2007).

However, prolonged periods of rest for players seem to lead to decreases in performance. Halftime (HT) passive recovery negatively impacts second-half repeated-sprint ability in team sports (Russell et al., 2015). Inadequate player preparation diminishes game tempo, affecting their competitive advantage (Mohr et al., 2004). HT passive recovery results in 1.1°C and 2.0°C reductions in core and muscle temperatures (Mohr et al., 2004). In a later study, core temperature dropped by $0.97 \pm 0.29^\circ\text{C}$ at HT (Lovell et al., 2007). VO_2 levels return to rest within approximately 5 minutes (Özyener et al., 2001). Galazoulas et al. (2012) found that a 10-minute bench rest led to decreased countermovement jump (CMJ) (13%) and 20m sprint performance (4%), with a more pronounced decrease after a 40-minute rest (20% and 6%, respectively). Re-warm up (RWU) strategies have been proposed to protect against physiological changes and performance decreases induced by passive recovery during HT (Russell et al., 2015; Hammami et al., 2018; Silva et al., 2018; González-Devesa et al., 2021; Koutsouridis et al., 2023).

Passive rest during basketball games could reduce athletes' performance and increase the risk of injury during the second half of the game due to loss of muscle temperature (González-Devesa et al., 2023). However, passive rest in basketball does not only exist during HT, but also during the game for substitute players. The time spent seated for the bench players can exceed 15 minutes (Alberti et al., 2014).

To our knowledge, only two researches have been conducted during a basketball game. In the study of Alberti et al. (2014), participants engaged in various seated activities (sitting, seated foot tapping, seated lower back mobilization), resulting an 8.48% reduction in jump height for all seated players after 20 minutes. However, 2-min activity is nearly sufficient to recover post-WU performance levels. In a recent study, Koutsouridis et al., (2024) found that a 3-min moderate-intensity RWU protocol performed on a cycle ergometer may diminish the negative effects of a 15-min passive rest on players' athletic performance.

Due to the lack of research on RWU protocols during basketball games, restrictions imposed by FIBA rules (2023) that prohibit any standing RWU activities during games, and the need for a shorter protocol than the one proposed by Koutsouridis et al. (2024), it is crucial to explore different RWU protocols with varying durations and intensities. Therefore, this study aimed to determine if a 1-minute high-intensity RWU protocol on a cycle ergometer could counteract the negative effects of passive rest on basketball players' physical abilities.

MATERIALS AND METHODS

Participants

The sample size for this study was determined using G*power 3.1 software, taking into account data from a previous study (Koutsouridis et al., 2024) that investigated the impact of a moderate-intensity cycling RWU on subsequent athletic performance. Utilizing an effect size (ES) of 1.0, an α -level of .05 and a power of 0.8

(Yanaoka et al., 2021), the analysis indicated that a minimum of 10 participants was required. The study involved 12 semi-professional basketball players, with an average age of 20.33 years (± 1.30), whose characteristics are presented in Table 1. All participants signed a consent form after receiving clarifications about the aim, procedures and potential hazards of the study. All procedures were performed in accordance with the code of the local ethics committee and the Helsinki declaration.

Table 1. Characteristics of the participants (mean \pm SD).

	Min	Max	Mean	Std. Deviation
Age (years)	19	22	20.33	1.303
Training age	3	13	9.50	2.939
Trainings per week	2	6	3.75	1.215
Body Mass (kg)	70.8	90.5	82.18	5.887
Height (cm)	174.0	195.0	183.86	6.515
BMI (kg/m ²)	21.80	28.77	24.37	2.184
Body fat (%)	5.51	22.43	12.64	4.681
VO _{2max}	36.48	60.29	49.93	5.834
WATTmax	224	320	292.00	26.751
7.5% of BM (kg)	5.31	6.79	6.16	.442
Resting HR (bpm)	54	91	73.50	11.890

Note. BMI = Body Mass Index, bpm= beats per minute, HR = Heart Rate, VO_{2max} = Maximum Oxygen Uptake.

Experimental design

Participants completed two experimental sessions using a counterbalanced, randomized order and a repeated measures design, preceded by an initial visit for the assessment of their maximum oxygen uptake (VO_{2max}). The athletes performed a standard basketball WU and then engaged in one of two protocols. The first protocol involved 15 minutes of passive rest (CON), while the second consisted of 13 minutes of passive rest, 1 minute of cycling at 80% of VO_{2max} and 1 minute of recovery (RWU80). Variables were assessed at two time points: after the warm-up (post-WU) and after the RWU protocol (post-RWU). The variables were CMJ, Modified Agility T-test (MAT), HR, body temperature (BT), perceived exertion (RPE) and perceived readiness rating (PRR). The study's design is presented in Figure 1.

Participants were instructed to maintain their regular lifestyle, exercise and diet during the study. They recorded all meals and drinks consumed the day before each trial, replicating the same dietary intake in subsequent trials to ensure consistency. Alcohol and caffeine were avoided 24 hours before each experimental session. During the study, players had access to water *ad libitum*.

	25-min	5-min	15-min	5-min
CON	General WU, Stretching, Specific WU	RPE, PRR, HR, BT, CMJ, MAT	Rest	RPE, PRR, HR, BT, CMJ, MAT
RWU80	General WU, Stretching, Specific WU	RPE, PRR, HR, BT, CMJ, MAT	13-min rest + 1-min cy- cling at 80% VO _{2max} + 1-min rest	RPE, PRR, HR, BT, CMJ, MAT

Figure 1. Summary of the study design.

Procedures

Participants received detailed instructions one week before conducting the study. Preliminary measurements (mass, height, body fat percentage, VO_{2max}) were performed during this period. Additionally, participants underwent multiple trials to familiarize themselves with the test procedures. Subsequently, the measurements were conducted on two separate days with a 48-hour difference. To minimize circadian effects, all measurements for each athlete were taken at the same time of day, with a maximum 15-minute difference. The average temperature and humidity in the indoor basketball court were $18.2^{\circ}C \pm 1.3^{\circ}C$ and $43.2\% \pm 8.5\%$, respectively.

The athletes were randomly divided into two groups. On the first day, one group executed the CON condition and the other group the RWU80, while on the second day the opposite. At the beginning of each day, athletes underwent a typical basketball WU, as in Galazoulas et al., (2012). Subsequently, they underwent post-WU measurements to assess their optimal performance. Afterward, they followed one of the two protocols and then underwent the same measurements again (post-RWU).

Measurements

VO_{2max} was assessed through a graded exercise test on a cycle ergometer, with participants maintaining a consistent cycling cadence of 80 revolutions per minute (rpm). The protocol began with a workload of 1.2 kg (96W) for 3 minutes, followed by an increase to 1.9 kg (152W) for an additional 3 minutes. Workload continued to increase by 0.3 kg per minute until voluntary exhaustion. Oxygen uptake (VO_2) was measured breath-by-breath using an automatic gas analyser (AE-310s, Minato Medical Science, Japan), averaged over 15-second intervals. VO_{2max} was calculated when two of the following three conditions were met: 1) VO_2 levelling off, 2) HR exceeding 90% of the maximum rate ($220 - \text{age}$), and 3) respiratory exchange ratio exceeding 1.05.

Body temperature was assessed using an infrared ear thermometer (TotiFar CT-30DX, OST, Jsinchu, Taiwan), as in the study by Galazoulas et al., (2012). HR data was collected utilizing the Polar Team Pro system (Kempele, Finland). Heart rate was collected at three time points for all participants (pre-WU, post-WU, post-RWU) through a transmitter worn by the athletes on a chest strap.

The CMJ was implemented for assessing participants' vertical jump and leg explosive power. Athletes performed three consecutive CMJ with an interval of 30 seconds. The OptojumpTM system (Microgate, Bolzano, Italy) was utilized for the recording the jumps and the highest jump was used for analysis. A Pearson correlation analysis revealed robust consistency across the three CMJ measurements ($r > 0.945$), showing a high level of measurement reliability.

MAT was chosen to assess athletes' performance, focusing on power-related physical abilities. The MAT evaluates multidirectional power expression, aligning well with basketball's dynamic movement patterns involving rapid changes in direction across various planes (Scanlan et al., 2021). All trials were timed with the 0.001s precision Witty photocell system (Microgate, Bolzano, Italy). The test procedure followed the format described in Scanlan et al., (2021). Participants performed the test once, as repeating the test would affect the acute effects of the RWU protocol.

Perceived exertion was evaluated through the 10-point scale of Borg (1982), while perceived readiness was assessed using Karu et al.'s (2000) 5-point scale.

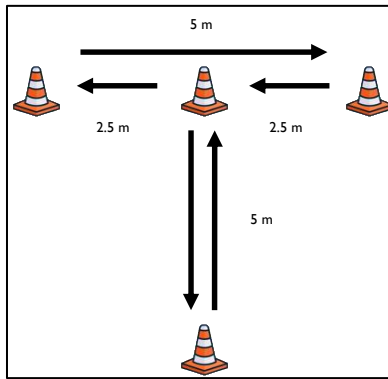


Figure 2. Modified Agility T-test.

Statistical analysis

The statistical analysis was performed utilizing SPSS computer software (version 28.0, SPSS Japan Inc., Tokyo, Japan). Mean \pm SD values are presented. To verify the model's appropriateness, the assumptions of the general linear model (GLM) were evaluated. A Two-Way Repeated Measures test (2 x 2, Time x Protocol) was used for comparing differences between measurements of times and protocols. Post-hoc multiple comparisons were conducted using the Bonferroni method when significant interactions and trial effects were found. The statistical significance level was set at $p < .05$. Additionally, partial eta squared values were computed to assess the effect size for all main effects and interactions, categorized as small (0.01 – 0.059), moderate (0.06 – 0.137) and large (>0.138) (Richardson, 2011). Cohen's d effect sizes with a 95% confidence interval were reported, where values exceeding 2.0 indicated a very large effect, 1.2 – 2.0 a large effect, 0.6 – 1.2 a moderate effect, 0.2 – 0.6 a small effect and 0.19 or lower a trivial effect (Hopkins et al., 2009).

RESULTS

The study aimed to investigate potential differences within each group between post-WU and post-RWU measurements, as well as differences between the two post-RWU measurements. Table 2 presents the means, standard deviations, percentage differences (PD), p -values, and Cohen's d effect sizes for all measurements.

The results of the two-way repeated measures ANOVA for CMJ revealed a significant main effect of Time ($F = 30.993$, $p < .001$, $\eta_p^2 = .738$). Notably, the difference between post-WU and post-RWU measurements reached significance in both CON and RWU80 conditions (CON: $p < .001$, $d = 1.630$, PD = -4.98%; RWU80: $p = .005$, $d = 1.007$, PD = -4.32%). Even though the CMJ was higher in RWU80 than in CON in post-RWU measurements, the difference was not statistically significant. As for the MAT, there was a significant main effect both for Time ($F = 18.052$, $p = .001$, $\eta_p^2 = .621$) and for Protocol ($F = 5.451$, $p = .040$, $\eta_p^2 = .331$). The difference between post-WU and post-RWU measurements was significant in both conditions (CON: $p = .039$, $d = .674$, PD = 3.19%; RWU80: $p = .008$, $d = .936$, PD = 2.45%). MAT performance was higher in RWU80 than in CON post-RWU ($p = .05$, $d = .631$, PD = 2.94%).

Significant effects were found in HR for Time, Protocol and their interaction in the two-way repeated measures analysis ($F = 83.076$, $p < .001$, $\eta_p^2 = .883$). HR was significantly decreased in CON group ($p < .001$, $d = 2.403$, PD = -23.42%), however, this decline was reversed in RWU80. The difference between the two post-RWU measurements was also statistically significant ($p < .001$, $d = 2.732$, PD = 37.72%). With regards to BT, there was a significant main effect of Time ($F = 36.675$, $p < .001$, $\eta_p^2 = .774$). Under both conditions, the

decrease in temperature between post-RWU and post-WU measurements was statistically significant (CON: $p < .001$, $d = 1.329$, $PD = -1.38\%$; RWU80: $p < .001$, $d = 1.322$, $PD = -1.00\%$).

Table 2. Statistical results.

Variable	Group	Post-WU	Post-RWU	Mean Diff.	PD	Sig.	Cohen's d
CMJ (cm)	Control	36.92 ± 2.20	35.08 ± 2.00	-1.84	-4.98%	<.001*	1.630
	RWU80	37.03 ± 2.92	35.43 ± 2.31	-1.60	-4.32%	.005*	1.007
	Comparison between postRWU measurements:			.35	1.00%	.615	.149
MAT (s)	Control	6.27 ± .41	6.47 ± .28	.20	3.19%	.039*	0.674
	RWU80	6.13 ± .38	6.28 ± .36	.15	2.45%	.008*	0.936
	Comparison between postRWU measurements:			.19	2.94%	.050*	.631
HR (bpm)	Control	128.08 ± 15.10	98.08 ± 12.56	-30.00	-23.42%	<.001*	2.403
	RWU80	128.25 ± 13.87	135.08 ± 10.48	6.83	5.33%	.127	0.477
	Comparison between postRWU measurements:			37.00	37.72%	<.001*	2.732
Body temp. (°C)	Control	37.00 ± .70	36.49 ± .41	-.51	-1.38%	<.001*	1.329
	RWU80	36.98 ± .44	36.61 ± .41	-.37	-1.00%	<.001*	1.322
	Comparison between postRWU measurements:			.12	0.33%	.374	.267
Perceived exertion	Control	2.333 ± .91	1.208 ± .81	-1.13	-48.22%	.003*	1.122
	RWU80	2.417 ± 1.16	3.042 ± 1.44	.63	25.86%	.058	.610
	Comparison between postRWU measurements:			1.83	151.82%	.002*	1.136
Perceived readiness	Control	4.042 ± .78	3.271 ± .89	-.77	-19.07%	.002*	1.151
	RWU80	3.875 ± .56	3.625 ± .46	-.25	-6.45%	.236	.362
	Comparison between postRWU measurements:			.35	10.82%	.252	.349

Note. Means for post-WU and post-RWU measurements ± SD, percentage differences (PD), p-values and Cohen's d effect sizes.

Significant effect for Time x Protocol interaction was found in RPE between the CON and the RWU80 group ($F = 21.560$, $p < .001$, $\eta_p^2 = .662$). Under the CON condition, RPE was significantly reduced in post-RWU compared to post-WU measurement ($p = .003$, $d = 1.122$, $PD = -48.22\%$), whereas this was not observed in RWU80. Additionally, comparing the two post-RWU measurements, RPE was significantly increased in the RWU80 ($p = .002$, $d = 1.136$, $PD = 151.82\%$). With regards to PRR, there was a significant main effect of Time ($F = 10.741$, $p = .007$, $\eta_p^2 = .494$). Significant difference was observed between post-WU and post-RWU in CON ($p = .002$, $d = 1.151$, $PD = -19.07\%$) but not in RWU80.

DISCUSSION

The major findings indicated that performance decrements were smaller under the RWU80 compared to the CON condition, whilst the differences between post-WU and post-RWU measurements remained statistically significant in most variables in both conditions. The athletes' performance in CMJ after RWU80 was slightly better compared to CON; However, the decrease in performance was statistically significant in both groups. On the contrary, performance in MAT during post-RWU measurements was significantly better after RWU80. Considering all the variables included in this study, our findings confirm that an 80% VO_{2max} RWU protocol on a cycle ergometer positively influences the subsequent performance of basketball players compared to a 15-minute passive rest. However, the protocol's intensity might lead to fatigue, explaining the non-significant improvements in some variables.

To our knowledge, only one study has investigated a RWU protocol on cycle ergometer in basketball players (Koutsouridis et al., 2024). Another study conducted during the game (Alberti et al., 2014), albeit without a

cycle ergometer, found that tapping or isometric contractions cannot prevent performance losses caused by passive rest. Other studies in basketball have been conducted during HT with protocols that are not applicable during the game (González-Devesa et al., 2023, Pociunas et al., 2018). Therefore, more research is needed to establish the scientific background, allowing athletes to implement protocols compliant with regulations of FIBA (2023).

In the current study, the decline in CMJ performance among basketball players who underwent passive rest for 15 minutes was 4.98% with large effect size. In contrast, when they participated in RWU80, the decrease was mitigated to 4.32%, though the difference is not statistically significant and the effect size is moderate. The corresponding decrease in CMJ performance in the study by Koutsouridis et al., (2024), following a 3-minute RWU at 40% of VO_{2max} , was only 1.72%. This indicates that a protocol of slightly longer duration with moderate intensity is more suitable before the athlete's engagement in the game. Several investigations during HT in soccer players demonstrated notable reductions in CMJ performance, with declines of 13.2% (Christaras et al., 2023), 7.6% (Edholm et al., 2015) and 6.76% (Fashioni et al., 2020) reported. The results of the RWU methods from the aforementioned studies were applied during HT on a soccer field (running, skipping, jumping, calisthenics, whole-body vibration, intermittent agility exercise). Therefore, they cannot be implemented during basketball games, nor can they be compared with the findings of the present study.

MAT performance decreased by 3.19% following 15 minutes of passive rest. However, this decline attenuated to 2.45% after RWU80, indicating moderate effect sizes in both conditions. Additionally, the RWU80 measurement was significantly better than the CON measurement between the two post-RWU assessments. In comparison, the RWU40 by Koutsouridis et al. (2024) mitigated the losses from passive rest more effectively, as the corresponding reduction was only 0.48%. Previous studies have frequently indicated that basketball players with better performance in agility tests are more successful in terms of competitive achievement (Versic et al., 2021). Change of direction and agility stand out as crucial physical attributes in basketball, given the frequent occurrence of dynamic directional changes during a game when athletes compete for positional advantage (Spiteri et al., 2015). However, to our knowledge, there is no other research investigating an agility test after RWU in basketball players.

In the present study, basketball players experienced a reduction in BT of 1.38% (0.51°C) after a 15-minute passive rest, compared to 1.00% (0.37°C) following RWU80, both reaching significant levels of difference and indicating large effect sizes. The observed decreases surpassed the results of Sargeant (1987) which indicated that each 1° C decrease in temperature is linked to a 3% decline in performance. The average temperature decrement of half a degree (0.5°C) in the CON condition resulted in approximately 5% and 3.2% performance decline in CMJ and MAT, respectively. Conversely, the smaller performance reductions (4.32% in CMJ and 2.45% in MAT) after RWU80 compared to the control condition may be attributed to the smaller (0.37°C) decrease in temperature. In Koutsouridis et al.'s study (2024), a longer 3-minute RWU at moderate intensity resulted in improved athlete performance, with a smaller temperature decrease (0.12°C) and reduced performance decrements (1.72% in CMJ and 0.48% in MAT). These results support previous research associating body temperature decrease with declines in sprint and jump performance in basketball players (Galazoulas et al., 2012) and sprint performance in soccer players (Mohr et al., 2004). Additionally, the findings are consistent with Galazoulas et al. (2012), suggesting that 'cooling-down' may have a more severe impact on jumping rather than running performance and with Mohr et al. (2004), concluding that temperature elevation is correlated with athletic performance.

There was a significant decrease in HR following a 15-min passive rest (23.42%). This result was completely reversed after RWU80 as the HR was increased compared to the postWU measurement by 5.33%. Any

protocol implemented in previous studies has led to increased HR compared to passive rest (Yanaoka et al., 2018a; 2018b; 2020; Yamashita & Umemura, 2022). Following initial increased HR, soccer players experience reduced HR during the first seven minutes of the second half compared to the passive rest condition. This phenomenon was attributed to the enhanced efficiency of the circulatory system which facilitated the transportation of gases, nutrients for energy production and removal of derivatives of biochemical reactions (Bang and Park, 2022). However, the small performance improvements in this study and the increased HR compared to post-WU levels indicated that the high intensity of the protocol did not have such a positive impact, as also reflected in the athletes' subjective measurements.

Following RWU, the RPE was significantly higher for the RWU80 protocol compared to the CON condition, with a differential of 1.83 points, representing a 151.82% increase. During reintegration into activity, the RPE for the RWU40 protocol was also elevated in comparison to the CON, showing a 1-point increase, with values of 2.19 versus 1.19 on the ten-point Borg scale (1982), as found in a similar study (Koutsouridis et al., 2024). These findings indicate that both RWU protocols resulted in higher perceived exertion than the CON, with the RWU80 protocol leading to a greater exertion. These findings align with the accepted understanding within Post-Activation Performance Enhancement (PAPE) protocols, where fatigue counteracts the potentiation effects that dynamic protocols may induce. According to Blazevich and Babault (2019), PAPE is observable only when fatigue diminishes. Additionally, in comparing post-RWU to post-WU conditions, RWU80 resulted in a performance decrement of 4.32% in the CMJ and 2.45% in the MAT. In contrast, RWU40 achieved smaller losses of 1.72% in CMJ and 0.48% in MAT. These results suggest that RWU80 was a sufficiently intense protocol to induce significant fatigue in athletes. Nonetheless, despite this fatigue, athletes were better prepared post RWU80 compared to 15 minutes of passive rest.

The above conclusion can be supported by the results of perceived readiness, where, to our knowledge, no study has examined it following a RWU protocol in any sport. Readiness significantly decreased in the CON condition, whereas in RWU80, the loss was not statistically significant. Comparing the two post-RWU measurements, athletes felt 10.82% more prepared when they underwent the RWU80 protocol compared to passive rest. Readiness results were further supported by athletes' performance outcomes and physiological factors, where all metrics were improved in RWU80 compared to CON.

This study had limitations regarding the measurement of muscle temperature and electromyographic activity. These parameters were not assessed during the trials, which limited the availability of crucial physiological data. Future research could investigate scenarios where players participate in game, then sit on the bench for an extended period before re-entering, allowing for an evaluation of the effectiveness of a RWU during their return. Such studies would offer valuable insights into optimizing performance strategies during extended periods of rest within games.

Practical applications

Despite the increasing placement of cycle ergometers behind team benches during games, there is a lack of scientific data regarding their use in RWU. Coaches can incorporate a short RWU protocol right before athletes' re-entering the game ensuring optimal performance. The results of the present study indicate that coaches have the flexibility to adapt the intensity and duration of the RWU based on the available time for its implementation. The RWU protocol need to be challenging enough in order to activate the neuromuscular system and sustain the players' body temperature, but simultaneously avoiding excessive fatigue.

CONCLUSIONS

A 1-min high-intensity RWU implemented on a cycle ergometer demonstrated a performance improvement in semi-professional basketball players when compared to a 15-min passive rest. The utilized protocol in this study mitigated the performance declines associated with passive rest, leading to athletes returning to physical activity at an elevated readiness level. All measured performance variables (HR, Body Temperature, CMJ, MAT, RPE, and perceived readiness) showed enhancement for basketball players following a 1-minute cycling RWU at 80% VO_{2max} , as compared to the 15-min control condition of passive rest.

AUTHOR CONTRIBUTIONS

Christos Koutsouridis conducted the literature review, developed the experimental design, performed the measurements and the data analysis and drafted the original manuscript. Christos Galazoulas contributed to the conceptualization and the experimental design, and together with Vasiliki Manou and Nikolaos Stavropoulos, provided supervision and project oversight. Dimos I. Prantsidis contributed to the visualization and the final review of the manuscript. All authors reviewed and approved the final version of the article.

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Acute effects of the sequence of concurrent high-intensity resistance and endurance exercises in recreational athletes

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ABSTRACT

This study aimed to assess the acute effects of the sequence of concurrent training (CT) on physiological, neuromuscular, and perceptive parameters in recreational athletes. Eighteen active men (mean \pm SD: 22.00 \pm 2.00 years; 79.40 \pm 9.87 kg and 175.62 \pm 6.35 cm) performed two CT sessions consisting of repeated sprint endurance exercise followed by resistance exercise (E-R) or the reverse sequence (R-E) in a randomized order. The E exercise consisted of 6x30s of cycling “all-out” interspersed by 15s of passive recovery, while the R exercise consisted of 3x15 repetitions near failure (1 repetition in reserve) of back squat exercise with rest intervals of 45s. Height in CMJ, heart rate (HR), rating of perceived exertion (RPE) after each exercise, and at the final of the session (sRPE) were recorded. The R-E sequence showed a higher HR at 10s, 1min and 6min ($p < .05$) post E exercise compared to R exercise. Significant protocol \times time interactions were observed for sRPE ($p < .001$) being higher after the R-E sequence compared to E-R sequence. RPE was significantly higher ($p < .01$) after E exercise compared to R exercise in both sequences, without differences between the E exercises. However, there were significant differences between the R exercises ($p < .01$) being higher in the R-E sequence. Our results suggest that the order of exercises during CT affects the second exercise when performed in a R-E sequence, with more cardiovascular stress and higher perceived exertions.

Keywords: Sport medicine, Acute fatigue, Training order, High intensity, Strength training.

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INTRODUCTION

The combination of resistance and endurance training in the one training program has been known as concurrent training (CT). Variables such as intensity, volume, exercise sequence, exercise mode and recovery period are used by coaches for obtaining the optimal training stimulus. Optimal physiological stress is necessary to progress to increasing training loads according to the overload principle. However, an insufficient recovery period could compromise the training adaptation (Fry et al., 1992), as for example, between resistance and endurance efforts. Therefore, the influence of the between-session recovery periods during CT could have implications about an impaired quality of endurance and resistance training sessions. In relation to the exercise sequence, residual fatigue has been found in the second exercise due to the previous one (Eddens et al., 2018), being able to generate an interference (Hickson, 1980). At the same time, the interference effect of the exercise sequence could be more relevant when high-intensity efforts have been performed during the CT session. For example, previous study (Jones et al., 2017) found an acute unfavourable response by performing endurance exercise prior to resistance exercise when this last one was conducted with high loads. Leveritt and Abernethy (Leveritt & Abernethy, 1999) found an impairment on resistance activity when high-intensity endurance exercise is performed before, mainly explained by an increase of blood lactate and reduction of isokinetic torque. Indeed, repeated sprints may promote acute interferences on resistance exercise, and it has been suggested that sprint-activities must be isolated from resistance training and it would be necessary an adequate recovery time (Coffey et al., 2009). However, it is remaining unknown the acute effects of the reverse order (endurance and resistance exercise) with high-intensity endurance effort. Regarding the resistance exercise performed before the endurance exercise, the resistance exercise with a high velocity loss (40%) induced higher metabolic, mechanical stress and residual fatigue on the subsequent endurance exercise performance (Nájera-Ferrer et al., 2021), being dependent of the level of fatigue (compared to 20% of velocity loss). These authors suggested that high-fatigue resistance exercise before endurance exercise should be avoided.

The countermovement squat jump (CMJ) height loss is used for monitoring the levels of fatigue during a training session (Jimenez-Reyes et al., 2016; Sanchez-Medina & González-Badillo, 2011) due to the strong correlations (0.92-0.97) observed between jump height loss and blood lactate and ammonia. In addition, heart rate (HR) recovery is suggested to be a marker of physical fitness (Shetler et al., 2001). Besides, it is used as a measure of training-induced disturbances in autonomic control. It allows quantifying the autonomic nervous system recovery after a high-intensity exercise (Borresen & Lambert, 2008). The HR recovery is slower than after submaximal exercise, contributing to the deceleration of HR after the cessation of exercise (Kannankeril et al., 2004). On the other hand, the rating of perceived exertion (RPE) scale is a simple, reliable and valid tool to monitor exercise intensity through a wide variety of exercise types such as endurance (Foster et al., 1996) and resistance exercises (Gearhart JR et al., 2002).

Therefore, the aim of this study was to assess the acute effects of the sequence of concurrent high intensity resistance and repeated sprint endurance exercises on physiological (HR recovery), neuromuscular (jump height loss) and RPE parameters in recreational athletes.

METHODS

Subjects

Eighteen active men participated in this study (mean \pm SD: 22.00 \pm 2.00 years; 79.40 \pm 9.87 kg and 175.62 \pm 6.35 cm). Subjects were non-smokers, free from any pre-existing medical conditions and musculoskeletal injuries, they performed varied sport activities (“gym”-based training, endurance exercises such as running

and swimming, and various sports such as soccer and basketball) and they were habitually exercising for >6h per week. Prior to the study, all subjects were informed about the testing protocols, possible risks involved and invited to provide written informed consent. The study was performed in accordance with the principles of the Declaration of Helsinki (October 2008, Seoul), and the experimental protocols were approved by the local ethics committee.

Experimental design

Subjects had previous experience in the training and testing employed in the study, and they were familiarized with protocols before data was collected. Subjects performed either endurance high-intensity session before the resistance session or reverse order. A 15-minute recovery period separated the training sessions. The training sessions were performed under control conditions (no strenuous activity 48h before). A period of at least 7 days separated the following training session, with an order of the exercises reversed (Figure 1). Both training sessions were conducted at the same time of the day for each individual in order to control for diurnal variation in hormone concentration. To examine the effects of exercise sequence on neuromuscular, cardiovascular, and perceptive parameters, the CMJ height and HR were recorded before each resistance and endurance exercise and 10s, 1min and 6min after. RPE was recorded at the end of the session (sRPE).

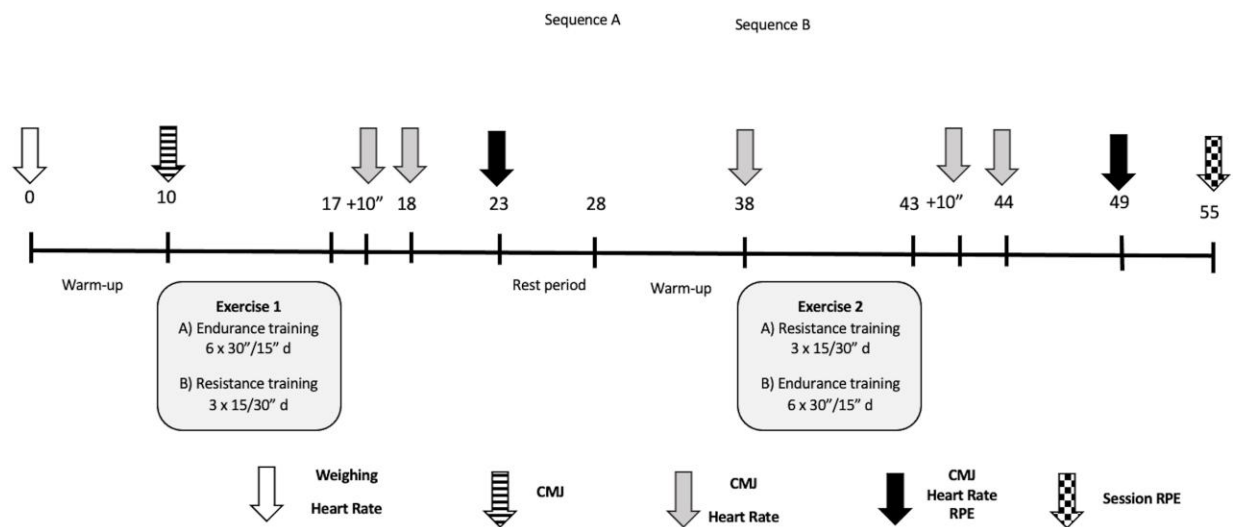


Figure 1. Overview of experimental design, indicating the training protocols and measurements.

Procedures

Repeated sprint endurance exercise

The repeated sprint endurance exercise protocol consisted of six 30-seconds “all-out” efforts performed in a cycle ergometer (Wattbike Ltd, Nottingham, UK) interspersed by 15-seconds of passive recovery. Moreover, they had a standardized countdown started at each effort and they were instructed to begin pedalling as fast as possible in each effort and trying to produce the highest power output possible. The repeated sprint endurance exercise was preceded by 10min of easy cycling as warm-up at 80-90 rpm.

Resistance exercise

The resistance exercise performed by the subjects consisted of 3 sets of 15 repetitions near failure of back squat exercise with rest intervals of 45s. Subjects were familiarized with the movement and warmed up prior to the training session. During training, the effort character (relationship between the repetitions realized and realizable) was used as a method of training control using repetitions in reserve, indicating to the subjects

that they should have an intensity rating of RPE of 9 out of 10, i.e., 1 repetition in reserve (Zourdos et al., 2016). It was found that experienced and novice lifters may not possess equal abilities to perform a true one-repetition maximum (1RM) lift, and as a result, it may not be appropriate to use % of 1RM as a method to assign training load in all populations reserve (Zourdos et al., 2016). All subjects training ~ 70% loads of the previously known 1RM. Therefore, 3 sets of 15 repetitions (RIR 1, RPE 9) and rest intervals of 45s are a typical session targeting muscular endurance (Helms et al., 2016).

Before the resistance training, subjects performed a specific warm-up for the back squat exercise consisting of i) ankle, hip, thoracic spine, and shoulder mobility; ii) unloaded squats; iii) 4-5 incremental load sets to find the load corresponding to 15 repetitions [1 repetition in reserve]). The training was carried out using a 20 kg free bar, weight plates and a squatting rack (Eleiko Sport AB, Halmstad, Sweden). The squats were completed such that the anterior thighs were parallel to the ground before extending to a standing stance indicating by a researcher the moment where the thigh was parallel to the ground for each repetition. The training was designed and supervised by two resistance training specialists who checked that the proposed training was adhered to.

Testing

Subjects performed several CMJ using an optical measurement system (Optojump-next, Microgate, Bolzano, Italy) before, during and after of the endurance and resistance exercises. The CMJ starting position was a standing position with a straight torso and knees extended and subjects were asked to keep their hands on the hips throughout the jump. They were asked to jump for maximum height possible and jumping height were recorded. Subjects squatted from a standing stance to a knee angle of ~90° and immediately rebounded to jump as high as possible with feet shoulder width apart with their hands placed on their hips, i.e., jumping without the aid of the arms.

HR was recorded during the training session using a chest strap and HR monitor (H9, Polar Electro, Kempele, Finland). RPE was recorded at 1min post each exercise and the session RPE at 30min of the end.

Statistical analysis

SPSS 24.0 (SPSS Inc., Chicago, IL) was used for the analysis of the data. Normality and homogeneity of variance were determined with the Shapiro-Wilks and Levene tests, respectively. A repeated measures (time-pre, 10s, 1min and 6min) ANOVA was applied to analyse the difference in HR and CMJ between exercise modes (endurance vs resistance) in each sequence. A paired samples t-test was performed to analyse the difference in sRPE between sequences and RPE after each exercise mode in each sequence. The results are expressed as means and standard deviation (SD). The level of statistical significance was set at $p \leq .05$. Effect size was calculated using partial eta squared (partial η^2) or Cohen's d. All graphs and figures were created using GraphPad Prism (version 8.0.0 for Mac OS, GraphPad Software, San Diego, CA, USA).

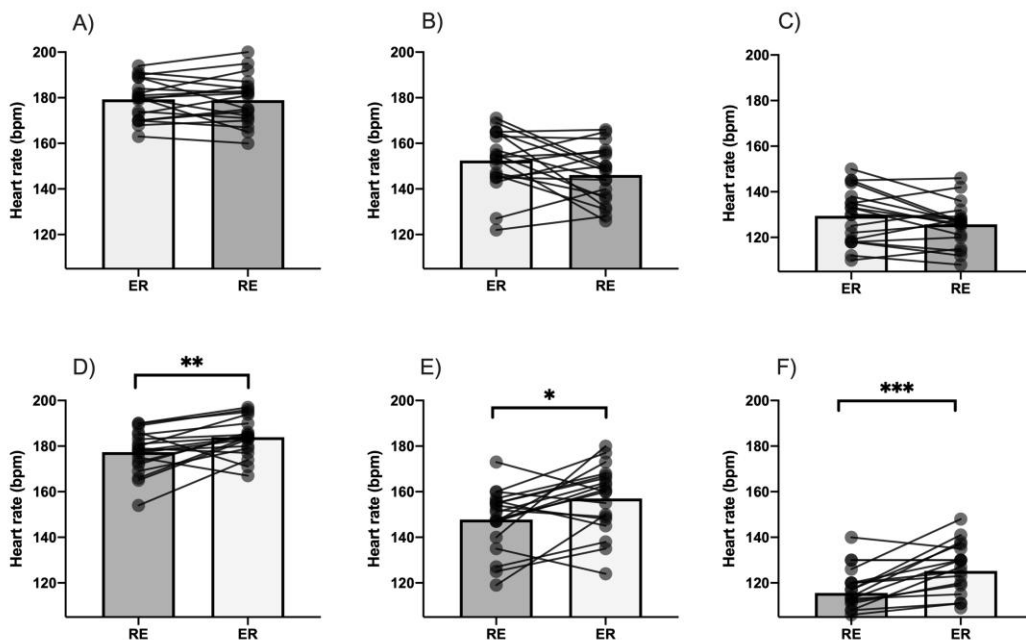
RESULTS

Results of the protocols on the CMJ, HR and sRPE are shown in the Table 1.

Significant protocol x time interactions were observed for HR ($p < .001$; partial $\eta^2 = 0.90$). There were no differences in HR between exercises mode in the sequence E-R at 10s, 1min and 6min after the exercise. However, in the sequence R-E, there were significant differences at 10s, 1min and 6min ($p < .05$), being higher after the endurance exercise compared to resistance exercise. In addition, both sequences started with a similar resting HR (69.68 ± 12.70 and 71.63 ± 11.30 bpm) (Figure 2).

Table 1. Results of the exercise sequence on CMJ, heart rate, RPE and session RPE.

Variables	Exercise sequence			
	Endurance			
	Pre	Post 10s	Post 1min	Post 6min
CMJ (cm)	37.21 ± 5.99	26.62 ± 6.69	28.03 ± 8.00	31.41 ± 6.69
HR (bpm)	69.68 ± 12.70	179.31 ± 8.85	152.47 ± 13.09	129.47 ± 11.87
RPE (a.u.)			17.67 ± 1.91	
sRPE (a.u.)				
	Resistance			
	Pre	Post 10s	Post 1min	Post 6min
CMJ (cm)	37.12 ± 5.05	31.23 ± 5.87	33.52 ± 5.96	36.63 ± 6.06
HR (bpm)	121.74 ± 23.60	178.95 ± 10.50	146.10 ± 12.32	125.68 ± 9.59
RPE (a.u.)			15.39 ± 2.03	
sRPE (a.u.)				
	Resistance			
	Pre	Post 10s	Post 1min	Post 6min
CMJ (cm)	36.16 ± 5.62	31.40 ± 5.24	33.26 ± 5.65	35.97 ± 5.29
HR (bpm)	71.63 ± 11.30	177.37 ± 9.41	147.79 ± 13.46	115.58 ± 11.27
RPE (a.u.)			16.84 ± 1.89	
sRPE (a.u.)				
	Endurance			
	Pre	Post 10s	Post 1min	Post 6min
CMJ (cm)	37.11 ± 5.44	26.76 ± 5.77	28.39 ± 6.58	32.86 ± 5.89
HR (bpm)	113.31 ± 14.39	183.89 ± 8.25	157.00 ± 14.68	125.21 ± 12.33
RPE (a.u.)			18.63 ± 1.46	
sRPE (a.u.)				



Note. * $p \leq .05$, ** $p \leq .01$; *** $p \leq .001$.

Figure 2. Individual values (lines) and average (columns) for heart rate post exercise of the sequence endurance-resistance at 10s (A), 1min (B) and 6min (C), and for the sequence resistance-endurance at 10s (D), 1min (E) and 6min (F).

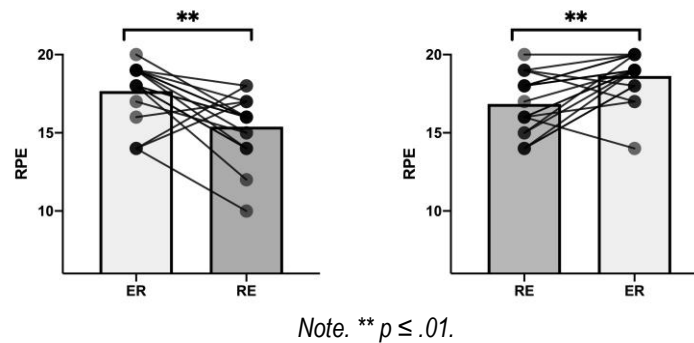


Figure 3. Individual values (lines) and average (columns) for session RPE of the sequence endurance-resistance (A) and for the sequence resistance-endurance (B).

Significant protocol \times time interactions were observed for sRPE ($p < .01$, Cohen's $d = 0.60$), being higher before the R-E sequence compared to E-R sequence (17.64 ± 1.28 a.u. and 16.53 ± 1.47 a.u.). RPE was significantly higher ($p = .002$, $ES = 0.87$) after endurance exercise compared to resistance exercise in the E-R sequence (17.67 ± 1.91 and 15.39 ± 2.03 a.u.) and in the R-E sequence ($p = .002$; $ES = 0.84$) (16.84 ± 1.89 and 18.63 ± 1.46 a.u.). There were no significant differences between the endurance exercises ($p > .05$; $ES = 0.44$). However, there were significant differences between the resistance exercises ($p = .008$; $ES = 0.71$) (Figure 3).

Finally, non-significant protocol \times time interactions were observed for CMJ (partial $\eta^2 = 0.31$).

DISCUSSION

The aim of this study was to assess the acute effects of the sequence of concurrent high-intensity resistance and endurance exercises on physiological, neuromuscular, and perceptive parameters in recreational athletes.

The main finding of this study was that there was no influence of exercise sequence on neuromuscular parameters. However, the HR was significantly higher post endurance exercise in the R-E sequence compared to the resistance exercise, while no differences were observed in the E-R sequence. In addition, the subjects perceived as a harder session the R-E sequence, being also harder the endurance exercise in that sequence.

From a resistance exercise acute effects standpoint, previous studies have shown that greater training load-volume (Abboud et al., 2013), sets performed to failure (Morán-Navarro et al., 2017) or a combination of multiple exercises performed in one set (Weakley et al., 2017) induce greater physiological strain for at least 24h post-exercise. In addition, greater resistance training intensities ($\geq 80\%$ of 1RM) induce greater stress than light-load (Draganidis et al., 2013; Hasenoehrl et al., 2016) and it could impair the subsequent exercise. Therefore, it seems reasonable consider several factors when a CT is designed and the effects on the subsequent exercises. In our case, the training volume was low (45 repetitions), intensities about 70% of 1RM, near to failure (1 repetition in reserve) and only 45s of recovery between sets.

As our results show, the R-E sequence had a higher cardiovascular stress (higher HR post exercise) and the effort perception of the subjects was more elevated after the endurance exercise, thus, the previous exercise should have influenced. Previous studies have reported that a single resistance training bout impairs the

subsequent endurance performance even in a period of 24-72h after (Burt & Twist, 2011; Doncaster & Twist, 2012). It is necessary to mention that the endurance exercise performed in our study was a high intensity effort (repeated cycling sprints of 30s) with a short recovery period (15s), therefore, the muscle fibres recruited were predominantly fast twitch. Some authors have speculated that the acute effects of resistance training may have greater deleterious effects on high intensity endurance activities, due to the fast twitch muscle fibres have greater susceptibility to muscle damage and glycogen depletion (Connolly et al., 2003), and predominantly recruited at intensities above the anaerobic threshold (Abernethy et al., 1990). However, we did not find differences in the jump height loss (as neuromuscular measure) during both sequence of training.

In relation to the recovery between exercise modes, our study had a passive recovery of 5min and a specific active warm-up of 10min previous the second exercise of the session. This short recovery period could have influence on the subsequent endurance or resistance exercise (according to the sequence). Robineau et al. (Robineau et al., 2016) compared the effects of R-E sequence on the same day, 6h and 24h before. These authors suggested an interference effect on endurance development for groups that undertook R-E sequence on the same day. Thus, the recovery period between exercise modes would be another factor to consider when concurrent training is prescribed in the same day. In our case, only 15min of recovery period (passive and active) could be insufficient and increase cardiovascular stress in the R-E sequence compared to E-R sequence. For example, a previous study shows that the type of warm-up (active/passive) does not seem to affect the subsequent high-intensity exercise performance (Gray & Nimmo, 2001).

Previous studies have found a considerable impact of neuromuscular fatigue in response to resistance exercise mode (Bird et al., 2013; Häkkinen et al., 1988; Stock et al., 2010) for up to 72h post-exercise. Nájera-Ferrer et al. (Nájera-Ferrer et al., 2021) found higher reductions in CMJ height along with elevated blood lactate concentration, following a R-E sequence but not in the E-R sequence. These authors suggested that high-fatigue resistance exercise before endurance exercise should be avoided to prevent the quality of the subsequent endurance exercise. However, in our case, both exercise modes in both sequences had a similar neuromuscular fatigue and does not appear to have influenced on the subsequent exercise.

Regarding the sRPE, previous study showed that this variable was not affected by the duration of the exercise session (Green et al., 2009), thus, the intensity of exercise seems to be key in the subjective ratings of effort. Di Blasio et al. (Di Blasio et al., 2012) compared three concurrent protocols on acute effects of objective and subjective variables. They found that the lowest increase in the energy expenditure, VO_2 and lowest decrease of proportion of oxygen in the expired air (FeO_2) were coupled with the lowest increase of the perceived exertion in the E-R sequence compared to R-E sequence. Therefore, the order of exercise affected both objective and subjective variables, due to the relationship between RPE and objective variables, such as HR and VO_2 . Another reason why the sRPE was higher after the R-E sequence in our study could be that the subjects perceived the endurance exercise mode as more demanding, and the timing of that exercise (at the final of the session) could affect the overall session perception. In this way, Kilpatrick et al. (Kilpatrick et al., 2009) reported that sRPE was affected by the perceived intensity taken during the final part of a running session.

CONCLUSION

In conclusion, our results suggest that the order of exercises during CT affects to the second exercise when performed in a R-E sequence, with a more cardiovascular stress and higher sRPE. Therefore, it is important to combine several variables (intensity and recovery between exercises, mainly) in a proper way to obtain a

better result during a CT program. Finally, we recommend avoiding the R-E sequence in endurance athletes to not impair the endurance performance or quality of endurance session.

AUTHOR CONTRIBUTIONS

Conception: Fernando González-Mohino and Victor Rodrigo-Carranza. Performance of work: Fernando González-Mohino and Victor Rodrigo-Carranza. Interpretation or analysis of data: Fernando González-Mohino, Daniel Juárez Santos-García and José María González-Ravé. Preparation of the manuscript: Fernando González-Mohino, Victor Rodrigo-Carranza Daniel Juárez Santos-García. Revision for important intellectual content: All authors. Supervision: Daniel Juárez Santos-García and José María González-Ravé.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

ETHICAL CONSIDERATIONS

All subjects gave written informed consent after a detailed description of the study procedures. The study was approved by the local Ethics Committee of the University (FGM02102019) and was conducted in accordance with the Declaration of Helsinki.

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Combining practical blood flow restriction with elastic band resistance training neither affects strength nor muscle thickness in young males

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ABSTRACT

The purpose of this study was to determine the effect of eight weeks of elastic band resistance training (EBRT) program associated with practical blood flow restriction (BFR) on muscle strength and hypertrophy. Fourteen physically active male participated in an eight-week upper limbs EBRT program, with one limb under BFR and the other with free blood flow (EBRT+BFR). Bilateral and unilateral elbow flexion exercises were performed three times a week, with three sets of 15 repetitions in each upper limb. Blood flow restriction was produced by an extensive band, implementing the pressure stipulated at 25% of the resting upper arm circumference. Significant main effect for time was found in elbow flexors muscle thickness measured with ultrasound to both training conditions, but no significant interactions in the time x group were identified. Relative strength gains measure with a dynamometer were $-0.5 \pm 10.2\%$ and $0.5 \pm 12.1\%$ in the arms trained with EBRT and EBRT+BFR, respectively. The relative gains in elbow flexor muscle thickness were $1.8 \pm 6.2\%$ with EBRT training and $5.5 \pm 6.7\%$ in EBRT+BFR (both $p > .05$). In conclusion, applying BFR to an EBRT was not superior at increasing upper limb muscular strength or hypertrophy in young adults compared to EBRT alone.

Keywords: Sport medicine, Muscle hypertrophy, Isometric strength, Strength training, Military personnel.

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INTRODUCTION

Resistance training with blood flow restriction (BFR) is a safe and effective method to promote strength gains and muscle hypertrophy (Patterson et al., 2019). This method uses an inflated cuff at the proximal end of the limbs during the exercise; restricting arterial blood inflow to the limb increases metabolic stress and stimulates muscle hypertrophy mechanisms (Loenneke et al., 2012).

Traditionally, to obtain good gains in strength and hypertrophy, training with a minimum resistance of 65% of the maximum dynamic strength (1 maximum repetition - 1RM) and six to 12 repetitions for each muscle group is recommended (Schoenfeld et al., 2016). However, for populations unable to mobilize high overload, low-intensity resistance training programs, ranging from 10 to 50% of 1RM (Takarada et al., 2000b; Lopes et al., 2019), combined with BFR, have been proven to be a strategy quite adequate. This population includes individuals who practice neuromuscular training with straps or elastic bands.

The Brazilian Army recommends elastic band resistance training (EBRT) as an alternative to maintain the physiological effects of military physical training on the neuromuscular system, mainly when the military cannot perform regular training or attend a gym (Brazil, 2020). Regarding the effects on strength, Lopes et al. (2019) indicated, in their systematic review with meta-analysis, that EBRT is a strategy that produces results similar to those generated by conventional gym equipment.

However, the effects on muscle mass gains have yet to be studied, and the available results come from studies with older people. Colado and Triplett (2008) demonstrated that hypertrophy in older women who trained with elastic bands was lower than in those who performed conventional resistance training.

Studies that investigated the effects of the application of BFR to low-intensity elastic bands resistance training observed that this procedure was capable of causing increases in muscle thickness similar to those caused by EBRT with moderate to high intensities in older women submitted to eight weeks of EBRT of upper limbs (Thiebaud et al. al., 2013). Similar findings were reported by Yasuda et al. (2015) in older men, who demonstrated significantly higher gains in the cross-sectional area of elbow extensors and flexors after 12 weeks of elastic bands resistance training combined with BFR than among older people who only performed EBRT.

According to Yasuda et al. (2014), applying BFR favours muscle activation. Their findings indicated a progressive increase in biceps and triceps muscle activation, monitored by electromyography, during elastic bands resistance training combined with BFR but not in the control condition, which performed the same exercises with free blood flow.

As muscle activation is a key factor for hypertrophy, the application of BFR to EBRT sessions could be significant adjuvant for strength and muscle mass gain in individuals who train with elastic bands. Furthermore, given the limited scientific evidence on the effects of EBRT on hypertrophy, especially in young adults, the proposed study aims to monitor the strength and hypertrophy gains resulting from an EBRT program combined with blood flow restriction in healthy young people.

This knowledge can contribute to a better understanding of the physiological adaptations inherent to physical training, aiming at prescribing a safe and more efficient method.

MATERIALS AND METHODS

Sample

Fourteen physically active male soldiers undergoing academic training at the School of Physical Education of the Army participated in the study. All of them were healthy and presented their latest results of routine medical examinations. The participants' mean (SD) age, stature, and body mass were 27.5 ± 2.8 years, 179.0 ± 7.1 cm, and 78.5 ± 6.9 kg, respectively. The exclusion criteria were possible recent upper limb injury, participation in regular resistance training programs for upper limbs in the last three months, and the use of ergogenic aids of any kind.

A minimum sample size of 12 participants would be stipulated to detect an effect size (ES) of 0.35. This value was obtained from a study from our laboratory examining the chronic effects of BFR on upper body strength gains. According to Beck (2013), for power analysis, the type of analysis was set to repeated measures ANOVA with within-between interaction, the required power was set to 0.80, alpha was set to .05, and the correlation between repeated measures was set to $r = 0.5$ (G*Power software, v.3.1.9.2).

All participants received a detailed verbal explanation of the study procedures and risks involved in the experimental procedures, and they signed a written informed consent form before participating in the study. The Army Physical Training Center Ethical Review Board approved the study under protocol #5.441.190.

Measures and procedures

Study design

The participants underwent eight weeks of EBRT in the upper limbs in free blood flow and BFR conditions. The BFR condition was applied in one of the arms, randomly distributed between the dominant and non-dominant limbs. Before and after the training period, measures of muscle strength, muscle thickness, arm circumference, and skinfolds of the upper limbs were taken. The first training session occurred five days after the initial tests, and the last one was held 72 hours before the last evaluation. During the study, all participants were constantly instructed not to perform any upper limb exercise not foreseen in conventional military physical training nor to adhere to any diet different from the usual one.

Practical blood flow restriction

Blood flow restriction was produced by an extensive band measuring 60 cm x 4 cm, implementing the pressure stipulated at 25% of the resting upper arm circumference.

Wilson et al. (2013) indicated that a rating of seven subjective perceived exertion (RPE on a 0-10 scale) corresponds to a moderate intensity of restriction that would be sufficient to generate appropriate metabolic responses to exercise. According to Aniceto et al. (2021), this RPE is achieved by performing a BFR of 25% of the upper limb circumference. For example, an individual with an arm circumference of 30 cm should receive a band tied to the extension 7.5 cm smaller than his arm circumference; that is, the researcher should tighten the band until the marking corresponds to 22.5 cm.

Training description

The volunteers were presented to the EBRT and BFR procedures through a familiarization session before the training period. On this occasion, they were asked to perform the movement with the band without tightening, tied to the upper limb, and without pressure. Then, they did the exercises with the elastic band, implementing the pressure stipulated at 25%.

Bilateral and unilateral elbow flexion exercises were performed three times a week, with three sets of 15 repetitions in each upper limb and 1-minute rest between sets. This protocol followed the Brazilian Army's Neuromuscular Training with Rubber Bands Instruction Booklet.

Purple elastic bands (Elastos Ind/Com Fisioterapia e Esportes, RJ, Brazil), equivalent to 4.8-9.1 kgf (according to data provided by the manufacturer), were used for the bilateral elbow flexion exercise. Black elastics, equivalent to 4.1-7.5 kgf were used for unilateral elbow flexion training. In the last three weeks of the protocol, a green elastic band (equivalent to 2.1-3.9 kgf) was added to both exercises.

The bilateral elbow flexion exercise was performed with the subjects standing up, with their feet parallel, knees slightly flexed, and hands in supination, holding the handles of the elastic band, which was attached to the volunteer's feet (Figure 1).

The individuals remained seated for the unilateral elbow flexion movement, with the elastic band under the foot ipsilateral to the upper limb that would perform the exercise. The subject held the elastic band with the hand in supination while the triceps region of the arm rested on the distal medial part of the thigh during the movement (Figure 1).

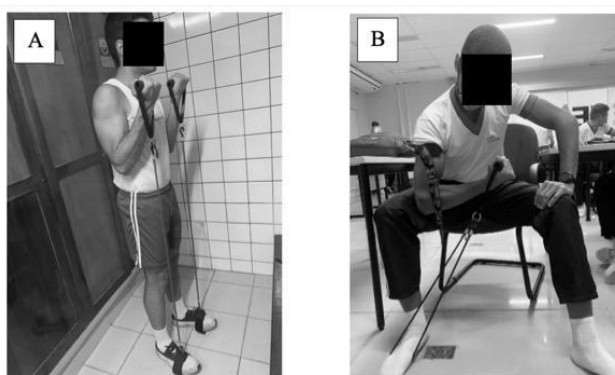


Figure 1. Example of the bilateral (A) and unilateral (B) elbow flexion exercises.

Muscle thickness and anthropometric measurements

Body mass, stature, muscle thicknesses, arm circumference and biceps skinfolds were measured by an experienced anthropometrist. Reproducibility of these measures was previously investigated in our laboratory (10 subjects, 2 measurements). Test-retest reliability yielded intraclass correlation coefficients of 0.96 for flexors muscle thickness, 0.99 for arm circumference, and 0.94 for biceps skinfolds, with a coefficient of variation of 0.7%, 0.5% and 3.2%, respectively.

Each individual was positioned in dorsal decubitus with arms extended along the body. Subsequently, the anatomical point on the upper part of the edge of the acromion, aligned with the lateral edge point located on the most proximal and lateral edge of the head of the radial bone, was marked. Afterward, the equidistant point between the two points was marked. The biceps point used to obtain the ultrasound measurement is located in the anterior portion of the biceps, at the height corresponding to the mid-acromial-radiale.

The images were obtained by an experienced evaluator using ultrasound equipment (GE Logiq, GE Healthcare, USA) with a 40 mm linear transducer, frequency of 10 MHz, and 6 cm of image depth. The transducer was moved over the skin with a conductive gel at the bicipital point.

The muscle thickness of collected images was analysed using public domain software ImageJ (National Institutes of Health, USA) to quantify measurements. Figure 2 illustrates an example of an image obtained by ultrasound.

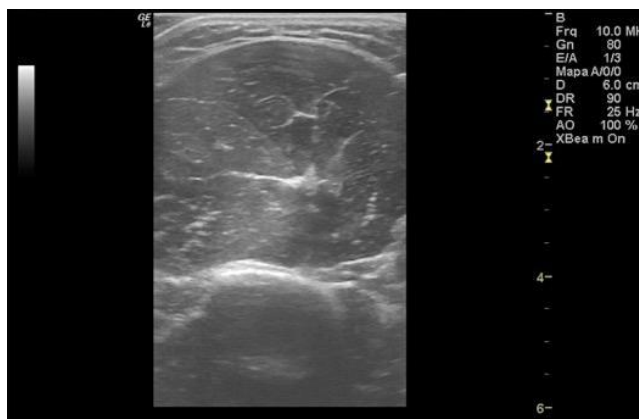


Figure 2. Typical ultrasound image of elbow flexor muscles at the biceps point.

Muscle strength measurement

The maximum unilateral isometric strength of the elbow flexor muscles was assessed using an adapted back dynamometer (Figure 3) (Smedley T.K.K. 5002, Takei Physical Fitness Test Type-3, Japan), which consists of a tensile strain gauge with a maximum capacity of 300 kgf.

The tests were applied at a 90° angle of elbow flexion. To start the procedure, the participants remained standing, with feet parallel to the dynamometer platform, knees slightly flexed, and hands in supination. The dynamometer was attached to a steel chain with a handle, which the subject used to perform elbow flexion. The maximum force used for analysis was the highest value presented after three attempts of 5 s, interspersed by 30 s. Participants received verbal stimuli during the tests to perform as hard as possible (Figure 3).

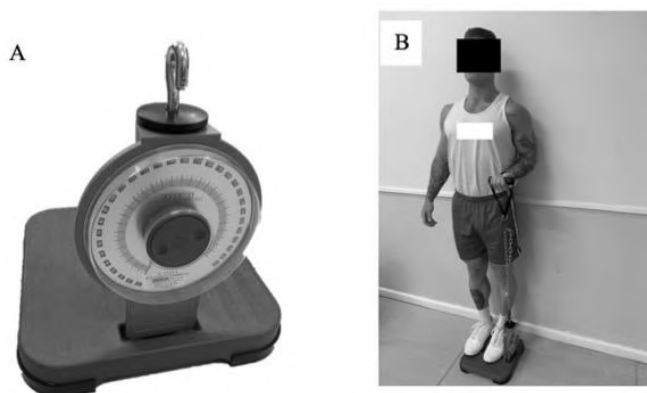


Figure 3. Illustration of the dynamometer (A) and the position used for elbow flexor muscle testing (B).

Statistical analysis

Two-way ANOVA with repeated measures in the second factor (time) was used to determine the effect of the independent variables, i.e., between-subjects factors (training with free blood flow or blood flow restriction)

and within-subjects factor of time on the dependent variables of muscle thickness and maximal isometric strength for the elbow flexors. All statistical analyses were performed using commercially available software (IBM SPSS Statistics for MacBook, Version 20.0; IBM Corp. Released 2011, Armonk, NY: IBM Corp.). All statistical analyses were tested at 95% probability.

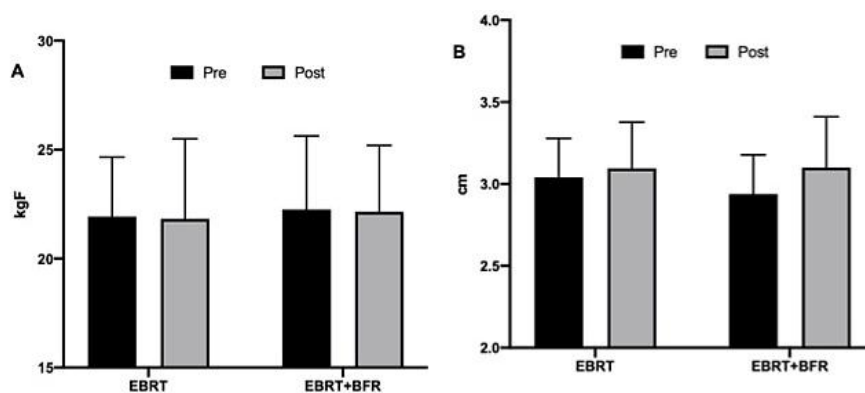
RESULTS

None of the volunteers reported adverse reactions during or after the exercise protocols. The mean upper arm circumference of participants receiving BFR treatment was $32,7 \pm 1.8$ cm, and the tightness produced by the extensible band during BFR exercise was $24,5 \pm 1.3$ cm, equivalent to 25% BFR.

Table 1. Changes in anthropometric measures in response to an elastic band resistance training (EBRT) and an elastic band resistance training combined to blood flow restriction (EBRT+BFR).

	EBRT		EBRT+BFR	
	Mean (SD)	Change (%)	Mean (SD)	Change (%)
Arm circumference (cm)				
Pre	32.5 (1.9)	0.1 (0.9)	32.5 (1.8)	0.1 (0.6)
Post	32.6 (2.3)		32.6 (2.0)	
Biceps skinfold (mm)				
Pre	3.2 (1.1)	-22.2 (20.4)	3.1 (1.1)	-20.2 (20.6)
Post	2.5 (1.2)		2.5 (1.1)	

Note. Significant main effect for time in both variable ($p < .05$).



Note. Significant main effect for time in muscle thickness ($p < .05$).

Figure 4. Changes in maximum unilateral isometric (A) and muscle thickness (B) of the elbow flexors in response to an elastic band resistance training (EBRT) and an elastic band resistance training combined to blood flow restriction (EBRT+BFR).

As shown in Table 1, both exercise modalities significantly increased subjects' arm circumference and significantly similarly decreased their biceps skinfold (time mean effect). However, no difference was detected between groups.

Figure 4 illustrates a significant main effect for time in muscle thickness variables to both training conditions. No significant interactions in the time x group were identified, indicating that EBRT was as efficient as EBRT+BFR in eliciting muscle mass gains in upper limbs. However, no significant differences were identified in isometric strength in response to the training period.

Relative strength gains were $-0.5 \pm 10.2\%$ and $0.5 \pm 12.1\%$ in the arms trained with EBRT and EBRT+BFR, respectively ($p = .824$). While the relative gains in elbow flexors muscle thickness were $1.8 \pm 6.2\%$ with EBRT training and $5.5 \pm 6.7\%$ in EBRT+BFR ($p = .063$).

DISCUSSION AND CONCLUSIONS

The primary purpose of this study was to monitor gains in strength and hypertrophy resulting from an elastic band resistance training (EBRT) program combined with or without blood flow restriction (BFR). The significant findings were that changes in strength and muscle mass following EBRT performed on the elbow flexors during eight weeks were similar to the obtained by EBRT combined with BFR.

In the same direction, literature about the effects of practical BFR method, i.e., using rubber tubes or elastic wraps to reduce blood perfusion, has suggested that this procedure is as effective as conventional resistance training in promoting strength gains (Luebbbers et al., 2014; Yamanaka et al., 2012).

It is important to note that the individuals did not significantly increase their elbow flexion strength with the training proposed here. Previous studies on the topic are scarce, and those available were conducted with older people. In the study by Thiebaud et al. (2013), for example, older women showed significant strength gains in both the EBRT group and the EBRT+BFR group after eight weeks of training. Yasuda et al. (2015) subjected older people of both sexes to elbow extension and flexion exercises using EBRT combined with or without BFR. They only observed significant gains in strength at the end of 12 weeks in the group that combined EBRT+BFR.

When gathering the available evidence on the isolated effects of EBRT on strength gains, unlike what was observed in the present study, the literature indicates that EBRT can provide strength gains in young, healthy men (Lopes et al., 2019). The failure of our protocol to result in significant gains in strength may have resulted from insufficient resistance of the elastic bands to cause adequate muscle activation. Muscle activation is a variable identified as essential for equalizing strength gains between exercises performed with elastic bands or conventional machines (Aboodarda et al., 2016).

Although we chose the elastic bands according to the volunteers' perception of effort and increased the resistance in the final third of the study, the resistance was still below what was necessary to trigger relevant adaptations in strength. While traditional resistance training must recruit all or almost all motor units since the beginning of the exercise (Kukulka & Clamann, 1981), the BFR possibly recruits a smaller number of motor units since most studies determine the number of repetitions, avoiding muscle failure. Then, the adopted protocols in these studies may have a different impact on the recruitment of motor units. (Yasuda et al. al., 2014).

On the other hand, muscle thickness did increase in both arms, suggesting that adding BFR to the elastic band training was ineffective at amplifying the hypertrophic effects of EBRT. The two previous studies that investigated the effects of EBRT combined with BFR were conducted with older people and found different results from ours. Thiebaud et al. (2013) pointed out that EBRT and EBRT+BFR could increase upper limb muscle thickness after eight weeks. Yasuda et al. (2015) demonstrated that significant gains in the cross-sectional area of elbow flexor and extensor muscles occurred only after EBRT combined with BFR. EBRT alone did not cause significant changes after 12 weeks.

The exact mechanism responsible for the hypertrophy process in BFR training is unknown, but several possibilities exist to explain the mechanisms. When BFR is associated with low-intensity training, there is an increase in the stimulus to muscle hypoxia, and, therefore, fundamental metabolic stress is produced to induce the mechanisms that would explain morphological adaptation. We can mention the release of anabolic hormones (Reeves et al., 2006; Takarada et al., 2000a), the reduction in the availability of myostatin (Laurentino et al., 2012), and cell swelling (Loenneke et al., 2012).

In the present study, the lack of additive hypertrophic effect of BFR on EBRT may be due to some reasons, including the applied BFR pressure. We used an adjustment based on the volunteers' arm circumference (Aniceto et al., 2021). However, this pressure was insufficient to determine the blockage of venous return, producing a reduced response in the metabolic stress expected to optimize muscular adaptations. Furthermore, the length of the training program (8 weeks in duration encompassing 15-20 workouts per subject) likely needed to be longer for differences to emerge in the training protocols if a difference exists. It is noteworthy that the relative gains in elbow flexors muscle thickness were $1.8 \pm 6.2\%$ with EBRT training and $5.5 \pm 6.7\%$ in EBRT+BFR ($p = .063$), indicating a tendency for more pronounced effects in the EBRT+BFR group over eight weeks. Thus, future studies employing a more extended training duration could increase the ability to detect significant changes in some variables.

Some methodological limitations apply to the current study. First, there may be better ways of assessing muscle strength than maximum strength testing on isometric equipment. Isokinetic dynamometry, considered the gold standard in assessing muscular strength and is more reliable and valid than other methods (Farrell and Richards, 1986), is suggested. There may also have been significant individual differences in the relative exercise intensity. One difficulty in using EBRT is determining the exact exercise intensity offered by the elastic bands between individuals.

Another aspect to be considered may be the cross-transfer effect. Resistance exercises performed unilaterally, where each limb works independently can indeed exhibit what is known as the cross-transfer effect. This phenomenon suggests that this effect occurs due to neural adaptations and possibly hormonal responses that benefit both limbs despite training only one. It underscores the interconnectedness and shared neural pathways between the limbs during resistance training (Wong et al., 2024).

In conclusion, this study demonstrated that using BFR in conjunction with an EBRT was not superior at increasing upper limb muscular strength or hypertrophy in young adults compared to EBRT alone.

AUTHOR CONTRIBUTIONS

All authors contributed to the study conception and design. Data collection and analysis were performed by André Soares, Rafael Siqueira and Claudia Meirelles. Statistical analysis was performed by Ramon Franco and Claudia Meirelles. The first draft of the manuscript was written by Claudia Mello Meirelles and Paulo Gomes and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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Panoramic view of the effects of active breaks in an educational context: A systematic review of the literature

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ABSTRACT

In education, optimising academic achievement (AA) and promoting attention and concentration are essential elements. The main goal of this systematic review (SR) is to analyse and synthesise the scientific evidence to examine the impact that the different interventions with active breaks (AB) have on the AA, attention, and concentration of the students in educational contexts. To do this, the PRISMA protocol is followed (REG INPLASY: INPLASY202390082). The documents that comply with the inclusion criteria for this research are 29 scientific articles extracted from the databases Web of Science (WOS), SCOPUS and ERIC. The specific goals of this study are detailed through 13 research questions related to the characteristics of the works and their results, e.g. thematic and geographic diversity, variability in the research designs, inclusion of several educational levels and academic contents, as well as the presence of common intervention modalities and heterogeneous durations. The panoramic view suggested by the results presents AB as an interdisciplinary topic of international interest mainly focused on basic education, with measure instruments that are diverse and have variable duration, which might influence the comparability between studies. Even though some studies back up the positive effects of AB, the heterogeneity of approaches and results highlights the need of future research in order to unify criteria and allow a better understanding of the effects of AB and their applicability in several educational contexts.

Keywords: Classroom-Based Physical Activity (CB-PA), Curriculum-Focused Active Breaks (CF-AB), Physically Active Lessons (PAL), Attention, Concentration, Academic achievement.

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INTRODUCTION

In education, optimising academic achievement (AA) and promoting attention and concentration are essential goals that, according to some studies, can be improved through physical activity (PA). According to Ruiz-Ariza et al. (2021), the modalities of PA that can be done in a school context are grouped in four categories: physical education lessons, active commuting to the school building, active breaks and pauses during the school day and physically active academic sessions. Watson et al. (2017) define active breaks in the classroom, or Classroom-Based Physical Activity (CB-PA), as short periods of PA that are done during regular lessons and the breaks between classes, that can or can't be related to the content in the syllabus. They can adopt three forms: Active Breaks (AB), which means short periods of PA as a break from the academic instruction; Curriculum-Focused Active Breaks (CF-AB), which are short periods of PA that include content from the curriculum; and Physically Active Lessons (PAL), which integrate PA in the classroom as a tool in the teaching-learning process.

Active breaks (AB) have arisen as an incipient strategy to improve these aspects. This investigation goes into scientific literature, synthesising an interesting variety of approaches and perspectives with the purpose of exhaustively analysing the relation between active breaks and their effect on attention, concentration and academic achievement, in order to shed light on the efficacy and the practical implications of this intervention in an educational context.

Among several investigations that have as subject of study the introduction of different PA modalities in the classroom, we can find Rasberry et al. (2011), who analysed the relation between PA at school and AA, finding mixed results. They concluded that the effect of practicing PA during school hours has no set pattern, since this practice may or may not influence AA, but it is not counterproductive. Norris et al. (2015) researched the effect of AB in educational variables in 11 articles, observing an improvement in maths, language, art, and social sciences in 1 study; and in social sciences in another. These authors emphasize having to consider the duration of the interventions, not being recommended to carry interventions that last less than 12 weeks in order to observe improvement thanks to practising physical activity in an educational context. Watson et al. (2017) evaluated the effects of PAL in AA, finding different results depending on the duration and the methodology of the interventions. Bedard et al. (2019) measured the impact of PAL on AA, cognitive functions, attention and enjoyment of 25 investigations done on students of between 3 and 18 years of age. The results of 20 studies reported improvement in attention, a small but positive effect on AA, but a negative effect on cognitive functions. Méndez-Giménez (2019) analysed the effect of PAL and AB in AA, cognitive performance, and health, including 11 studies in his analysis. He found improvement in the amount of moderate and intense PA in 5 studies, and improvement in concentration, cognition, and task time in 2; improvement in executive function was shown in 1, and 4 articles evidenced improvement in AA. However, he emphasized the diversity of interventions and results in this field. Sneek et al. (2019) analysed several interventions in maths, observing notable differences in 13 of the 29 studies carried out; however, in 14 other studies no notable differences were found, which suggests great variety of investigations in this field. Ruhland and Lange (2021) examined the impact of CB-PA (PAL) on attention and behaviour when carrying out tasks, finding significant differences in selective attention in 2 of 6 studies, and in concentration just 1 study showed a positive effect after the intervention. Peiris et al. (2022) evaluated the impact of PAL and CMB interventions on the variables AA, cognitive indicators, health habits, and health. The results showed considerable improvement in attention and concentration in 2 studies, and a positive and significant effect on maths in 6 investigations, 2 on reading, 1 on orthography, and 1 on learning a new language. Daly-Smith et al. (2018) researched the impact of interventions based on AB (n = 8) and PAL (n = 9) on cognitive variables, AA and behaviour in students of between 4 and 14 years of age. About attention, only 1 study showed considerable

differences. When it comes to AA, the AB interventions didn't show immediate improvement, but they did after 10 and 20 minutes. Masini et al. (2020) related AB to the levels of PA and behaviour in the classroom, finding significant effects in the moderate to vigorous PA; however, considerable improvement in cognitive functions or AA (maths, social sciences, reading) wasn't observed. Infantes-Paniagua et al. (2021) studied the relation of PA inside the classroom, during lessons (with or without academic content), or between classes with the variables of attention and concentration. The effect on the selective attention variable was moderate amongst the intervention and control groups; the effect on the concentration variable was insignificant amongst both groups. Loturco et al. (2022) analysed the effect of different interventions based on PA done with primary and secondary students, on the AA in maths, language, reading and composite scores. Even though the authors remind us that AA can vary due to a multitude of external factors, they point out that the impact of the interventions on AA and their effect on cognition is higher with higher intensity and longer interventions.

In face of the diversity and heterogeneity of studies, the main purpose of this systematic review (SR) is to analyse and synthesise the scientific evidence to examine the impact that different interventions with active breaks (AB) have on the academic achievement (AA), attention and concentration of the students in educational contexts.

MATERIAL AND METHODS

The standards that were established by PRISMA 2020 (Page et al., 2021) were the driving axes for the methodological development of the systematic review. It consists of 5 stages (Zawacki-Richter et al., 2020) that are presented below. The protocol is registered in INPLASY (Reg. INPLASY202390082).

Stage 1: Research questions

On Table 1 are presented the research questions analysed in the SR.

Table 1. Classification of the research questions and their initial coding.

Research questions	
PI.1	What year was the article published?
PI.2	What is the position of the journal in databases?
PI.3	What are the topics of the articles according to the category of the journal in databases?
PI.4	What is the geographic distribution of the publications?
PI.5	What research methodologies are used in the selected studies?
PI.6	Comparator?
PI.7	What education levels are included in the research? Or age of the participants?
PI.8	Number of participants?
PI.9	What areas of knowledge are involved in the studies?
PI.10	What kind of interventions have been used in the research?
PI.11	Duration of the intervention?
PI.12	What measure instruments have been used to measure the variables?
PI.13	What is the relation of active breaks with the attention, concentration, and academic achievement variables?

Stage 2: Eligibility criteria and information sources

Inclusion-exclusion criteria

The criteria were: type of document (open access scientific articles published in scientific journals), language (English, Spanish), time period (from the beginning until 30/11/2022), education level (preschool education,

primary education, lower secondary education, upper secondary education, vocational training, university education); research methodology (empirical studies with quantitative methods that aren't theoretical review articles), type of intervention (1. Active Breaks (AB) (short periods of PA as a break from academic instruction), 2. Curriculum-Focused Active Breaks (CF-AB) (short periods of PA that include content from the curriculum), 3. Physically Active Lessons (PAL) (PA in the classroom as a tool in the teaching-learning process), 4. Active Recesses (AR); comparator (passive control group, or group without physical activity; intervention group or groups based on PA during the school day and in the classroom; no control group); variables (attention, concentration, academic achievement).

Information sources

The databases used in the SR were Web of Science (WOS), SCOPUS and ERIC.

Stage 3: Search strategies

The classification parameters of keywords and filters sequence of the libraries used in the SR were established: “*Activity Break**” OR “*Active Class**” OR “*Classroom Movement Break**” OR “*CMB*” OR “*Physically Active Learning*” OR “*PAL*” OR “*School Based physical active*” OR “*Active Break**” OR “*Active Lesson**” OR “*Physically Active Classroom**” OR “*Active School Break**” OR “*School Physical Activity Break**” OR “*Classroom based physical activity*” OR “*Movement Break**” AND “*Academic Achievement*” OR “*Academic performance*” OR “*Academic Progress*” OR “*Academic Success*” OR “*Educational Achievement*” OR “*Academic Achievement*” OR “*Scholastic Achievement*” AND “*Attention*” AND “*Concentration*”.

The search was delimited using the following filters sequence in the WOS search: 1) Main collection of Web of Science. 2) Collections: Social Science Citation Index (SSCI) -- 1956 -. 3) Inclusion criteria: Type of document: Article. 4) Inclusion criteria: Open access. The filters sequence used in the search in SCOPUS and ERIC: Type of document: Article.

Stage 4: Process for the selection of studies

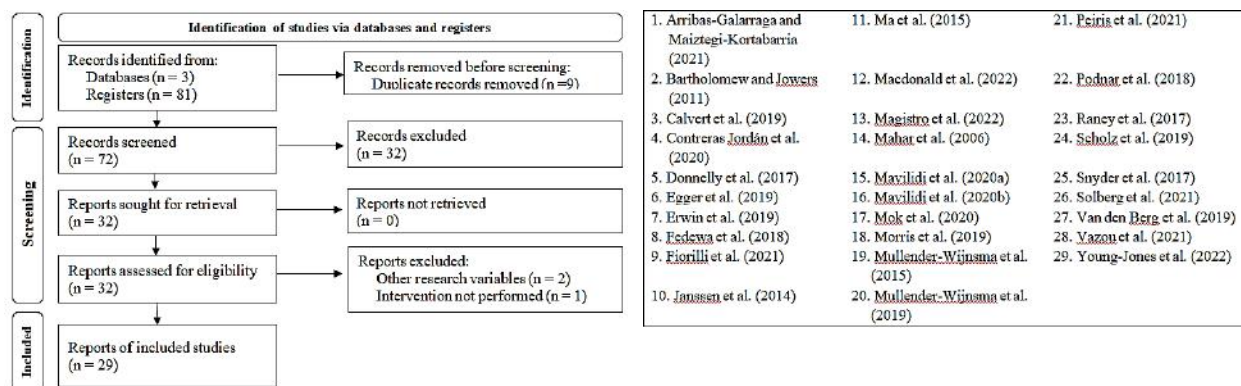


Figure 1. Flow diagram.

Stage 5: Coding and data synthesis

The bibliometric manager Zotero was used to compile and organise sources efficiently. After that, to synthesise and analyse the compiled information, a coding sheet with 13 specific fields was used. This sheet structured and categorised the data in a systematic way, facilitating the identification of patterns and relations in the information.

ANALYSIS AND RESULTS

PI.1. Publication year of the article

The years fluctuate between 2006 and 2022. In 2006, 1 publication (14). 2011, 1 publication (2). 2014, 1 publication (10). 2015, 2 publications (11,19). 2017, 3 publications (5, 23, 25). 2018, 2 publications (8, 22). 2019, 7 publications (3, 6, 7, 18, 20, 24, 27). 2020, 2 publications (1, 2). 2021, 5 publications (1, 9, 21, 26, 28). 2022, 5 publications (12, 13, 29, 15, 16).

PI.2. Impact index in JCR and/or SJR of the journal

The results of the impact of the journal in which the article was published indicate the following distribution: a total of 9 articles have been published in journals with a Q1 score in JCR (3, 10, 14, 15, 16, 17, 18, 21, 27). In a JCR Q2, a total of 5 investigations (5, 6, 9, 11, 19). In Q3 of JCR, 2 articles (26, 28). In Q4, a total of 2 articles published (12, 22). In journals with a Q1 score of SJR, 2 investigations (2, 13). Q3 of SJR, 1 article (8). Q4 of SJR, 2 investigations (24, 25). In journals with a Q2 score of JCI, 3 publications (1, 7, 20). In journals with a Q4 score of JCI, 1 publication (4).

PI.3. Thematic category of the journals according to the databases (WOS, SCOPUS, ERIC)

1 article (25) was published in the journal *Education*. 7 investigations (1, 4, 7, 12, 19, 20, 23) were published in the journal *Education and educational research*. 2 investigations (6, 9) were published in the journal *Health Care Sciences and Services*. 1 publication in the journal *Pediatrics* (15). 1 publication (24) in *Physical Therapy, Sports Therapy and Rehabilitation*. 1 article published in the journal *Psychology, Developmental* (28). 7 articles (2, 5, 16, 17, 21, 26, 27) were published in the journal *Public, Environmental and Occupational Health*. 6 publications in *Sport Science* (8, 11, 13, 14, 18, 22, 29). 1 article (29) published in *Teaching, Learning, Pedagogy, Education, Higher Education*.

PI.4. Geographic distribution of the publications

Most publications are from the United States, with a total of 8 articles (2, 5, 6, 14, 15, 19, 28, 29). In second place comes the Netherlands, with 7 investigations (3, 10, 12, 13, 18, 20, 26) published. In third place, United Kingdom with 4 publications (7, 8, 9, 23). In fourth place, Switzerland with 3 articles (16, 21, 27). In fifth place, with 2 articles (1, 4), Spain. And with only 1 publication, Canada (11), Croatia (22), Germany (24), Hong Kong (17), Turkey (25).

PI.5. Research methodologies

The review shows two studies that don't specify the used methodology. Amongst the rest of studies there are 2 studies of longitudinal character registered, the others (27) are transversal studies. 12 of the 29 analysed investigations use a quasi-experimental design, and 6 claim to be experimental. The rest of investigations don't explain the applied design.

Out of the 29 studies that compose our research, 10 use a quantitative methodology, 2 a mixed method and there is no research detected that complies with the inclusion parameters in this study that has used an exclusively qualitative methodology. The other investigations don't clarify it. When it comes to the type of study depending on the analysis they do, 2 are descriptive, 5 correlational, 2 make a regression analysis, 3 do multilevel analysis and 3 apply Cluster analysis.

PI.6. Comparator

Out of the 29 articles analysed, in 18 studies (1, 2, 5, 13, 14, 15, 16, 17, 18, 19, 21, 23, 24, 25, 27, 28), the participants were grouped in 1 passive control group or group without physical activity and in 1 intervention

group. In 4 of the studies (3, 4, 7, 22) there was no control group. In 4 studies (9, 12, 20, 26), 1 passive control group or group without physical activity and 2 intervention groups. The participants of 1 study (8) were divided into 2 intervention groups and no control group. And in 1 investigation (11) there was one group used both as control and intervention.

PI.7. Education levels of the participants

In section 7 of the analysis of results, out of the 29 reviewed articles, 23 articles had students of different levels of primary as participants of the investigation. In 3 articles (7, 14, 28), the participants were students at the age of preschool education. 2 of the articles (1, 26), were focused on secondary students. And 1 of the reviewed articles (21), on university students.

PI.8. Total N

The total number of participants varies from 29 until 3036.

PI.9. Areas of knowledge (subjects)

When analysing the types of intervention, out of the 29 studies, 10 investigations (1, 2, 9, 13, 15, 16, 18, 25, 27, 29) measured the AA of just one subject. 4 studies (7, 8, 19, 26), of 2 subjects. 4 studies (5, 6, 12, 20), of 3 subjects. 2 studies (17, 23) used more than one subject to measure the impact of active breaks on AA. Out of the 20 studies that analysed the impact of the interventions on AA, 16 investigations analysed the impact of active breaks on maths (5, 6, 7, 8, 9, 12, 13, 15, 16, 18, 19, 20, 25, 26, 27, 29) and 8 investigations (5, 6, 7, 8, 12, 19, 20, 26) used reading as an indicator of AA. 4 studies analysed the impact on orthography (1, 5, 6, 20). 1 study (29), on arts and language and 1 study (2) on word spelling.

PI.10. Type of intervention

Out of the 29 reviewed studies, in 13 of them (1, 2, 3, 5, 12, 13, 14, 17, 19, 22, 23, 27, 28) the interventions were composed by different CF-AB programmes. 7 other articles (4, 11, 16, 18, 21, 24, 29) have AB as a basis of the intervention. 2 studies (20, 25) have PAL as a basis. On the other hand, 7 studies (6, 7, 8, 9, 10, 15, 26) have used more than one type of intervention, allowing to analyse the effect of the different interventions.

PI.11. Duration of the intervention

The duration of the interventions fluctuates from only 1 intervention until a duration of 3 years. Only 1 session (9, 17, 29). Short-term interventions (1-4 weeks): 1 week (18), 10 sessions (4), 16 days (3), 3 weeks (11, 21), 4 weeks (2, 15). Medium term interventions (5-9 weeks): 5 weeks (25, 27); 7 weeks (1, 10, 28), 9 weeks (23). Long-term interventions (over 4 months and up to 3 years): 9 months (17, 8, 26), 20 weeks (6), 21 weeks (19), 1 year (12, 14, 22, 24), 2 years (7, 13, 20). 3 years (5).

PI.12. Measure instruments

This section compiles the instruments used to measure the different variables in each of the areas in which AB were implemented.

Academic achievement: maths

Wechsler Individual Achievement Test-Third Edition (WIAT-III) (5); arithmetic operations, visuospatial functions, Heidelberger Rechentest (HRT 1-4) (6); Mathematics Inventory (MI) (7); FastBridge Learning math and reading standardized assessment, Rasch Unit RIT Scale (8); MATH (9); WISC-IV (13); Individual Basic Facts Assessment Tool (IBFA), scales of the Programme for International Student Assessment (PISA) (15); Maths Addition and Subtraction, Speed and Accuracy Test' (MASSAT) (18); Tempo-Test Rekenen, reading

ability, Eén-Minut-Test (19); The Speed-Test arithmetic (20); Common Summative Assessment (CSA) (25); national tests of the Norwegian Directorate for Education and Training (26); reading comprehension, orthography, maths/arithmetic with CITO; Learning quiz score (29).

Academic achievement: reading

Wechsler Individual Achievement Test-Third Edition (WIAT-III) (5); Salzburger Lesescreening (6); Reading Inventory (RI) (7); Fast Bridge Learning math and reading standardized assessment (8); Wechsler Individual Achievement Test—2nd Edition—Australian Standardised Edition (WIAT-II) (12); Eén-Minut-Test (1-Minute Test) (19); One-Minute test (20); Norwegian Directorate for Education and Training (26).

Academic achievement: orthography

"Dictated text" ad hoc (1) active participation of two independent teachers specialised on physical education and primary to evaluate the lessons (2); Wechsler Individual Achievement Test-Third Edition (WIAT-III) (5); Hamburger Schreib-Probe (HSP 1–10) (6); The Speed-Test arithmetic (20).

Academic achievement: language and art

Learning quiz score (29).

Academic achievement: others

Mok et al. (17) used The Attitudes toward Physical Activity Scale (APAS) to measure the dimension of learning of content related to health and nutrition, social learning, environmental management, basic curricular learning, character development and exposition to arts and culture. Raney et al. (23) measured the knowledge on health, physical education, competences on nutrition, sciences, maths, and music through a 40 questions multiple choice quiz created ad hoc.

Attention

D2 attention test (1, 4, 11); Stroop Color and Word (SCWT) (9); subtest 'Sky Search' of the Daily attention test for children (TEA-Ch) (10); The Selective Visual Attention test (13); self-assessment through an analogic visual scale (21); Strengths and Weaknesses of ADHD-symptoms and Normal behaviour (SWAN) rating scale (28).

Concentration

D2 attention test (1, 4); Analogic visual scale, self-administered, of 10 cm (21); KT1 test (24).

PI.13. Relation of active breaks and academic achievement, attention and concentration variables

PI.13.1. Impact of active breaks on AA

Impact of active breaks on maths AA

In Table 2 are presented the results of the 16 investigations that analysed the impact of active breaks on maths. The results of 9 reviewed studies (6, 7, 9, 12, 13, 15, 19, 20, 26) indicate significant results in AA. However, 7 investigations (5, 8, 16, 18, 25, 27, 29) didn't identify significant differences.

Impact of active breaks on reading AA

In Table 3 are shown the results of the 8 investigations (5, 6, 7, 8, 12, 19, 20, 26) that analysed the impact of the interventions on reading AA.

Impact of active breaks on orthography AA

In Table 4 are presented the results of the 5 studies that analysed the impact on orthography (1, 2, 5, 6, 20).

Table 2. Impact of active breaks on maths AA.

	Author	Impact of active breaks on maths AA
5	Donnelly et al.	No significant difference between groups after 1 year, 2 years, 3 years and pre-post ($p < .05$).
9	Fiorilli et al.	Significant effect groups ($F_{2,123} = 3.68$; $p = .027$; $\beta = 0.66$; $\eta_p^2 = 0.06$). FIT (moderate-vigorous PA) better than CON (sedentary pauses) ($p = .023$; $d = .597$), no significant difference between CREAT (combination of cognitive-creative and conditional tasks) and FIT and between CREAT and CON ($p > .05$). Significant effect ($F_{1,123} = 10.82$; $p = .001$; $\beta = 0.90$; $\eta_p^2 = 0.08$). Post, higher scores for the intervention (pre: 26.6; post: 27.3; $p < .001$; $d = 0.155$). Significant interaction group-time ($F_{2,123} = 5.40$; $p = .005$; $\beta = 0.83$; $\eta_p^2 = 0.08$). Significant difference FIT (pre: 27.1; FIT post: 28.8; $p < .001$; $d = 0.344$), CON (FIT post: 28.8; CON post: 25.3; $p = .011$; $d = 0.621$).
6	Egger et al.	Significant difference post-test between groups ($F_{2,138} = 7.34$, $p = .001$, $\eta_p^2 = .096$). With significant difference G1 (high cognitive commitment, high physical effort) ($p = .001$) and G3 (high cognitive commitment, low physical effort) ($p = .002$) pre-post compared to G2 (low cognitive commitment, high physical effort).
7	Erwin et al.	Decreased significantly ($b = -10.90$, $t(1540) = -2.08$, $p = .04$) between winter 2016 and spring 2017. Significant difference ($b = 11.89$, $t(1540) = 2.28$, $p = .02$) in white students between winter 2017 and spring 2018. Between winter 2016 and spring 2017 white students significantly lower compared to students of two or more ethnicities ($b = 16.97$, $t(1540) = 2.26$, $p = .02$). No significant difference in gender, ethnicity, or grade as a result of the additional recess break given in 2017-2018.
8	Fedewa et al.	No significant difference ($b = -0.07$, $SE = 0.05$, $p = .19$, $ES = 0.07$) between groups. The difference in the intra-classroom correlation coefficients (CCI) between the reference model and the final model was .090 ($[.011 - .010] / .011$), 9% of the variance in maths measured in autumn.
12	Macdonald et al.	Significant general effect groups $F_{2,46} = 8.48$, $p = .001$, $\eta^2 = .269$ Small effect pre-post-test in group N (Cohen's $d = .10$, $p < .699$). Big effect pre-post-test in group R (Cohen's $d = 1.71$, $p < .001$) and group M (Cohen's $d = 1.31$, $p < .001$). Significant difference ($p < .001$) post-test between groups R and M compared to group N. Better progress group R ($p = .001$) and M ($p = .019$) than N.
13	Magistro et al.	Intervention group better result compared to control group (principal effect, $F_{1,80} = 24.32$, $p < .001$) and the scores of the participants improved over time (principal effect, $F_{3,240} = 180.66$, $p < .001$). Bigger effect in intervention group over time compared to control group (interaction group * time, $F_{3,240} = 14.43$, $p < .001$, $d = 0.9$ (big)). T4 better results in intervention group compared to control group (principal effect, $F_{1,80} = 28.90$, $p < .001$).
15	Mavilidi et al. (2020a)	Significant effect between AB and control group ($DM = 2.92$, 95% CI = 0.07 a 5.77; $p = .045$). No significant effect between AB and combined maths and control group. No significant effect between AB and AB and combined maths.
16	Mavilidi et al. (2020b)	Negative relation between AA and anxiety ($r = -0.27$, $p = .018$), the higher anxiety, the lower AA. Negative relation between anxiety and results during ($r = -0.24$, $p = 0.042$) and at the end of the test ($r = -0.43$, $p = .049$), and in the difficulty of the task ($r = -0.31$, $p = .014$). In both conditions, the very anxious ($M = 4.06$, $DT = 1,41$) obtained worse results than the not very anxious ($M = 5.11$, $DT = 1.72$).
18	Morris et al.	No effect on the TDM intervention group (model 1) pre-post ($b=1.03$, $SE=0.69$, 95% CI=-0.32, 2.39, $p=0.136$, $d=0.25$), nor in the TDM intervention group (model 2) ($b=1.23$, $SE=0.77$, 95% CI=-0.29, 2.74, $p=0.113$, $d=0.27$), neither on the control group ($b=-1.10$, $SE=0.70$, 95% CI=-2.48, 0.28, $p=.117$, $d=0.25$). No effect of the TDM intervention group total number of errors ($b=-0.63$, $SE=0.36$, 95% CI=-1.34, 0.08, $p=0.08$) nor in the control group ($b=0.61$, $SE=0.44$, 95% CI=-0.26, 1.47, $p=.168$)
19	Mullender-Wijnsma et al. (2015)	Significant interaction between the condition and the grade regarding post-test ($F_{1,209} = 26.48$, $p < .05$), but no significant effects. Intervention group 3 grade higher scores than control group 3 grade. Intervention group 2 grade lower scores than control group 2 grade.
20	Mullender-Wijnsma et al. (2019)	Significant improvement of the intervention group in the results of the mathematical velocity test ($t = 3.99$; $p < .005$; $ES = 0.35$) and in the results of the maths test ($t = 5.83$; $p < .005$; $ES = 0.54$) compared to the control group (period T0-T3)

25	Snyder et al.	No significant difference between both groups ($t(30) = -1.732, p=.094$).
26	Solberg et al.	Intervention of aerobic PA (path C) obtained an effect of 28% of the total effect of 1.73 points (95% CI: 1.13 a 2.33) and a direct effect (path C') of 1.24 points (95%, CI: 0.58 s 1.91).
27	Van den Berg et al.	No significant effect between groups after the intervention, effect between groups of 0.40 points (95% CI: -0.4 a -1.2).
29	Young-Jones et al.	No significant difference after any intervention. No significant difference between groups ($H(3) = 1.1, p = .781$) after the intervention of low PA, moderate intensity PA, yoga and control.

Table 3. Impact of active breaks on reading AA.

	Author	Impact of active breaks on reading AA
5	Donnelly et al.	No significant difference between groups after 1 year, 2 years, 3 years and pre-post ($p = .056$).
6	Egger et al.	No significant difference between groups G1 (high cognitive commitment, high physical effort), G2 (low cognitive commitment, high physical effort) and G3 (high cognitive commitment, low physical effort) ($F_{2,138} = 1.46, p = .236, \eta_p^2 = .021$).
7	Erwin et al.	Winter 2016 was significantly lower for black students than for white students ($b^{\wedge} = -9.90, t(1308) = -2.04, p = .04$). No significant difference in gender, ethnicity, and grade in the reading AA as a result of the additional recess between 2017-2018.
8	Fedewa et al.	Active Breaks (AB) significantly higher scores (pre-post) ($b = -0.12, SE = 0.05, p = .009$) than Curriculum-Focused Active Breaks (CF-AB). 0.13 effect, small difference between both groups. Score varies depending on the grade, since third and fourth grade students had higher scores than the fifth graders, with a small size effect ($SE = 0.15$ for third grade compared to fifth grade; $SE = 0.14$ for fourth grade compared to fifth grade).
12	Macdonald et al.	Big effect pre-post-test in N group (Cohen's $d = 1.27, p < .001$), in group R (Cohen's $d = 1.30, p < .001$) and group M (Cohen's $d = 1.54, p < .001$). Significant difference ($p < .001$) post-test between group M compared to group N. Group M significantly bigger improvement ($p = .017$) than N class.
19	Mullender-Wijnsma et al. (2015)	Significant interaction between condition and grade regarding post-test of ($F_{1,208} = 5.41, p < .05$), but no significant effects Intervention group 3 grade higher scores than control group 3 grade.
20	Mullender-Wijnsma et al. (2019)	No differences found between intervention group 2 grade and control group 2 grade. No significant differences ($t = 1.40; p = .16; ES = 0.08$) compared to control group.
26	Solberg et al.	Aerobic PA intervention (path C) obtained a direct effect of 0.89 points (95%, CI: 0.15 a 1.62) that lowered (path C') to 0.40 points (95% CI: 0.48 a 1.28).

Table 4. Impact of active breaks on orthography AA.

	Author	Impact of active breaks on orthography AA
1	Arribas-Galarraga et al.	Significant difference between experimental and control group ($p < .01$) (pre-post). No significant difference in averages ($Z = -0.279, p = .78$) after the intervention of the intervention group compared to the control group.
2	Bartholomew et al.	The results indicate improvement of control group with a small but insignificant benefit in relation to the intervention group (Cohen's $d = -.22; p = .11$).
5	Donnelly et al.	No significant difference between intervention and control groups after 1 year, 2 years, 3 years and pre-post ($p = .366$).
6	Egger et al.	No significant difference between groups G1 (high cognitive commitment, high physical effort), G2 (low cognitive commitment, high physical effort) and G3 (high cognitive commitment, low physical effort) ($F_{2,138} = 1.26, p = .287, \eta_p^2 = 0.018$).
20	Mullender-Wijnsma et al. (2019)	No significant difference ($t = 1.31; p = .19; ES = 0.14$) compared to control group.

Impact of active breaks on language and art AA

The results of Young-Jones et al. (29) indicate no significant differences after any intervention.

Impact of active breaks on AA: others

Two of the reviewed studies used more than one subject to measure the results. Raney et al. (23) measured the knowledge on health, physical education, nutrition competences, sciences, maths, and music through a quiz. The results indicate significant differences in the intervention group after 6 weeks (+80.5 ± 12.4%; d = 1.42, with considerable effect, $p < .001$). But there were no significant differences between sexes ($F_{1.89} = 0.01, p > .05$) or between the control and experimental groups ($F_{1.89} = 0.05, p > .05$).

Mok et al. (17) point out that learning, in reference to the subjects about health and nutrition, social education, environmental management, basic curricular learning, character development, art and culture, has a notable effect between both groups after the intervention. With an effect during the time of $F_{443.503}, p < .01, \eta^2 = .177$ and a significant effect between time and group, in favour of the intervention group ($F_{236.484}, p < .01, \eta^2 = .103$).

Pl.13.2. Impact of active breaks on attention

In this section are shown the results obtained after the review of the 29 articles included. Out of all the analysed articles, 8 investigations have analysed the existent relation between the different types of active breaks and the attention of the students. The total number of studies (1, 4, 9, 10, 11, 13, 21, 28) indicate significant differences on attention after the intervention. In Table 5 are shown the main results of the reviewed studies that have analysed the impact of active breaks on attention:

Table 5. Impact of active breaks on attention.

	Author	Impact of active breaks on attention
1	Arribas-Galarraga et al.	Significant difference ($Z = -3.361, p = .001$) in experimental group pre-post, no significant difference between groups.
4	Contreras Jordán et al.	Significant difference pre-post ($Z = -6.916, p = .000$).
9	Fiorilli et al.	Significant effect in groups ($F_{2.123} = 3.12; p = .047; \beta = 0.59; \eta^2 = .048$), group FIT (moderate-vigorous PA) is faster than CON (sedentary pauses) (9,83 compared to 12,23; $p = .034; d = 0.428$). No significant difference between FIT groups and CREAT group (combination of cognitive-creative and conditional tasks) (9.83 compared to 11.00; $p = .48$) and between CREAT and control group ($p = .45$). Significant effect in time ($F_{1.123} = 18.83; p < .001; \beta = 0.99; \eta^2 = 0.13$), post-test results faster after the breaks (pre: 11.8 - post: 10.2; $p < .001$). Significant effect between group and time ($F_{2.123} = 10.47; p < .001; \beta = 0.98; \eta^2 = 0.14$). Higher performance FIT group with significant differences $p < .001$ (pre: 11.6; post: 8,1; $p < .01; d = 0.764$).
10	Janssen et al.	Significantly lower scores (pre-post) intervention group passive breaks ($B = -0.27; IC$ of 95%: -0.35 to -0.18) than control. Significant improvement in selective attention. Scores (pre-post) vigorous PA group ($B = -0.29; IC$ of 95%: -0.39 to -0.19) significantly lower than control group, significant improvement in selective attention, but not in the passive rest ones. Moderate PA intervention, the scores (-0.59; IC of 95%: -0.70 to -0.49) (pre-post) were lower (significant improvement in selective attention and bigger effect) and significantly lower than control, passive rest, and intense PA intervention.
11	Ma et al.	Significant difference pre-post-test intervention group ($p < .05$) in D2 test. All measures in D2 test improved from week 1 to week 2 ($p < .05$). Significant difference ($p < .05$) between day 1 and day 2 in every result. Significant difference ($p < .05$) between day 3 and 4 for TE, Eomis and E%.
13	Magistro et al.	Significant differences ($p < .05$) between intervention group and control group in phases T2, T3 and T4. With effect on the intervention group of $F_{3.240} = 48.65, p < .001$ and on the control group of $F_{1.80} = 21.23, p < .001$. Group time effect, $F_{3.240} = 7,71, p < .001, d = 0.3$ (small). Bigger in the intervention group in T4 (main group effect, $F_{1.80} = 4.20, p = .044$).

21	Peiris et al.	Significant difference (pre-post) between the classes with active breaks and the classes without active breaks in group A (DM=1.5, 95% CI=1.1 to 1.9, p<.001) and in group B (DM=1.4, 95% CI=1.0 to 1.8, p<.001). No differences between the effects between class type (p= .796) nor class time (p=.194).
28	Vazou et al.	Significant effect of the walkabouts programme between the time and the group for attention ($F_{1,194} = 64.95, p < .001, \eta^2 = .25$) and for behavioural control ($F_{1,194} = 59.22, p < .001, \eta^2 = .24$), between the time and the group and the level for attention ($F_{2,194} = 17.23, p < .001, \eta^2 = 0.15$) and for behavioural control ($F_{2,194} = 11.92, p < .001, \eta^2 = 0.11$), and between group and grade for attention ($F_{2,194} = 5.33, p = .006, \eta^2 = 0.05$) and for behavioural control ($F_{2,194} = 9.09, p < .001, \eta^2 = 0.09$). Preschool groups: No significant difference between groups after the intervention nor in behavioural control. Primary school groups (nursery): Principal significant effect and an interaction time x group (intervention, control) both for attention ($F_{1,48} = 17.28, p < .001, \eta^2 = .26$; $F_{1,48} = 116.18, p < .001, \eta^2 = .71$) and for behavioural control ($F_{1,48} = 21.84, p < .001, \eta^2 = .31$; $F_{1,48} = 61.23, p < .001, \eta^2 = .56$). Intervention group significant difference pre-post ($t = 105.69, p = .000, d = 1.75$; $t = 50.19, p = .000, d = 1.33$). Control group significant decrease pre-post ($t = 43.16, p = .000, d = -.72$; $t = 25.83, p = .000, d = -.75$). Primary school group (2 nd grade): Significant principal effect and interaction time x group (intervention, control) both for attention ($F_{1,71} = 10.21, p = .002, \eta^2 = .13$) and for behavioural control ($F_{1,48} = 21.84, p < .001, \eta^2 = .31$; $F_{1,71} = 12.84, p < .001, \eta^2 = .15$). Intervention group significant difference pre-post both in attention ($t = 12.18, p = .001, d = 0.45$) and behavioural control ($t = 10.78, p = 0.002, d = 0.49$). Control group significant decrease pre-post in behavioural control ($t = 43.16, p = .000, d = -.72$; $t = 25.83, p = .000, d = -.75$).

PI.13.3. Impact of active breaks on concentration

The existent relation between active breaks and the concentration variable was analysed in 4 articles (1, 4, 21, 24) out of the 29 that were reviewed (Table 6).

Table 6. Impact of active breaks on concentration.

	Author	Impact of active breaks on concentration
1	Arribas-Galarraga et al.	Significant difference (pre-post). Experimental group ($Z = 2.947, p = .003$) and control group ($Z = -2.983, p = .003$). No significant difference between groups ($p < .05$).
4	Contreras Jordán et al.	Significant difference pre-post ($Z = -7.273, p = .000$).
21	Peiris et al.	Significant difference (pre-post) between the classes with active breaks and the classes without active breaks in group A (DM=1.4, 95% CI=1.0 a 1.9, p<.001) and in group B (DM=1.6, 95% CI=1.2 a 2.1, p<.001).
24	Scholz et al.	T1 no significant difference between control and intervention group ($p = .96$). T2 and T3 higher score intervention group with significant difference ($p \leq .001$) between control and intervention group. Significant difference ($p \leq .001$) in the times T1 and T2, T2 and T3 both in control and intervention group. Significant difference between T1 and T3 in both groups ($p \leq .02$). No significant differences between sexes ($p \geq .74$).

DISCUSSION

This SR analyses exhaustively the relation between AB and their impact on attention, concentration, and AA in a school environment. The results of the investigations included in this review, as it happened in other studies (Méndez-Giménez, 2019; Sneck et al., 2019) are not easy to interpret due to the variety of

methodologies used, the types of intervention, the variety of the composition of the intervention and control groups, the educational levels of the participants, the number of participants of each study, the areas of knowledge measured to analyse the impact on AA, the duration of the investigations and the instruments used to measure the variables of each study.

When interpreting the results of AA it must be taken into consideration its multifactoriality, so we agree with Loturco et al. (2022) in that AA can vary for a variety of external factors. Moreover, through the carried analysis, just like Watson et al. (2017), it is concluded that the effects of AB on the different variables vary depending on the duration of the intervention and the instrument of measure used. However, in line with the review done by Sneck et al. (2019), the improvement in the results in AA after the AB were significant in a greater number than the non-significant. This way, in maths –even though it brings to light the heterogeneity and disparity in the impact of the AB on AA when looking at the results, like it happened in the work of Sneck et al. (2019)–, it is concluded that there exists a general positive effect in favour of the different interventions with AB in the AA in maths. About the impact on AA in orthography, the results suggest that, despite certain variations in the results, in general the assessed interventions don't show statistically significant impacts. Along the same lines, the results related to language put into question the impact of AB on AA. However, Loturco et al. (2022) point out that the different interventions based on PA have a limited impact on AA in favour of AB, which has been substantiated in this review. Additionally, it should be pointed out that the results of the interventions done with PA of higher intensity and with longer interventions have a bigger effect on AA.

When considering the results of the investigations where they used more than one subject to measure the performance and impact of AB, the results, as it happened in the work of Méndez-Giménez (2019), make clear the complexity of AA and the great variety of investigations and results. However, when observing the effect of the interventions, in agreement with other reviews (Norris et al., 2015; Bedard et al., 2019; Loturco et al., 2022) the final results indicate improvement, but it is not always significant.

When it comes to the impact of the different interventions on attention, the reviewed documents (Watson et al., 2017; Ruhland and Lange, 2021; Daly-Smith et al, 2018) agree in pointing out that AB have a positive influence on the students' attention, which backs up the idea that incorporating AB in the school environment can be beneficial for the attention of the students. The results related to concentration (Contreras Jordán et al., 2020; Peiris et al., 2021), suggest that AB can have a positive impact on the students' concentration. Moreover, the Scholz et al. (2021) study backs up the results of the review by Watson et al. (2017), in which longer interventions, with a duration of between 1 and 3 years, obtained better results compared to shorter studies. However, the heterogeneity of the results brings up some interesting questions about the moderators that could influence the effects of the AB on concentration. It is important to add that these significant differences weren't observed in all studies equally, which suggests that the relation between AB and concentration is complex and can vary depending on the circumstances.

This review offers a vision of the relation between active breaks and AA, attention, and concentration in an educational environment. While some studies back up the positive effects of AB, the variability in the investigation designs, methods in the application of AB (number of participants, subjects and varied contents, duration, intensity, intervention programmes, measure instruments) and the variability in the results highlight the need for future investigations to better understand the effects of these interventions and their applicability in different educational contexts.

CONCLUSIONS

The most outstanding conclusions related to the specific goals are the following:

- Thematic and geographic diversity: the research comes from various disciplines and countries, which reflects a global interest in active breaks in education.
- Variability in the investigation designs: different methodological approaches, from intervention and control groups to more complex designs, which highlights the importance of considering the particularities of each study.
- Different educational levels: several educational levels are approached, with a predominant focus on primary school students.
- Varied subjects and content: various subjects and academic content for the interventions, which suggests great interest from the teachers and the necessity of exploring how these differences affect the results.
- Common modalities of intervention: the intervention of the type “*Curriculum-Focused Active Breaks*” and “*Active Breaks*” were the most frequent, which raises questions about their efficacy compared to other modalities.
- Heterogeneous duration of the interventions: they varied greatly in duration. It is concluded that temporality affects, and longer interventions are shown to be more effective.
- Diverse measure instruments: the diversity stands out, which emphasizes the importance of standardising the tools for future investigations.
- Impact on academic achievement: the heterogeneous results are made evident. The complexity and diversity of the interventions is highlighted, as well as the importance of considering external factors when evaluating their impact on academic achievement.
- Impact on attention: it consistently presents significant improvement after implementing AB, backing up the idea that these can have a positive impact on attention and behaviour during tasks.
- Impact on concentration: the results are more varied, indicating the complexity of these processes and the influence of contextual factors. Even though some studies suggest significant improvement, others show mixed results, highlighting the necessity of interpreting with precaution the conclusions about the impact of active breaks on these areas.

As a final conclusion, a panoramic view of the effects of AB in an educational context is offered. One of the important aspects that these results suggest is the distribution of publications in journals with various approaches, which cover areas like education, health, sport, psychology, and pedagogy. The diversity of countries of origin of the publications suggests a global interest in exploring the impact of AB in the school context, and it could reflect cultural differences and pedagogic approaches in relation to this strategy. A key element that comes up in the results is the diversity in the investigation designs, which might influence the interpretation of results and highlights the importance of considering the particularities of each study when analysing the effects of AB. Even though evidence of intervention with AB has been found in all educational levels, the fact that a great number of articles involved primary school students brings up a predominant approach on basic education. This fact influences the applicability of the results on other educational levels and raises the necessity of further investigating the effects on superior levels.

The subjects and academic content used in the interventions also showed a significant variability, with emphasis on maths (16 interventions), reading (8 interventions), and orthography (5 studies). These results suggest the necessity of exploring if certain subjects are more susceptible to the positive effects of AB, and if the intervention modalities differ depending on the academic content.

About modalities of intervention, it was observed that CF-AB (13 investigations) and AB (7 investigations) were the most common. This brings up the question if it exists a modality that stands out in terms of impact on AA, attention, and concentration, as well as the necessity of examining how different approaches can complement each other in an educational environment. It is fundamental to emphasize that the duration of the interventions varied greatly, from one-time interventions to investigations that expanded over the course of three years. This diversity in duration may have significant implications for the persistence of the observed effects and suggests the need to understand how temporality influences the efficacy of active breaks.

It is important to point out that the measure instruments used to compile data also presented variability, which might influence the comparability of the results among studies, and makes clear the importance of standardising the measure tools in future investigations to allow a more precise comparison and deeper understanding of the effects of AB.

Finally, we want to highlight that these studies reveal heterogeneous results on the effects of AB interventions and highlight the importance of considering several external factors when evaluating their impact on attention, concentration and AA.

AUTHOR CONTRIBUTIONS

This work has been done with a team, but the responsibilities have been distributed as follows:

- -Conception and design of the study: Silvia Arribas Galarraga, Julen Maiztegi Kortabarria.
- -Data compilation: Julen Maiztegi Kortabarria.
- -Data analysis and interpretation: Silvia Arribas Galarraga, Julen Maiztegi Kortabarria, Izaskun Luis de Cos and Saioa Urrutia.
- -Report redaction: Julen Maiztegi Kortabarria, Silvia Arribas Galarraga.
- -Report review: Silvia Arribas Galarraga, Julen Maiztegi Kortabarria, Izaskun Luis de Cos.

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Mental training for college athletes: A comparative analysis of Chinese and Western approaches and innovations

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ABSTRACT

This paper examines the development of mental training in sports, emphasizing the differences between China and other countries in terms of training methods and research approaches. The study employs a literature review method to analyse existing domestic research and draw conclusions. Numerous studies have shown that mental training is crucial for enhancing athletes' performance. By investigating the definitions of mental training in various regions and assessing the current state of mental training in Chinese universities, this study highlights these differences. The findings reveal several gaps between China and other countries in this field: 1) China's research on mental training started relatively late, with limitations in both content and depth; 2) deficiencies in research design, including limited scope in subject and sample selection, unclear operational definitions of variables, and insufficient control of extraneous variables; and 3) a lack of empirical research and methodological innovation in mental training. These findings suggest that China needs to expand and enhance research in mental training, with a particular focus on empirical studies and methodological innovation, to bridge the gap with other countries.

Keywords: Mental training, Sports performance, College athletes, Chinese, Western.

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INTRODUCTION

Success in competitive sports depends heavily on two factors: skill (including strength and endurance) and motivation (e.g., mental attitude, confidence)(Locke & Latham, 1985). Mental training, as an integral part of athletic training methods, has received much attention for its effectiveness in improving mental and physical aspects of athletic performance. This mode of training has evolved over the last century, with innovations in methodology accelerating markedly in the mid-20th century. For example, Vealey (2007) noted that the application of mental training has expanded from elite competitive sport to the field of physical education, particularly amongst young people involved in sport. Mariani et al. (2019) further emphasize the importance of mental training for the dual development of physical and mental health in young athletes and professionals. The diversity of mental training techniques - from mental imagery to positive thinking training - suggests a tailored approach to teaching and learning that aligns with the nuanced motor skills required in a variety of sports (Lindsay et al., 2023).

The first explorations of mental training began in the early 20th century and have evolved over the past century. Subsequently, the systematic development of mental training occurred in the mid-20th century (Lochbaum et al., 2022). This adaptive approach has been shaped by historical contexts, socio-cultural factors, and the diverse needs of sports disciplines in different countries and eras (Adeyeye et al., 2013; Jain et al., 2015; Subathra et al., 2021; Zhang et al., 2021). Currently, research on psychological training is more focused on the perspective of elite athletes (Si et al., 2011; Si et al., 2021; Галинська & Бінсюй, 2022). Research on the psychological condition of college athletes is weak, and this is an area that few Chinese scholars have explored (Fang et al., 2023). This study adopts an inductive literature review method to critically review a variety of psychological training methods and distil the effects of various psychological training methods on athletic performance, aiming to assess the applicability and effectiveness of these psychological training strategies, analyse the current status of domestic scholars' research in the field of psychological training, and put forward the research strengths and shortcomings of Chinese and Western scholars in a bid to provide other scholars with research on the psychological training of university student-athletes to provide valuable references for other scholars' research on the psychological training of college athletes.

METHODOLOGY

In the research methodology section, the researcher used an inductive literature review method to construct the design of this study. The purpose of the study was to analyse the effectiveness of mental training methods in improving the athletic performance of Chinese college athletes through a literature review and to identify research gaps compared to international studies. This section describes the research design in detail.

Data collection

Source Academic databases (CNKI, Web of Science, Google Scholar).

Types: empirical studies, theoretical papers, review articles, master's theses, doctoral dissertations.

Keywords: mental training, mental skills training, athletic performance, college athletes, China.

Through data collection, the author retrieved 300 pieces of related literature, including 200 pieces of Chinese literature and 100 pieces of Western literature. By analysing and comparing, the author sorted out the differences between Chinese and Western research fields, research contents, research objects, and research methods in the field of mental training.

Table 1. Literature quantity summary table form.

Literature geography	A study of college athletes	A study of elite athletes
China	175	25
International	12	88

Note. Unit: Articles.

Data analysis

Literature classification: Literature was categorized according to mental training techniques, research focus, sample size, and research methods.

Techniques: Goal setting, visualization, positive thinking, meditation, self-talk, relaxation

Research focus: college athletes.

Sample size: Large versus small scale studies.

Research methods: empirical research, experimental design, qualitative analysis.

Evaluation criteria

Relevance: To determine the relevance of each study to the research objectives.

Quality: To assess the methodological rigor and validity of each study.

Findings: Extract the main conclusions related to the effectiveness of mental training methods and their impact on athletic performance.

Gaps: Identify gaps in research focus, sample diversity and methodological innovation.

Comparative framework

International and Chinese studies: Comparison of the development, application and effectiveness of mental training methods.

Development: Historical evolution and current trends.

Application: specific techniques used and their implementation in training.

Effectiveness: Measurement of results and performance improvement.

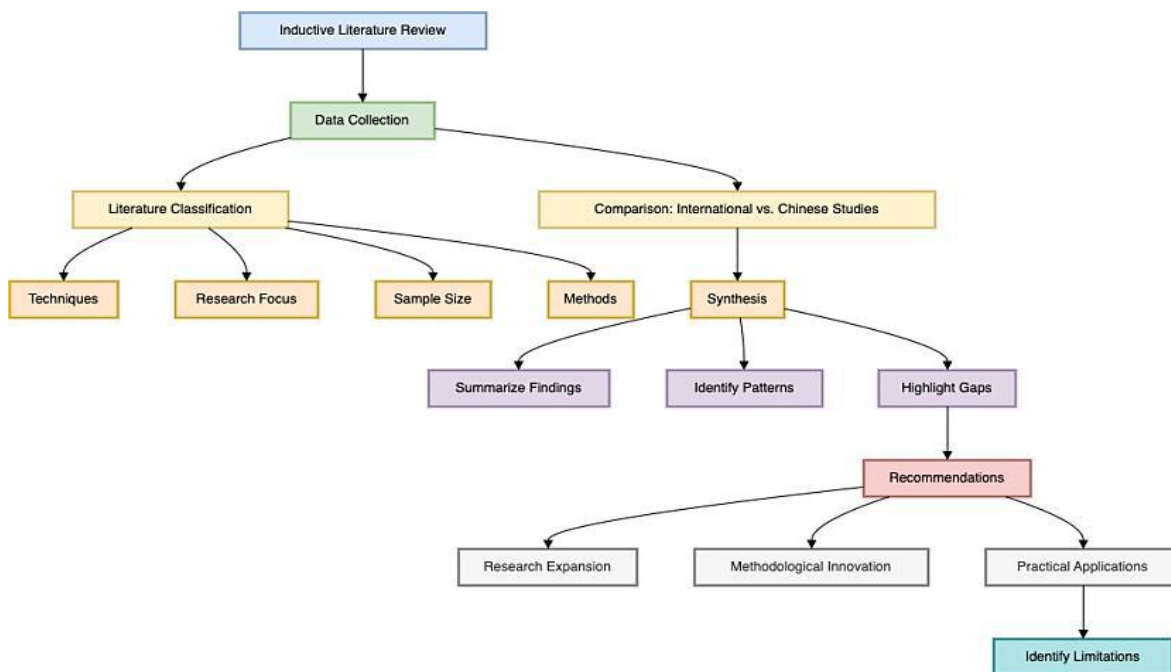


Figure 1. Conceptual framework for analysing national and international research on mental training.

Synthesis

Summarize findings: Compile the main findings of the literature review.

Identify Patterns: Identify common themes and differences between Chinese and foreign studies.

Highlighting Gaps: Highlighting areas where Chinese research is lagging behind or where there are significant gaps.

This conceptual framework (Figure 1) was adopted in this paper to comprehensively analyse the effectiveness of mental training in improving athletic performance, with a particular focus on Chinese college athletes, as well as to provide valuable insights for future research and practical applications.

DEFINITION OF MENTAL TRAINING

In sports, when it comes to training, we can quickly associate it with physical training, strength training, endurance training, speed training, etc. However, few people can think of the fact that athletes' performance and athletic performance also have a very important relationship with the athletes' psychological state, and a more stable and positive psychological state can bring a positive impact on athletes' performance, and mental training is becoming an important training component used in sports training (Glass et al., 2019). In recent years, sport psychology has received more and more attention from scholars, and mental training and mental skills training have become popular contents of research in many fields of psychology and sports science. Psychological skills training (PST) refers to the learning and practice of a mental skill, which is a strategy of mental state regulation that can help athletes regulate their mental state and emotional state so that they can better perform their sport in competition and improve their sports performance at the same time (Kumari & Kumar, 2016). Western scholars (Sponholz, 2012) and Eastern scholars (Jingjing, 2023) have reached a consensus that PST has at least two goals: the first is to help athletes perform at a more desirable level of athletic performance and improve athletic performance through mental training. The second is to help athletes achieve better self-development and life development through long-term mental training. Chinese scholar Jian (2023) believes that mental training is an important way to exercise and improve the mental ability of high-level athletes, and that positive and effective mental training can not only improve athletes' athletic ability and performance, but also exercise their psychological tolerance, so that athletes can always remain calm, complete the game and achieve good athletic performance. Slagter et al. (2007), who defined mental training as the practice of attentional skills, believed that mental training can have an impact on the brain and cognitive functions and stimulate the brain to process or perceive accordingly. Turgut and Yasar (2020), who believed that mental training refers to the practice of skills that can change the mental state in a certain way, which can help athletes to better regulate and control their own athletic performance, said that mental training can improve athletic performance and improve the mental ability of athletes. However, the pattern of mental training has not been specifically delineated in previous studies, and future research should enhance the understanding of how each mental training category applies specifically to each sport.

WESTERN SCHOLARS' RESEARCH ON MENTAL TRAINING TECHNIQUES: STRENGTHS AND LIMITATIONS

Western scholars' research on mental training started earlier, and scholars have developed a series of mental training techniques such as meditation, imagery, goal setting, visualization, self-talk, positive thinking and so on through testing. Through experiments and measurements, these techniques have been proved to have obvious functions of improving sports performance (Glass et al., 2019; Lin et al., 2021; Ungerleider, 2005). Through scholars' research on mental training, we provide an overview of commonly used mental training

techniques, which are goal setting, visualization techniques, positive thinking meditation, self-talk, and relaxation techniques.

Goal setting is the same as the SMART method of goal setting, i.e., setting achievable, measurable, time-bound, and specific goals to give athletes clarity and focus. Locke and Latham (1985) explored in their article a study of NCAA football coaches comparing coaches with a better win-loss record to coaches with a poorer win-loss record over a period of 5 years, using goal setting techniques were more likely to help players win games. In subsequent research (Weinberg & Gould, 2023), goal setting was found to have a positive impact on athletic performance, primarily in the form of improved free throw shooting after goal setting practice. Weinberg and Gould research provided a detail data for the goal setting, that this goal setting may give athletes psychological cues to reach greater performance.

Imagery training is also often referred to as visualization and mental rehearsal (Gould et al., 2014). In sports training, imagery is understood as imagining the physical sensations and visual images of movement without movement (Simonsmeier & Buecker, 2017). Many scholars have conducted practical studies on imagery training, and these studies have confirmed that imagery training can effectively help athletes improve their sports performance (Ladda et al., 2021). Based on current studies, the reason for the incomplete application of imagery method in physical training may be that different sports are not suitable for imagery-based training. In addition, researchers need to expand the detailed data of the experiment in different sports events.

Positive thinking and meditation, a common approach to mental training, are often used in combination in sport. Their positive effects on athletic performance have been confirmed by several studies. Hut et al. (2023) concluded from a controlled trial that college athletes' sport anxiety and enjoyment of sport improved after mental skills training (PST) and a positive thinking intervention (MSPE). Baltzell and Akhtar (2014) concluded from an experiment with female athletes that positive thinking meditation training can help athletes stabilize their emotions and focus more on the present moment, which can have a positive impact on improving athletes' game status and sport performance. In these studies, there is still a need to refine the research across sports and expand the selection of sample sizes in the studies to ensure that Positive Mindfulness Meditation is a mental training technique that can be generalized to all sports and sports groups.

Self-talk, often referred to as self-talk, is an area of research that has historically attracted the attention of psychologists and philosophers (Fritsch et al., 2024; Hardy et al., 2004; Hatzigeorgiadis et al., 2011; Tod et al., 2011). In the field of athletic training, self-talk has been shown to have a positive impact on athletic performance, especially in sports where motor technique dominates (Hatzigeorgiadis et al., 2011). Clearly, there is a reciprocal relationship between sports performance and self-talk. However, in the studies of Western scholars, there are more positive studies on self-talk and fewer reverse studies, e.g., whether athletes' negative psychological performance in competition or training is influenced by negative self-talk, which suggests that the diversity of studies and the exploration of research perspectives should be broadened in this area of research.

Deep breathing, also known as diaphragmatic breathing, is a technique used to relax the mind and body by inhaling deeply and exhaling slowly (Toussaint et al., 2021). Incorporating relaxation techniques such as deep breathing into a daily sports training program can help athletes reduce anxiety and improve performance (Parnabas et al., 2014). In addition, Ismail et al. (2022) showed that deep breathing techniques not only help athletes improve mental toughness, but also regulate pre-competition stress. While most researchers have explored the direct relationship between deep breathing and relaxation and anxiety relief, fewer have

examined the relationship between deep breathing and athletic performance, and the findings lack support from multiple data sources.

Based on current research, it is evident that Western scholars have certain advantages and limitations in the field of mental training research. The advantages include:

Early initiation and mature theoretical framework

Western countries began research on mental training early, leading to the development of a well-established theoretical framework. This system encompasses various psychological intervention techniques, including cognitive behavioural therapy, positive thinking training, and visualization. These methods are not only applied in clinical psychology but are also extensively used in sports, education, and other fields.

Extensive empirical research

Western research in mental training is characterized by a substantial number of empirical studies, particularly randomized controlled trials (RCTs), which provide robust evidence supporting the effectiveness of these interventions. This rigorous research design enhances the scientific credibility of the findings.

Interdisciplinary collaboration

Research in this area often involves cross-disciplinary collaboration among fields such as psychology, neuroscience, and physiology. This interdisciplinary approach offers a more comprehensive understanding of the mechanisms underlying mental training, contributing to insights into its multifaceted impact on athletic performance and mental health.

However, there are also certain limitations in these studies:

Long-Term and continuity issues

Much of the existing research on mental training focuses on short-term experimental studies. Consequently, conclusions are often drawn from short-term data, with a lack of long-term tracking and exploration of the enduring effects and practical applications of mental training.

Research subjects and sample size

Many studies have dealt mainly with elite and professional athletes, with fewer studies on adolescents, college athletes and amateur athletes. This limits the generalizability of the findings to a wider population. In addition, the relatively small sample sizes of some studies may lead to variability in the findings and reduce the overall robustness of the data.

Research design and methodology

Most research relies on observational methods and tends to use a single research methodology, such as questionnaires and self-reports, which can introduce subjective bias. In sport, research has tended to focus on psychological training only, neglecting the integration with physiological training, which hinders a comprehensive understanding of the overall improvement of athletic performance.

REVIEW OF CURRENT RESEARCH ON MENTAL TRAINING FOR COLLEGE ATHLETES IN CHINA

China's research on sport psychology started late, and there is no unified theory and complete training system for mental training, and the application of mental training among college athletes has not yet been popularized (Kunfeng & Yonghai, 2022). According to the current study, Chinese scholars' research on mental training

mainly focuses on the following aspects, i.e., representation training, positive thinking meditation, self-talk and relaxation training. (Kunfeng & Yonghai, 2022; Lee, 2021)

Imagery training is a relatively well researched mental training method in China in recent years, but it is still at a relatively superficial stage (Jiahui, 2021). Changzhu and Pei (2001) studied the concept, theory and main research areas of imagery training, and he believed that imagery refer to all psychological phenomena that are characterized by images on the surface. Imagery training can not only help athletes better acquire and consolidate sports skills, but also effectively deal with athletes' anxiety, regulate the activation level, and promote the rehabilitation of sports injuries. In addition, research on imagery training has also been carried out in various sports. For example, the application of imagery training in college dance teaching (ye, 2006), the application of badminton training in universities Yi (2008), the application of swimming teaching in universities (Hui, 2014), the application of volleyball training in universities (Haijing, 2007), the application of golf teaching (Wenlong et al., 2019) and so on. Although the research on imagery training in China is still in a relatively shallow stage, and the conclusions drawn from the research are not so convincing (Zhihui, 2018), it is undeniable that imagery training can help the learning of motor skills, and it is a very effective mental training method (Peiquan et al., 2023). However, it is worth noting that imagery training can also be subdivided into several contents, and the adaptability of these subdivided imagery training contents to the training contents of sports is easily overlooked by researchers (Maolin et al., 2020), which will be an obstacle to the development of more targeted and effective training methods.

Positive thinking meditation training is an effective mental training method to help athletes relieve mental fatigue, which can positively regulate the human brain and nervous system (Yexuan, 2024). However, judging from the current research situation in China, the research on integrating positive thinking meditation into the daily training of college athletes is still very scarce, and has only gradually increased in the past two years. In her master's thesis, Huaru (2023) Mental fatigue in college athletes was studied in a master's thesis, and it was observed that mental fatigue in athletes could be effectively alleviated after a positive thinking intervention. Fengbao et al. (2024) conducted a psychological intervention study on 300 college athletes from a sports university in their research and found that athletes with high levels of positive thinking were more able to enjoy and focus on the game and produce a higher level of fluency experience during the game. From the current study, the potential application of mindfulness training across all sports and its implementation as a supplement to physical training in daily routines requires further investigation. It is crucial to expand the scope of research to determine whether mindfulness training can not only alleviate mental fatigue but also enhance athletic performance. Additionally, research should explore the feasibility and effectiveness of incorporating mindfulness training into the daily training regimen across various sports disciplines.

Self-talk is a common mental training method used by many Chinese coaches in their daily training, who often ask athletes to tell themselves "*I can do it*", "*I can do it*" and other self-affirming words to stabilize the athletes' psychological state and improve athletes' confidence and performance (Liu et al., 2023). However, a search of the CNKI website revealed that there are only 79 studies on self-talk in the field of sport, which has only gradually increased in the last decade, and there is no localized research in the field of self-talk, and there is a lack of localized and innovative design of research methodology and measurement tools (Jingchao, 2021). However, it is undeniable that in recent studies, self-talk has answered yes to whether it can improve athletes' sports performance. Xiaoting and Hongwei (2016) conducted an experimental control analysis on national tennis youth athletes and college tennis players respectively, and the results of the study showed that self-talk had a stronger effect on improving first serve accuracy for college athletes, and that self-talk was able to effectively improve the athletic performance of college tennis players. However, improving athletes' ability to self-talk during daily training requires more attention from academics and coaches. Current

research in China has mainly emphasized experimental evaluations between coaches and athletes, but there is a need to explore external factors as well. For example, the popularity of the Internet and the impact of educational measures on athletes may be critical to the development of effective self-talk strategies. Further research in these areas may provide a more comprehensive understanding of how to optimize athletes' self-talk training.

Relaxation training, also known as ideological relaxation, refers to training in accordance with certain procedures to regulate one's physiological and psychological activities, so that both physiology and psychology tend to be in a relaxed state (Mengyao, 2019). According to the classification of forms, it is divided into apparent relaxation, imaginative relaxation, biological relaxation, progressive relaxation and so on, and according to the classification of methods, it is a total of respiratory regulation, music regulation, psychological suggestion regulation and other methods (Qingjiang, 2014). In the field of mental training, relaxation training has been researched by Chinese scholars as a point of mental training, but the number of studies is also very scarce, with studies focusing on swimmers, sparring athletes, basketball players, and fencers (Qing, 2022). For example, Dianshuai and Zhenguo (2023) conducted an intervention study on the fatigue phenomenon of college student sparring athletes, and pointed out that music conditioning has a very good effect on muscle relaxation, which not only improves the athletes' psychological state, but also effectively relieves muscle fatigue, cardiorespiratory skill fatigue, and nerve fatigue. Chinese scholars' research on relaxation training mainly concerns its effects on relieving muscle and nerve fatigue. However, studies on the specific forms and methods of relaxation training are scarce. In addition, comprehensive studies on the broader effects of relaxation training on sports performance are lacking. To better understand the potential benefits and applications of relaxation training in sport, further exploration is needed in these areas.

Current research on mental training in China is still in its early stages. The scope of research is not yet comprehensive, and the depth of investigation is relatively limited. This presents a significant opportunity and motivation for Chinese scholars to further explore and develop the field of mental training.

THE GAP BETWEEN CHINA AND WESTERN COUNTRIES IN MENTAL TRAINING RESEARCH

An analysis of existing literature reveals several gaps between Chinese and international research on mental training, particularly in areas such as research content and quantity, research design, and innovation and practical application.

Research content and quantity

Chinese research on sport psychology commenced later compared to other countries, resulting in a relatively limited body of work. For example, a search in CNKI (China National Knowledge Infrastructure) yielded only 3,386 articles related to mental training, with even fewer empirical studies on college athletes (Fang et al., 2023; Ziyang & Hang, 2023). This paucity of research is notable, especially as China's socio-economic development progresses and the Chinese government sets more refined goals for sports development, such as those outlined in the "*14th Five-Year Plan for Sports Development (2021)*". This plan aims to establish world-class sports centres that integrate training, science, technology, medical care, and services, and to promote the application of mental training (Ziyang & Hang, 2023). Therefore, "*mental training*" has been attracting more and more attention from Chinese scholars in recent years. A search of CNKI (China Knowledge Network) for 200 articles related to mental training and college athletes revealed that research related to mental training of college athletes peaked in 2022 and 2023. As shown in Figure 2.

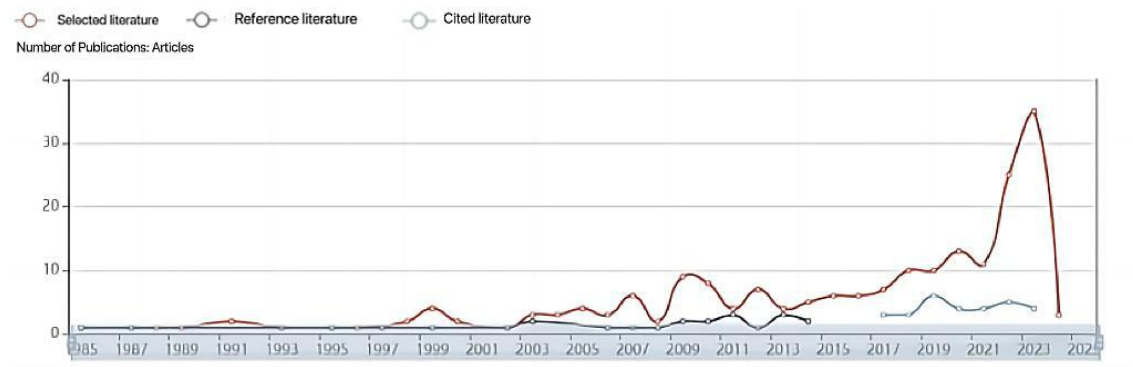


Figure 2. Analysis of overall trends in research associated with mental training in college athletes.

Current research in China focuses on broader concepts, with less research on more detailed elements of mental training, such as representational training, including visual representation, auditory representation, kinaesthetic representation, and environmental representation. Chinese scholars have insufficiently explored these more specific areas, and this is a research gap that needs to be filled by Chinese scholars. In addition, it is worth noting that there is an obvious lack of research on the influence of negative factors by Chinese scholars, such as the influence of coaches' negative emotions, negative words, and emotional states on athletes' psychological state and athletic performance, as well as the generative mechanisms behind these negative influences, which are also of great significance in mental training research (Jian & Hongmin, 2020; Jingchao, 2021).

Research design

Chinese studies often face limitations in terms of sample size and scope of selection, which may affect the reliability and generalizability of the findings. For example, Yashi (2019), Leipo (2013), Junbin and Wensheng (2005), Yi (2008), Qian (2018) selected small sample sizes in their experimental studies. Inconsistent results or non-significant differences in some mental training studies occur from time to time, and this phenomenon is likely to be due to the small sample size, so that no significant differences can be detected (Ye, 2023). In terms of the experimental process, many current studies lack clear operational definitions of dependent, independent and intermediate variables, which undermines the reliability and validity of the experiments. There are also deficiencies in the quantitative control of exogenous variables, which should be minimized, which is crucial for accurately assessing the effects of mental training (peng, 2009).

Innovation and practical application

There is limited theoretical and methodological innovation in mental training research in China. In particular, there is a lack of autonomy in experimental research, mental training research has not yet formed a research system based on localization, and in the use of measurement tools and questionnaires, most of them are directly applied to scales that have been developed abroad (Jingchao, 2021), and there is a lack of innovative research on the scales in line with the characteristics of Chinese athletes. In terms of practice, there is a lack of integration of research and practice, and training in colleges and universities still lacks a comprehensive training model that includes mental training. Secondly, psychological assessment is often overlooked in the assessment of college athletes (Kunfeng & Yonghai, 2022). This has led to an underestimation of the role of mental training in the overall development of athletes (Jingjing, 2014). This, coupled with the relative lack of research on mental training by Chinese scholars and coaches' lack of knowledge of sport psychology, has led to a lack of systematic mental training programs and a well-developed mental training system in China for both professional and college athletes (Pei, 2020).

In summary, although China has made some progress in mental training research in recent years, it is still in the primary stage, and many mental training techniques lack detailed and specific research and application. Chinese scholars still have many limitations in this research field, such as limited innovation in research methods, insufficiently comprehensive methods, insufficient depth of exploration, and insufficient practical application. Addressing these limitations is crucial to promoting the development of this field and developing more effective and evidence-based mental training methods for Chinese athletes.

CONCLUSION

This study explores the important role of mental training in improving athletic performance through an inductive literature review, summarizes the current status of research on mental training of Chinese college athletes, and compares and analyses the strengths and weaknesses of Chinese and Western research in the field of mental training. The findings indicate that mental training methods such as goal setting, imagery, mindfulness meditation, self-talk, and relaxation significantly improve athletes' psychological states, alleviate anxiety, and enhance athletic performance. These methods even have positive effects on athletes' future development and mental health. However, the study reveals that while mental training is widely recognized and implemented in the international sports community, its application among university athletes in China is still limited. Furthermore, China's empirical research, methodological innovation, and systematic application of mental training lag behind international standards. Specifically:

- China's research on mental training began relatively late, with limited content and insufficient depth.
- Deficiencies in research design, including a limited scope in selecting research subjects and sample sizes, and a lack of rigor in controlling variables during experiments.
- A lack of empirical research and methodological innovation, with most studies focusing on theoretical discussions rather than practical applications, and insufficient research based on localized contexts.

Future research should place greater emphasis on the empirical nature of the study, the broad application of research and practice, the specificity of mental training in different sports, and the rigor of the research design. Meanwhile, research should focus on interdisciplinary cooperation, integrating insights from psychology, neuroscience, sports science, and education to reveal the intrinsic mechanisms of mental training and its applications in various fields. In addition, the use of the Internet, virtual reality (VR) and augmented reality (AR) technologies can facilitate the development of personalized mental training programs. Examining the effects of external factors on athletes' psychological changes and performance will deepen our understanding and improve the effectiveness of mental training interventions. With the increasing emphasis on athletic performance in Chinese colleges and universities and the breakthroughs made by scholars around the world in sport psychology research, the role of psychological training in athletic training will become more prominent. Therefore, systematic and sustained research is an important means to improve the effectiveness and application of psychological training. Research and application in this field need more professionals' long-term attention and efforts.

AUTHOR CONTRIBUTIONS

Tang Yangyang contributed significantly to the conception and design of the study, conducted the literature review and data analysis, and prepared the manuscript draft. She also integrated feedback from co-authors to revise the manuscript for intellectual content and ensured the accuracy and integrity of all aspects of the research. Lim Seong Pek supervised the overall research process, providing guidance on the study's design and methodology. He contributed to refining the comparative framework and offered critical revisions to

enhance the manuscript's quality. Additionally, he oversaw the submission process and correspondence with the journal.

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No potential conflict of interest was reported by the authors.

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Athletes' perception of perceived quality at the CESA BM 2022

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ABSTRACT

Nowadays, numerous sporting events of diverse nature take place every week. This highlights the importance of conducting studies to assess their quality and determine the best event to participate in. Obtaining this information will allow organisers and managers to improve the services offered in order to meet the growing demands of users. The purpose of this study was to analyse the perception of quality by the athletes who attended and participated in the Campeonato de España de Selecciones Autonómicas de Balonmano 2022 (CESA BM 2022), with a gender breakdown. The sample consisted of 514 athletes. Data collection was carried out telematically by means of an online survey using the "Encuestas" tool of the University of Murcia. Perceived quality elements were assessed, as well as the importance of performance, segregated by gender and category of participation. The main results revealed that for athletes, the best rated dimension was "Future intentions", while the worst was "Perceived value". Some conclusions drawn from this study include that the female gender of the sample perceived higher quality compared to the male gender. It was also observed that players in the infantile category perceived higher quality than cadets and juniors, and statistically significant differences were also found between the various elements of the study.

Keywords: Impression, Sport event, Manager, Gender, Handball.

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INTRODUCTION

Sporting events have a significant impact on the social life of the community, while promoting sport and physical activity, improving the quality of life of citizens. They also play a key role in the economic and tourism development of the organising locality. In the field of sport management, it is possible to identify and classify sport events in various ways, such as their type, scale or target audience. In this study, a national sport event will be analysed, specifically a Spanish Championship by Autonomous Communities, which belongs to the grassroots category. These events are attractive for municipalities, as they attract young people from all Spanish regions for one week and it is a great way to increase the popularity of the municipality. At the same time, family and friends of the participants also come to the town to support the athletes and take advantage of the opportunity for local tourism.

With an increase in demand comes an increase in supply, so quality is becoming an imperative need for companies in terms of developing strategies that allow them to stand out in a competitive market (Gálvez and Morales-Sánchez, 2011; Reyes-Robles, et al. 2022). When talking about quality, it is important to mention what Llorens and Fuentes (2000) stated, some organizations and experts have searched for a definition for the concept of quality, but the truth is that there is no concrete definition that can be determined as the best one. Perceived quality can be defined as the judgement created by users, based on individual interests and expectations in relation to the service obtained. Furthermore, if a review of the scientific literature is made, other accepted meanings can be found, such as: “consumers” overall impression of the relative superiority or inferiority of a company and its services’ (Bitner and Hubber, 1994, p.7). Zeithaml (1988) defines it as the “*consumer's judgement of the excellence or superiority of a product or service*”.

Quality is seen as a point of differentiation within the sports industry, which can lead to greater satisfaction of both loyal users and future customers, as well as to the enhancement of one's own corporate image (Afthinos et al., 2005; Chelladurai and Chang, 2000 and Parasunaman et al., 1985). For this reason, one of the main objectives of companies today is to maintain customer loyalty and provide additional value to their products or services (Tsitskari et al., 2006). The importance of measuring the service quality is explained by Calabuig et al. (2010), who point out that the study of the elements of satisfaction will provide organisations with greater loyalty and organisational improvement in their sports projects.

After an extensive review of perceived quality from the academic literature there are some results that are interesting. Related to the perceived quality of athletes a study was carried out by Ballesteros (2019), whose work was articulated with the CAPPEP tool (Angosto, 2016a). This study aimed to evaluate the perceived service quality of the participating athletes and correlate it with sociodemographic variables at the XVII Half Marathon in 2018 to improve future editions. The perceived quality of the athletes was defined as “good”, and could be “*excellent*”, as this is what the athletes' sporting level demands.

In relation to the participant's perception, Vegara-Ferri, Carboneros and Angosto (2021), carried out a study in which the objective was to evaluate the perception of the participating sports tourists on the quality of the event, socio-cultural perception, destination image and future intentions, comparing the possible differences between national and foreign tourists participating in an international nautical event. Some of the conclusions obtained were that the highest rated item is the socio-cultural perception followed by the intentions to return to the event and to the host town. On the other hand, the perception of the quality and image of the event are the worst rated of the event.

A study carried out by Vicente, Cerro-Herrero, Angosto and Prieto-Prieto (2021), has as one of its objectives to analyse the quality perceived by trail runners and to identify the socio-sportive factors that determine the quality of the event. The data collection was done with the (CAPPEP) of Angosto et al. (2016a) and as results it was determined that: some of the conditions that determine the quality of an event are related to socio-sporting factors of the athlete, such as their level of studies or their federated status; some of the factors of higher perceived quality in this event were the treatment with the staff as well as the factors inherent to the development of the event; however, the worst rated factor was the complementary services to the event.

MATERIAL AND METHODS

Participants

The group of athletes was composed of 514 subjects, including 240 males and 274 females who competed in the following age groups: Infantile male and female, composed of children 12-13 years old; Cadet male and female, composed of children 14-15 years old; and Junior male and female, where young people up to 17 years old competed. Some interesting data collected from this sample are as follows: 19.5% have been playing handball for 5 years or less, 68.8% have been playing for between 6 and 10 years, and 11.7% have been playing for more than 10 years; it can also be seen that the sample is very evenly distributed among the categories, with a 32.1% response from Infantile, 34% from Cadets, and 33.9% from Juniors; in reference to the weekly training of the respondents, more than half of them (54.3%) train between 6 and 10 hours a week; finally, among other characteristics, it can be seen that 57.8% of the respondents have competed in past editions of the CESA BM.

Research instruments

The survey used for this study was CAPEPP (Angosto, 2014) to which the importance of performance variable proposed by Hyun and Jordan (2019) was added. The CAPPEP questionnaire is divided into two sections. The first section, "*Perceived quality*", consisted of ten items divided into four dimensions: communication, staff, logistical organisation and complementary services. A second section "*General quality*" was composed of five items, divided into four dimensions: general quality of the event, perceived value, satisfaction and future intentions.

The response scale was a five-point Likert-type scale (1- Strongly disagree; 7- Strongly agree) for both tools. Finally, socio-demographic and sporting variables were included, such as age, gender, studies completed, autonomous community in which the respondent resides, time practising handball and category in which he/she participates; this first part was also completed with some questions on time spent practising sport and questions related to the organisation of CESA BM 22.

Procedure

The procedure carried out to develop this research study consisted, firstly, of a review of the existing literature on perceived quality and the instruments used to identify which tools are most suitable for assessing participants in an event. Finally, it was decided that the most suitable instrument for this work would CAPPEP (2016). Subsequently, once the evaluation instrument had been identified, the event organisers were contacted to inform them of the interest in carrying out an evaluation study of the event, the objectives and the evaluation tools. In the second phase, the survey was passed out to athletes of the CESA BM 22 by the selection delegate. The questionnaires were administered the 13-15th April with a link, which redirected respondents to the relevant questionnaire. The data were recorded electronically through the "*Encuestas*" tool of the University of Murcia. Finally, once the event was over, the data were coded and analysed for the

writing of the final study. This study was approved by the Ethics Committee of the University of Murcia (iD: 2491/2019).

Data analysis

Data analysis was performed using the SPSS v.28.0 statistical software licensed by the University of Murcia. Descriptive statistics were calculated for quantitative variables (mean and standard deviation) and for qualitative variables (frequency and percentage). For the comparative analysis between groups, a Student's t-test was performed to analyse the differences between two groups, on the one hand, the difference between the gender of the respondents (male and female). For the comparative analysis between three groups, the ANOVA test was carried out to analyse the differences between the different categories competing in this CESA BM: infantile, cadet and youth. To analyse the difference between groups, the Tukey post hoc test was used. The significance level was set at a value of $p \leq .05$. Cohen's d effect size (cut-off points: 0.20 = small effect; 0.50 = medium effect; 0.80 = large effect) was estimated for continuous variables (Domínguez-Lara, 2018). Similarly η^2 : partial eta squared: effect size 0.01 (small), 0.06 (medium), 0.14 (large) according to Cohen (1988); $p < .05$.

RESULTS

Perceived quality of athletes

Table 1 shows the data obtained from the questionnaires completed by the athletes who participated in CESA BM 22, from which information was obtained on the aspects mentioned above and which will be discussed below. The sub-dimension of "*Communication*" is made up of three items, the best perceived by the athletes being "*The organisation complies with the planned schedules*" ($M = 4.48 \pm 0.72$). On the other hand, the worst rated item was "*The dissemination and promotion of the event*" ($M = 4.05 \pm 0.82$).

The sub-dimension "*Staff interaction*", showed that the highest rated item was the friendliness of the existing staff to adequately attend the event ($M = 4.60 \pm 0.63$); while the lowest rated item was the staff's willingness to help ($M = 4.45 \pm 0.75$). Next, the sub-dimension that was posed to respondents was "*Logistical structure*". The worst rated of this sub-dimension was the item dealing with the attractiveness of the posters and visual aspects of the event ($M = 4.09 \pm 0.84$).

To conclude the descriptive analysis of the Perceived Quality, the sub-dimension "*Complementary services*", composed of two items, will be mentioned. The best rated item mentioned the number of support services ($M = 4.13 \pm 0.93$). On the other hand, the worst rated item was the number of services in the vicinity of the sports facility ($M = 3.67 \pm 1.1$).

The next dimension to be analysed is General Quality, in which athletes were asked about variables such as the "*General quality of the service*" ($M = 4.29 \pm 0.84$). This was followed by the sub-dimension "*Perceived value*", made up of a single item dealing with the comparison of this CESA with others ($M = 3.44 \pm 1.16$). The next sub-dimension is "*Satisfaction*", being one of the best perceived, and related to the satisfaction of attending a CESA ($M = 4.79 \pm 0.52$).

Concluding the descriptive analysis of this second dimension, we will mention the sub-dimension "*Future intentions*", composed of 2 items and being the best perceived by the athletes. The best rated item was the one that assessed the intentions to attend a CESA again ($M = 4.87 \pm 0.42$). On the other hand, the least valued item was the item recommending the CESA to colleagues ($M = 4.75 \pm 0.56$).

The last dimension of this survey is called “*Importance of performance*” and was composed of four items obtained from the work of Hyun and Jordan (2019). The most highly rated item was the item dealing with the importance of doing well for selection ($M = 4.8 \pm 0.46$). In contrast, the lowest rated item was the satisfaction with one's own performance ($M = 3.75 \pm 0.92$).

Table 1. Athletes' perceived quality.

	Average	Typical Dev.
Perceived quality		
Communication	4.25	0.6
CESA is well promoted and disseminated, providing sufficient practical information about it.	4.05	1.8
During the event, clear and precise information is given in order to know the development of the competition	4.21	0.8
The organisation is on schedule.	4.48	0.7
Interaction		
The organisation's staff is willing to help.	4.45	0.8
Volunteers are friendly and helpful.	4.60	0.6
Logistic structure		
The material elements used by the event are visually attractive (banners, hoardings, banners).	4.09	0.9
The results and the podium are visible to all spectators.	4.27	0.9
CESA 2022 has sufficient and adequate refreshment points.	4.1	0.9
Complementary services	3.96	0.8
CESA 2022 has sufficient support services (toilets, changing rooms, cloakroom, massage areas, stands, etc.).	4.13	0.9
Near the pavilion there are easily accessible shopping facilities (cafés, bars).	3.67	1.1
General quality		
Services' general quality	4.29	0.8
In general, the service offered by the organisation is adequate.	4.29	0.8
Perceived value	3.44	1.2
The quality of this CESA can be considered superior when compared to other CESAs.	3.44	1.2
Satisfaction	4.79	0.5
Overall, attending CESA is a satisfying experience.	4.79	0.5
Future intentions	4.8	0.4
I am willing to keep coming back for more editions of CESA.	4.87	0.4
I will recommend attending CESA to my friends and teammates.	4.75	0.6
Importance of performance		
It was important for me to get a good result with my team.	4.54	0.7
It was important for me to perform well for my team.	4.8	0.5
I am satisfied with the performance of my team at CESA 2022.	4.02	1
I am satisfied with my individual performance at CESA 2022.	3.75	0.92

A correlational analysis was made between all the sub-dimensions addressed in this questionnaire (Table 2). All variables were statistically, positively and significantly related to each other, highlighting the variables “*Communication*” and “*General quality of the event*”; and “*Communication*” and “*Complementary services*”, with moderate values of $r = 0.620$ and $r = 0.616$, respectively. In contrast, the lowest relationships were found between the variable “*Perceived value*” and “*Future intentions*”, with an $r = 0.178$.

Table 2. Descriptive and correlation analysis of the factors.

Subdimension	1	2	3	4	5	6	7	8
1. Communication	--							
2. Staff interaction	.509**	--						
3. Logistic elements	.504**	.431**	--					
4. Complementary services	.616**	.474**	.565**	--				
5. General quality	.620**	.531**	.490**	.635**	--			
6. Perceived value	.438**	.337**	.407**	.489**	.484**	--		
7. Satisfaction	.429**	.328**	.362**	.332**	.488**	.331**	--	
8. Future intentions	.370**	.256**	.274**	.286**	.385**	.178**	.554**	--

Note. ** The correlation is significant at the .01 level (bilateral).

Perceived quality by gender

Next, we will look at the data obtained from a gender perspective (Table 3). In general, women had a better quality perception of the event than men. The best rated item for both genders was future intentions (Men = 4.75 ± 0.64 ; Women: 4.85 ± 0.36). On the other hand, the lowest rated item was one that dealt with the comparison of this CESA to others (Men = 3.29 ± 1.18 ; Women: 3.57 ± 1.12). It should be noted that statistically significant differences were found in all dimensions, except for the dimension dealing with the importance of performance.

Table 3. Perceived quality by gender-segregated sportsmen and women.

Subdimension	Male	Female	t	p-value	d-Cohen
	M (DT)	M (DT)			
Communication	4.15 (0.65)	4.33 (0.5)	-3.68	.001*	-0.325
Staff interaction	4.40 (0.73)	4.63 (0.49)	-4.21	.001*	-0.372
Logistic elements	4.04 (0.76)	4.30 (0.66)	-4.31	.001*	-0.381
Complementary services	3.83 (0.82)	4.08 (0.7)	-3.81	.001*	-0.337
General quality	4.10 (0.9)	4.45 (0.74)	-4.86	.001*	-0.429
Perceived value	3.29 (1.18)	3.57 (1.12)	-2.77	.006*	-0.245
Satisfaction	4.71 (0.61)	4.86 (0.4)	-3.20	.001*	-0.283
Future intentions	4.75 (0.64)	4.85 (0.36)	-2.75	.006*	-0.243
Importance of performance	4.61 (0.58)	4.69 (0.54)	-1.6	.110	-0.141

Note. * $p < .05$; Cohen's d: Cohen's d; (0.20 = small effect; 0.50 = medium effect; 0.80 = large effect).

Table 4. Perceived quality according to competition category.

Subdimension	Competition category				F	Sig.	η^2
	Infantile	Cadet	Junior	Total			
	(n = 165)	(n = 175)	(n = 174)	(n = 514)			
	M (DT)	M (DT)	M (DT)	M (DT)			
Communication	4.43 (0.47)	4.15 (0.61)	4.16 (0.60)	4.25(0.58)	13.45	.00+ [^]	0.05
Staff interaction	4.67 (0.47)	4.39 (0.73)	4.53 (0.61)	4.53(0.63)	8.87	.00+	0.03
Logistic elements	4.31 (0.67)	4.11 (0.73)	4.12 (0.74)	4.18(0.72)	4.11	.02+ [^]	0.02
Complementary services	4.28 (0.66)	3.8 (0.78)	3.83 (0.78)	3.96(0.77)	21.93	.00+ [^]	0.08
General quality	4.61(0.58)	4.1 (0.88)	4.18 (0.91)	4.29(0.84)	19.40	.00+ [^]	0.07
Perceived value	3.92 (0.95)	3.44 (1.17)	2.99 (1.15)	3.44(1.16)	30.70	.00*	0.11
Satisfaction	4.93 (0.28)	4.78 (0.53)	4.67 (0.63)	4.79(0.52)	11.20	.00+ [^]	0.04
Future intentions	4.91 (0.25)	4.78 (0.41)	4.74 (0.51)	4.81(0.41)	8.44	.00+ [^]	0.03
Importance of performance	4.82 (0.46)	4.58 (0.54)	4.57 (0.62)	4.65(0.56)	11.56	.00+ [^]	0.04

Note: *Significant differences between all groups (infants - cadets - juniors); + Significant differences between infants and cadets; [^] Significant differences between infants and juniors; [^] Significant differences between cadets and juniors; $p < .05$.

Perceived quality according to competition

The next comparative analysis to be carried out will compare the differences in perception that occurred depending on the category in which each athlete competed (Table 4). As can be seen, the athletes competing in the children's category were the ones who best perceived the quality of the event in general, while the cadet and junior athletes exchanged ratings. The sub-dimension best rated by the child athletes was "Satisfaction" ($M = 4.93 \pm 0.28$); while the cadet and junior athletes perceived the sub-dimension "Future intentions" best (Cadets = 4.78 ± 0.41 ; Juniors = 4.74 ± 0.51). However, all three categories perceived "Perceived value" as the worst subdimension (Infantile = 3.92 ± 0.95 ; Cadets = 3.44 ± 1.17 and Juniors = 2.99 ± 1.15). It should be noted that statistically significant differences were found between the different groups.

DISCUSSION

By reviewing the current scientific literature and making a comparative work, we found that the results obtained in relation to the quality perceived by athletes are similar to what can be read in prestigious scientific articles. It is important to highlight which were the best perceived variables, being "Future intentions" and "Satisfaction", this result is understood since these championships is a unique experience for players in training category to experience high level sport with experiences of professional sport; in the same way it can be seen in the scientific literature, when the perceptions of quality and satisfaction are high the intentions to return to participate in future editions increase (Magaz-González et al. 2021; Milovanovic et al. 2021).

Similarly, it would be interesting to note that, as with spectators, "Staff interaction" is highly valued, including their willingness to help and friendliness; in the scientific literature there are studies that support these results, such as those of Angosto (2016b), Ramos et al (2021) or Madruga-Vicente (2021). In terms of the worst-perceived variables in this questionnaire, "Complementary services" is mentioned, not having a direct relationship with the management of the event, but rather with the location of the pavilions where the events were organised and the scarcity of services in the vicinity. It is also worth mentioning that this is usually a variable that is highlighted negatively, as can be seen in the results obtained in Ramos et al (2021) and Madruga-Vicente (2021) and should serve to improve these aspects of the organisation of sporting events. To conclude, it should be noted that the worst rated sub-dimension was "value", which mentioned the comparison with previous editions.

In the following, we will discuss some of the results obtained by differentiating the participating athletes by gender, with the aim of verifying the different ways in which athletes perceive a service depending on their gender. It is remarkable to say that statistically significant differences were found in all sub-dimensions, except "Importance of performance". Also, as explained above, the results indicate that women have a higher perception of quality. It will be said that the sub-dimension most highly rated by both female and male players are "satisfaction" and "future intentions", followed by "personal interaction". However, the worst rated sub-dimension was "value" and, for both sexes, the comparison of this edition with previous editions made them perceive that this CESA did not bring them as much as other past experiences.

Finally, we will analyse some of the results obtained by segmenting them by competition categories (Infantile, Cadet and Youth), with the aim of checking the different ways in which athletes perceive a service depending on the category in which they play. As can be seen, in general terms, the category that best perceived the quality of the organization of the event were the players in the infantile category, with the subdimension "satisfaction" and "future intentions" being the best valued, and statistically significant differences were also found between infantile, cadet and juvenile; followed by "personal interaction", in which significant differences

were only found between infantile and cadet. If we look at the two remaining categories, it can be seen that they perceive quality in a similar way, but intermittently in their evaluations. The sub-dimensions of "Communication", "Staff interaction", "Logistic elements" and "Complementary services" were perceived with higher quality by cadets; while juniors perceived the sub-dimensions of "Overall quality of the event", "Perceived value" better, this being the only sub-dimension where statistically significant differences were found between all groups, "Satisfaction", "Future intentions" and "Importance of the performance". This could be justified by explaining the number of experiences a youth player has had, having participated in a greater number of CESAS and being able to make a more critical analysis of this experience.

CONCLUSION

Once the results have been presented and confronted with the existing scientific literature, some of the conclusions obtained from the two sample groups and the contributions of this study in the field of sport management and perceived quality will be mentioned.

The main conclusions obtained from the specific objectives set out in this study are:

1. The dimension of perceived quality with the highest score is the intention to continue attending future editions and the satisfaction of attending this type of events. The sportsmen and women value very positively the intention to recommend the event to their friends or third parties.
2. The results of participants according to gender show higher scores for women than for men. Statistically significant differences were found in the comparison between athletes.
3. The results of the perceived quality according to the competition category of the athletes indicate that children's players perceive the quality of the event significantly better than cadets and youth athletes.
4. Good individual performance is more highly valued by the athletes than good collective performance.

AUTHOR CONTRIBUTIONS

Liam Cano-Coyle, José Miguel Vegara-Ferri, and José María López-Gullón, conceived and designed the investigation, collected data, analysed and interpreted the data, drafted the manuscript, and approved the final version submitted.

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Physiological response in professional female soccer players: Comparison between small-sided games and laboratory exercise testing

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ABSTRACT

The aim of this study was to describe the physiological characteristics and energetic requirements of small-side games (SSG) in female players by means of ambulatory gas exchange measurements using a breath-by-breath (B × B) approach. Eight female professional soccer players participated in this study. This study was divided into two sessions: laboratory exercise testing and SSG field testing. Both tests were performed using simultaneous gas exchange measurements. The incremental ramp exercise test was performed using portable metabolic carts breath by breath (B×B) and a treadmill, to measure the maximum oxygen uptake (VO_{2max}) and maximum heart rate (HR_{max}) of each player. In the SSG field test, the metabolic carts (B×B), was used during SSG to measure oxygen uptake (VO_2), average heart rate (HR_{ave}), breath frequency (fB), minute ventilation (VE), energy expenditure (EE), and heart Rate and O_2 Pulse (VO_2/HR). Activity profiles were assessed by professional technical coaches (n = 2). A total of 152 passes were included in the four-a-side SSG analysis. Specifically, 85.53% of the total passes were categorized as successful passes and 14.47% were categorized as failed passes. VO_2 during SSG was 83.90% of the VO_{2max} , and HR_{ave} during SSG was 84.42% of the HR_{max} . The independent t-test showed a difference between blood lactate levels post-SSG and blood lactate after the incremental ramp-like exercise [$p = .001$; $F = 97.294$]. Four-a-side SSG have sufficient physiological demands for female players, characterized by achieving the minimum standard of physiological response with maximum aerobic capacity.

Keywords: Sport medicine, Four-a-side, Football training, Match analysis, Metabolic demands, Performance.

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INTRODUCTION

Football is a sport that has the characteristics of multidirectional and intermittent field sports (Low et al., 2020; Sarmiento et al., 2018). Because of these characteristics, it is not surprising that, in soccer, a good combination of physiological, technical, and tactical skills is needed to support the performance of each athlete (Vella et al., 2022). The complexity of these needs seems to be followed by increased scientific interest in this sport to help coaches improve athletic performance (Formenti et al., 2021). Unfortunately, it is necessary to recognize that the study focus is on males, and study on females is limited (Vella et al., 2022). This is unfortunate, given the strong growth in female soccer, with evidence of 1.2 million federative licenses already granted in Europe alone (Crossley et al., 2020).

To improve the performances of athletes during matches, several experts revealed that fitness factors such as maximum oxygen uptake (VO_{2max}), muscular tone, or maximum heart rate (HR_{max}) are some of the factors that can affect the performance of some high-intensity actions such as jumps, kicks, and sprints (Crossley et al., 2020; Hecksteden et al., 2022; López-Fernández et al., 2017; Sarmiento et al., 2018). Interestingly, these demands can lead to acute fatigue in athletes, therefore, they are required to have high metabolic demands (Thorpe et al., 2017). In response to these challenges, coaches and sports scientists are currently conducting various types of measurements of specific drill training that aim to improve the performance of athletes according to the physiological demands during real matches (Hill-Haas et al., 2011).

Small-sided games (SSG) are one of the specific training programs that are currently popular and developing in soccer training (Clemente et al., 2021; Esposito, 2024; Hill-Haas et al., 2011). Coaches and sports scientists believe that SSG can improve the performance of athletes, considering that SSG can reproduce the technical, tactical, and even physical demands of soccer matches (Clemente et al., 2021; Hill-Haas et al., 2011). Based on this evidence, experts are currently conducting an analysis of the effectiveness of SSG in the physiological characteristics of athletes by modifying the number of players, pitch size, surface analysis, and rules (ex. the use of goals and/or goalkeepers) (Clemente et al., 2021; Hill-Haas et al., 2011). The purpose of these modifications remains the same, that is, to find an SSG design that is identical to the physiological demands during soccer matches (Clemente et al., 2021; Hill-Haas et al., 2011).

Several previous studies have proven that SSG can provide sufficient physiological characteristics to replicate the physical demands of soccer matches (Clemente et al., 2021; Hill-Haas et al., 2011; Mara et al., 2016). For example, Mara et al. (Mara et al., 2016) revealed that during SSG in males with the concept of 4 vs. 4, the players showed an average heart rate (HR_{ave}) of 87.2% of the HR_{max} . Moreover, several previous studies have also revealed that similar results: SSG of 5 vs. 5 (HR_{ave} is 89% of HR_{max}); 6 vs. 6 (HR_{ave} is 87% of HR_{max}); and 8 vs. 8 (HR_{ave} is 79% of HR_{max}) (Hill-Haas et al., 2011; López-Fernández et al., 2018). Although previous studies have reached the same conclusions, the findings remain unclear and debatable to experts (Hill-Haas et al., 2011). Various assumptions, such as the length of the game, rest period, presence or absence of keepers or goalposts, and activity profile, are some of the factors that are assumed to be the differentiators in each of these findings (López-Fernández et al., 2018).

On the other hand, from a physiological perspective, Hoff et al. (Hoff et al., 2002) stated that the relation between heart rate and oxygen uptake (VO_2) is an important factor to assess the validity of exercise intensities in soccer specific training. Specifically, this statement was proved by Hoff et al. (Hoff et al., 2002) by conducting tests between physiological response on SSG and laboratory maximum testing and concluded that HR_{ave} during SSG is 91.3% of the HR_{max} , and the VO_2 during SSG is 84.5% of the VO_{2max} . Furthermore, previous studies have also revealed that the physiological characteristics of the players are related to the

activity profile based on mechanical efficiency (Alt et al., 2020; Hoppe et al., 2020). In other words, physiological training can increase or decrease the mechanical power output at a given physiological response (Hoppe et al., 2020). Therefore, it is important to understand the relationship between physiological characteristics and activity profiles (Hoppe et al., 2020).

Unfortunately, some of these studies were only conducted on male soccer players, and specific physiological changes during SSG in female soccer players have not yet been found (Hill-Haas et al., 2011; Manson et al., 2014). To the best of our knowledge, study on female soccer players is currently limited to differences in surface, metabolic, and time-motion analyses (López-Fernández et al., 2017; Manson et al., 2014). To address the gap in the literature on the physiological responses of female soccer players during SSG, the purpose of this study was to (i) describe the physiological characteristics as well as energetic requirements of SSG in female players by means of ambulatory gas exchange measurements using a breath-by-breath (B × B) approach and (ii) to assess activity profile during SSG. Therefore, we expect that these findings can add to the scientific literature on the physiological characteristics of female players and provide relevant information to coaches and athletes for designing trainings based on the use of SSGs.

MATERIALS AND METHODS

Participants

Eight professional female soccer players participated in the observational study and experimental procedures. Three of the participants were Indonesian national team athletes, and the other five were professional athletes who played in the highest caste league of Indonesian female soccer. All participants were confirmed to be in accordance with the inclusion criteria in this study, namely: (1) registered as Indonesian professional female players, (2) had a history of training 15 hours per week, (3) had participated in the minimum national competition, (4) did not smoke, or had no history of smoking; (5) had no concomitant diseases and no use of any anti-inflammatory or antioxidant drugs, (6) and had no musculoskeletal injuries in the 6 months before the start of the study. Athletes who were not familiar with the concept of SSG and did not pass the medical examination before the start of the study were excluded. The goals, benefits, and risks for all coaches and athletes were confirmed. After the participants received this information, they provided informed consent to participate. The study was approved by the local Clinical Study Ethical Committee of POLTEKKES Bandung (10/KEPK/EC/III/2023) in accordance with the Declaration of Helsinki.

Experimental design

The study was conducted for three weeks, during the break session of the Indonesian female tournament, where two measurement sessions were performed each week. All participants were asked to refrain from strenuous exercise 24 hours previous the measurement sessions, avoid drinking alcohol, and prepare themselves as they would for an official competition. All participants were asked to familiarize themselves with the procedures each session. The study was divided into two sessions: laboratory exercise and field testing. A three-day break was provided between the two sessions in order to ensure that each participant could recover. During recovery, healthy diets and light physical activity were provided to participants to maintain their fitness. In the laboratory sessions, anthropometry and an exhaustive incremental ramp-like exercise test were used to measure maximal ergometric parameters. In the field test session, participants were evaluated on a natural grass surface in the four-a-side SSG. Both tests were performed with simultaneous gas exchange measurements and were carried out at the player's regular training time (16:00 to 18:00) and weather conditions (dry; 28-30°C; 55-60% relative humidity). The rating of perceived exertion (RPE) Borg's CR10-scale modified by Impellizzeri et al., (Impellizzeri FM, 2004) was used in both

measurement sessions. where 0 indicates rest, 1 indicates very easy, 2 indicates easy, 3 indicates moderate, 4 indicates somewhat hard, 5 indicates hard; 6–7 indicate very hard; 8–10 indicate maximal.

Laboratory test

In the laboratory test session, anthropometric measurements were carried out indoors and supervised by a female medical representative ($n = 1$) and an administrator officer ($n = 1$). The body weight and body fat of each participant were measured using the Omron Digital Weight Scale HN 289, while height was measured using a Seca 214 Portable Stadiometer (Cardinal Health, Ohio, USA). During the measurement, the participants wore light clothes and were barefoot. Body mass index (BMI) was calculated as body mass (kg) divided by height (m) squared.

Following the anthropometric measurements assessment, a Lactate Pro analyser (Arkray, Shiga, Japan) was used to measure and analyse the blood lactate levels of each participant. Blood lactate was obtained from the fingertips (100 μL of sample). A standardized warm-up of 20 minutes was conducted prior to the incremental ramp exercise test. The incremental ramp exercise test was performed on a treadmill (LODE-Treadmill V2 CPET-01, Netherlands) to measure the maximal oxygen uptake and maximum heart rate (HR_{max}) of each player. During the test, HR and respiratory gas exchange were measured using short-range telemetry (Garmin HRM-Dual™, USA) and portable metabolic carts breath-by-breath basis (BxB) (Cosmed K5, Italy), respectively. The collected data were averaged over 10 seconds.

Before use, the Cosmed K5 was warmed for 60 min. Furthermore, gases calibration was carried out based on the instructions and recommendations of the Cosmed K5 guidelines (turbine gainIN = 1016; turbine gainEX = 1001; syringe = 3000mL; V_t threshold = 50 mL; flowmeter temp = 34°C), BxB cal. Factors (O_2 trimmer = 598; O_2 gain = 1029; O_2 base line = 124 mV; O_2 delay = 720 ms; O_2 speed = 1098; O_2 rise time = 190 ms; O_2 fall time = 190 ms; CO_2 trimmer = 589; CO_2 gain = 972; CO_2 base line = 3761 mV; CO_2 delay = 690 ms; CO_2 speed = 6000; CO_2 rise time = 90 ms; CO_2 fall time = 90 ms; PCal B \times B = 727 mmHg), and gas reference (cylinder $\text{O}_2 = 16\%$, cylinder $\text{CO}_2 = 5\%$, ambient $\text{O}_2 = 20.93\%$, ambient $\text{CO}_2 = 0.04\%$).

The protocol of the incremental ramp-like exercise test was adopted from previous studies (Apriantono et al., 2020; Winkert et al., 2020). Before the start of the measurement session, participants were asked to use the Cosmed K5 mask based on the size of each participant. In this session, each participant ran for 4 min at 10 km/h at an inclination of 1% and 5%, respectively. The treadmill speed was increased by 2 min at 1 km/h until exhaustion was reached. Exhaustion was defined as the plateau attained by the relationship between oxygen uptake (VO_2) and running speed. Maximal oxygen uptake and HR were defined as the highest recorded values during incremental ramp-like exercises. Immediately after the test, blood lactate levels were obtained. In this session, laboratory officers ($n = 2$) and administrators ($n = 1$) assisted with installation details and control over data retrieval.

Small side games (SSG) field test

In this study, we considered and used the four-a-side SSG recommended by Mara et al. (Mara et al., 2016), considering that this SSG formula is widely used in study and is familiar to female soccer players in several previous studies. On the other hand, the findings of Zubillaga et al. (Zubillaga et al., 2013) also strengthen this study as this study encouraged the achievement of individual player areas in matches ranges from $77.91 \pm 32.72 \text{ m}^2$ to $96.19 \pm 22.66 \text{ m}^2$, as well as ratio ranges from 1:1 to 1:1.3. The details of the SSG provisions are listed in Table 1.

Prior to the start of the SSG, the study had coaches actively involved in encouraging players to make the maximum effort. On the other hand, the SSG asks the players to all possessions for as much time as possible. Eight participants were divided, consisting of a full back (n = 2), a playmaker (n = 4), and a striker (n = 2), divided into two separate teams (one team consisted of a fullback, two playmakers, and one striker). There were no goalposts or keepers involved in this study, considering that the intensity of the game is improved in this situation (Mara et al., 2016).

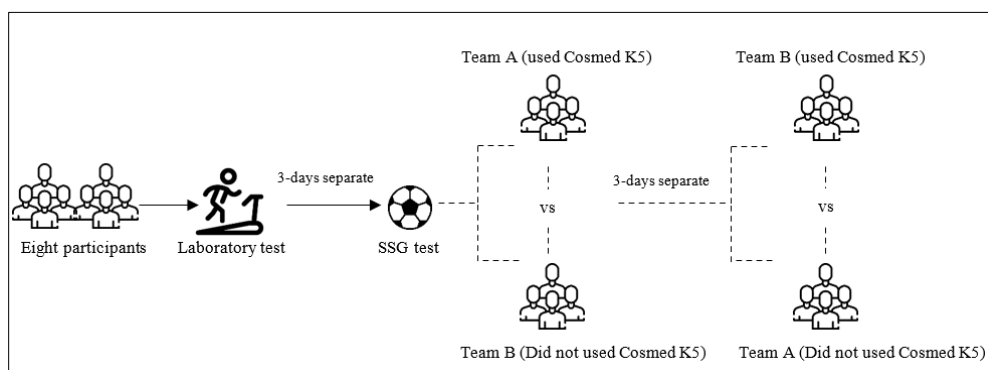
One of the teams competed using the Cosmed K5 against the team that did not use the Cosmed K5. Two matches were used for the field test analysis (Figure 1). One for the match design). A total of 3 min of recovery that allowed 2 min of passive recovery (participants were allowed to drink water *ad libitum* to prevent dehydration), and then 1 min of active recovery work (low-intensity ball-passing exercises) prior to the second half of the session were provided to the players. During passive recovery, internal load measurements were not performed using the Cosmed K5. A three-day break was given between the two matches of the SSG field test to provide a total recovery.

During the SSG, each participant wore a portable metabolic device, which was placed on the back of the player, and a mask according to the face size of each player (Cosmed K5, Italy). Specifically, the Cosmed K5 output measurements during the match simulation were VO_2 , HR_{ave} , breath frequency (fB), minute ventilation (VE), energy expenditure (EE), and VO_2/HR . The weight of the Cosmed K5 was 900 g (see Figure. 2). The Garmin HRM-Dual™ (USA) was used to measure the HR during the match. During this field test session, lactic acid measurements were performed before the start of the match and immediately after the match. Lactic acid measurements were performed using a lactate pro analyser (Arkray, Shiga, Japan), and were obtained from the fingertips (100 µL sample). The collected data were averaged over 10 s and analysed in relation to the maximal values achieved during the laboratory treadmill tests.

Table 1. Detail of four-a-side SSG characteristics.

Game duration (min)	Duration of the recovery between SSG matches	Pitch area (m)	Pitch total area (m ²)	Pitch ratio per player (m ²)
4	2 min (passive); 1 min (active)	20 x 20	400	50

Notes: SSG – small side games.



Notes: SSG – small side games; Three-day breaks between each session were used for recovery.

Figure 1. Flow of data measurements on laboratory and SSG field testing.

Activity profiles

In this study, professional technical coaches (n = 2), who had experience in technical training of female soccer players for a minimum of 10 years, were involved in the analysis of activity profiles. Two match analyses

were performed by technical coaches. The assessment of activity profiles during SSG was based on a previous method (López-Fernández et al., 2017; Mara et al., 2016; Zubillaga et al., 2013), and included: (i) The total passes are the total number of times the player kicks the ball (success or failed) to another member of their team during SSG; (ii) A successful pass occurs when the player kicks the ball and the ball is received by another member of their team; (iii) A failed pass occurs when the player kicks the ball and the ball is not received by another member of their team.

Statistical analysis

Statistical analysis was performed using IBM SPSS software version 25.0. All data were tested for normal distribution using the Shapiro-Wilk test and Levene's statistics. The one-way analysis of variance (ANOVA) with an independent t-test was used to determine differences in blood lactate and RPE variables. Confidence intervals (95% CI) were calculated to indicate the magnitude of the change. Statistical significance was set at $p < .05$.

RESULTS

Anthropometry and activity profile

Table 2 describes the anthropometric characteristics of professional female soccer players, who have an average age of 20.5 ± 1.51 years. In the activity profile analysis, in two matches, the average number of passes was 76 ± 5.65 passes, with a total of 152 passes in the two matches. Specifically, 85.53% of the total passes were categorized as successful passes, and 14.47% were categorized as failed passes (see Table 3).

Table 2. Anthropometric characteristics of Indonesian female soccer players.

Variables	$\bar{X}(SD)$
Weight (kg)	$50.14 \pm (4.85)$
Height (cm)	$156.6 \pm (3.35)$
BMI (kg/m ²)	$20.41 \pm (1.67)$
Body fat (%)	$23.40 \pm (2.51)$

Table 3. Activity profile during SSG.

Total pass ($\bar{X} \pm SD$)	Successful pass ($\bar{X} \pm SD$)	Failed pass ($\bar{X} \pm SD$)
76 ± 5.65	65 ± 1.41	11 ± 2.82

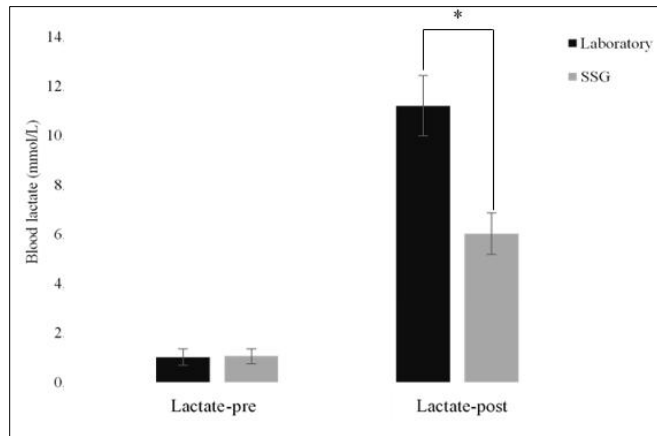
Table 4. Physiological characteristics of female soccer players during laboratory and SSG field tests

Variable	$(\bar{X} \pm SD)$
VO _{2max} (mL/min/kg)	49.32 ± 1.68
VO ₂ (mL/min/kg)	41.38 ± 5.11
HR _{max} (Bpm)	193.39 ± 7.42
HR _{ave} (Bpm)	163.25 ± 8.75
f _B (min ⁻¹)	52.62 ± 3.86
V _E (l min ⁻¹)	60.31 ± 4.98
EE (kcal/min)	9.81 ± 1.29
VO ₂ /HR (mL/beat)	13.66 ± 1.35

Abbreviations: VO_{2max}, average maximum oxygen uptake during the incremental ramp exercise test; VO₂– average oxygen uptake during match simulation; HR_{max}– average maximum heart rate during the incremental ramp exercise test; HR_{ave}– average heart rate during match simulation; f_B– breathing frequency during match simulation; V_E– minute ventilation; EE– energy expenditure; VO₂/HR– heart Rate and O₂ Pulse.

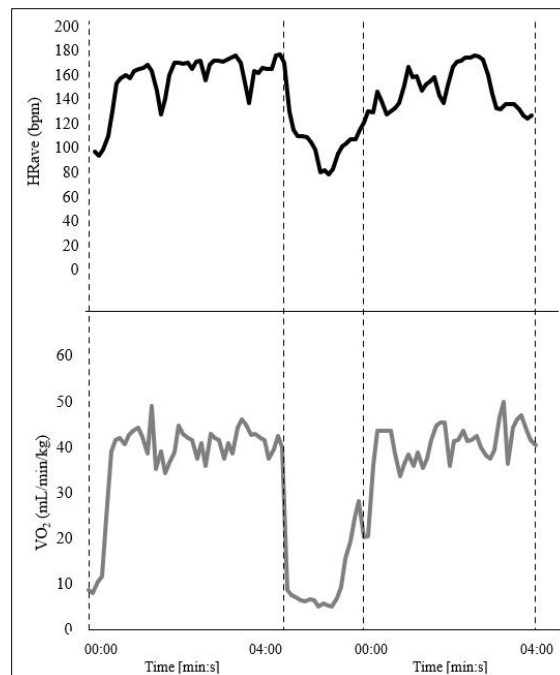
Physiological characteristics

The ANOVA test showed that there was no significant difference in lactate levels pre-SSG with the lactate levels incremental during the incremental ramp-like exercise Y [$p = .818$; $F = 0.055$], however, there was a significant difference between blood lactate levels post-SSG and after the incremental ramp-like exercise [$p = .001$; $F = 97,294$] (Figure 2). Regarding physiological measurements, during laboratory and field tests, the results showed that VO_2 during SSG was 83.90% of the VO_{2max} , and the HR_{ave} during SSG was 84.42% of the HR_{max} (see Table 4 and Figure 3 to see a detailed comparison of physiological characteristics during SSG). On the other hand, there were significant differences between laboratory and SSG field tests results on the RPE Borg's CR10-scale [$p = .001$; $F = 18,667$] (Figure 4).



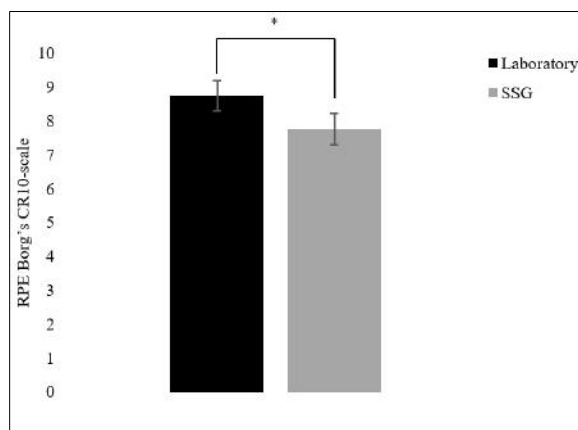
Notes. Lactate-pre – blood lactate response before laboratory and SSG field test, Lactate-post – blood lactate response after laboratory and SSG field test. *Statistically significant differences between lactate levels during laboratory and SSG tests ($p < .05$).

Figure 2. Changes in female soccer players during laboratory and SSG field tests.



Notes. VO_2 – average oxygen uptake during SSG; HR – average heart rate during SSG. Rest time between rally is three minutes.

Figure 3. VO_2 and HR results during SSG of female soccer players.



Notes. RPE - Rating of perceived exertion Responds. *Statistically significant differences between lactate levels during laboratory and SSG tests ($p < .05$).

Figure 4. Differences of RPE Borg's CR10-scale between laboratory and SSG field tests.

DISCUSSION

The aim of this study was to describe the physiological characteristics and energetic requirements of SSG in female players by means of ambulatory gas exchange measurements using a breath-by-breath ($B \times B$) approach, and to assess the activity profile during SSG. In line with the study objectives, this study succeeded in revealing quantitative facts related to the physiological characteristics of female soccer players. The major findings are as follows: (1) this study shows that SSG reflects a training regimen design that can build the aerobic capacity of female soccer players by showing a physiological response that is close to the high aerobic capacity of female soccer players; (2) physiological responses during SSG reflect that it is intermittent training, evidenced by a significant difference in post-intervention lactate levels between the laboratory test and the SSG field test; and (3) SSG can improve technical and tactical skills, as evidenced by more successful passes than failed passes.

This study used four-a-side SSG as a design in the data collection process. Although many experts modify SSG based on the number of players, pitch size, analysis surfaces, and rule modifications, four-a-side SSG are considered to be one of the most desirable exercise designs because they can satisfy the physiological demands of female players (López et al., 2019; López-Fernández et al., 2017, 2018; Mara et al., 2016). This is in line with the findings of this study, which support previous study (Mara et al., 2016). This study revealed that HR_{ave} during SSG was 84.42% of the HR_{max} , which is in line with study conducted by Mara et al., (Mara et al., 2016) where the results stated that four-a-side SSG can be used as an exercise design that can perform aerobic conditioning stimulus and increase the anaerobic ability of female players, when compared to medium-side games (MSG) and large-sided games (LSG). This is indicated by the higher percentage of HR_{ave} of the HR_{max} responses during SSG ($87.2 \pm 5.7\%$) compared to MSG ($86.3 \pm 6.1\%$) and LSG ($83.9 \pm 4.9\%$).

Most of the previous studies revealed that the HR_{ave} during SSG of various sizes showed similar results, with an average of $>80\%$ of the HR_{max} . Only the study conducted by Della et al., (Dellal et al., 2012) where 8 vs. 8 male players performed SSG at a pitch dimension of 60×45 , with a time of 4×4 min/3 min rest, resulted in an HR_{ave} of $71.7 \pm 6.3\%$ of the HR_{max} . Meanwhile, there has been no study on female soccer players that shows an $HR_{ave} < 80\%$ of the HR_{max} during SSG of various sizes. In response to this phenomenon, this study agrees with Hill-Haas et al., (Hill-Haas et al., 2011) who stated in their systematic review that motivational,

technical and tactical factors, the number of players, and even the surface when performing SSG can affect the intensity of the game, resulting in HR_{ave} variations among various types of methods of SSG.

To the best of our knowledge, there is no study that is quantitatively related to VO₂ during SSG in female soccer players. Until now, study related to VO₂ during SSG has only been conducted in male players. For example, Hoff et al. (Hoff et al., 2002) analysed the internal loads on six male soccer players using five-a-side football SSG and found that the HR_{ave} during these was 91.3% of the HR_{max}, and the VO₂ was 84.5% of the VO_{2max}. Therefore, this study cannot compare the results of this study in a balanced way with previous studies, but it can be understood that the physiological responses during SSG in female and male soccer players seem to have similarities. The reason is, our results shown the VO₂ percentage response was very similar to the results of Hoff et al. (83.90% and 84.5% of VO_{2max}) (Hoff et al., 2002).

The physiological responses found in this study can strengthen previous evidence, which supports the idea that SSG is a training method that provides sufficient physiological demands for soccer players, especially female players. For example, Ohlsson et al. (Ohlsson et al., 2015) stated that HR_{ave} should reach 81–87% of their individual HR_{max} to reproduce the physiological demands of real matches. Considering that the quantitative results in this study show an HR_{ave} during four-a-side SSG of 84.42% of the HR_{max}, it provides evidence for female soccer players and athlete trainers to use SSG as an exercise design that can replicate the physical demands of soccer matches. Furthermore, the results of this study can complement previous studies on female soccer players, which were limited to several variables such as interface surface, metabolic power, time motion analysis and speed, and difference in pitch size during SSG.

In addition to important findings related to HR_{ave} and VO₂ responses during SSG, the findings in this study also reveal another interesting phenomenon, where post-intervention lactate levels during laboratory tests was significantly higher than post-intervention lactate levels during the SSG field test. This seems to emphasize that the SSG is a training design that reflects the characteristics of soccer matches, namely intermittent field sports. This can be observed from the low lactate levels after the SSG field test. The systematic review revealed by Proia et al. (Proia et al., 2016) seems to provide some explanation to this phenomenon. As a result of performing SSG intermittently, Cori's cycle can occur, in which lactate derived from the muscles is transported to the liver through gluconeogenesis to synthesize glucose, which then enters the bloodstream. Furthermore, Cori's cycle does not cause high lactate results after the SSG field test in this study.

Although this study has provided a novel approach regarding the physiological characteristics of female soccer players, there are some limitations. First, this study did not consider the influence of the circadian rhythm and menstruation rhythm on the physiological measurements in female soccer players. Second, this study only measured physiological responses in four-a-side SSG, hence, future studies should examine the different physiological responses in female soccer by comparing the interface surface, pitch size, and number of players during SSG. Third, regarding blood samples, we only analysed lactate levels, therefore, we encourage future studies to use blood biomarkers such as creatine kinase (CK), C-reactive protein (CRP), serum glutamic oxaloacetic transaminase (SGOT), or serum glutamic pyruvic transaminase (SGPT) to address the unanswered questions in this study.

CONCLUSION

This study shows that four-a-side SSG meet the physiological demands of female soccer players, marked by the achievement of a minimum standard of physiological response with maximum aerobic capacity.

Therefore, the use of four-a-side SSG can be recommended for coaches and female soccer players to increase aerobic capacity while still paying attention to the concept of developing an activity profile.

Practical implication

This study has concretely explained the physiological characteristics during SSG and the match activity profile, especially in professional female soccer players. Based on the findings of this study, we can provide the following recommendations to female soccer athletes and coaches to consider : (1) Four-a-side SSG quantitatively (VO_2 during SSG is 83.90% of VO_{2max} , and HR_{ave} during SSG is 84.42% of HR_{max}) can be assessed as a training regimen design that illustrates the importance of aerobic needs in soccer in female players, therefore, they can be considered as an appropriate exercise that can improve aerobic performance; (2) coaches and athletes should be encouraged to pay more attention to tactics in the use of four-a-side SSG, considering that these tactics can affect the development of the athlete's activity profile; and (3) paying attention to environmental factors such as temperature, surface, as well as dehydration and rehydration factors in conducting four-a-side SSG should be promoted, considering that some of these components can affect the quality of training.

AUTHOR CONTRIBUTIONS

Conceptualization: Tommy Apriantono, Nia Sri Ramania, Wildan Bahrul U'Lum, Bagus Winata. Data curation: Wildan Bahrul U'Lum. Investigation: Bagus Winata, Wildan Bahrul U'Lum. Methodology: Tommy Apriantono, Nia Sri Ramania, Wildan Bahrul U'Lum. Supervision: Tommy Apriantono. Validation: Tommy Apriantono, Bagus Winata. Visualization: Wildan Bahrul U'Lum. Writing – original draft: Bagus Winata. Writing – review & editing: Bagus Winata, Tommy Apriantono. All co-authors have contributed to the published work and agree to its publication in JHSE.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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Evaluation of sports tourism development policy in Sumedang: An implementation of the logic model

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ABSTRACT

The local government is making serious efforts to develop tourism in several destinations in Sumedang. Various policies regarding tourism were created to facilitate the implementation of regional tourism. To ensure the level of success of tourism policies, researchers evaluated sports tourism policies. Materials and Methods. The research method used is an evaluation method with a logic model with keys including context, input, activity, output, outcome, and impact. Research subjects include local governments, sports players, tourists, and the community. The research instruments used included interviews with 32 questions, observation, and documentation. Results. The results of this research include a context (policy, organization and program objectives), input (human resources, number of sport tourism, budget, facility time, and activities (training, material development, program implementation, and event promotion), output (participants, total income, increased employment opportunities, and improved regional image), outcome (knowledge, behaviour, social conditions, and economic quality), impact (social change, improved quality of life) Conclusions. This research provides implications for policymakers to maximise local governments' role in developing regional tourism, especially sports tourism. Evaluation of sports tourism policies in this research provide suggestions for local governments to review and make sports tourism a priority tourism.

Keywords: Tourism policy, Sports tourism, Evaluation, Logic model, Local government.

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INTRODUCTION

Tourism is one of the government's mainstay sectors because Indonesia has abundant tourism potential (Fadjarajani et al., 2022). Currently, the tourism sector is the country's largest foreign exchange earner. The development of the tourism sector in Indonesia is increasingly rapid. Viewed from a geographical aspect, this can affect Indonesia in terms of wealth, natural resources, human resources, and culture, which are tourist attractions both locally and internationally.

According to the World Tourism Organization World Travel and Tourism Council (WTTC), current tourism developments in 2018 placed Indonesia in ninth position with the fastest tourist growth in the world. Apart from that, in 2018, the Indonesian Minister of Tourism was selected as the Best Tourism Ministry in Asia Pacific, and the Ministry of Tourism was designated as the best in Asia Pacific. Regarding the competitiveness of national tourism through the Travel and Tourism Competitiveness Index (TTCI), Indonesia has reached rank 40 out of a target of 30 in 2019. Tourism in Indonesia has shown significant development (Kemenparekraf, 2020). With the continued development of the national economy and increasing people's needs for living standards, more and more people are participating in physical exercise and tourism (Sato et al., 2018; Wicker, 2020).

Sports Tourism is a form of combined sport and tourism activity where people can participate actively in sports activities and experience sports culture or passively by watching sports events for the purpose of making sports the main content (Duglio & Beltramo, 2017; Jiménez-García et al., 2020; Knop, 2004; Qi & Tang, 2022). Sport Tourism is a form of special interest tourism in the world of tourism and is widely developed in various regions because it can encourage tourists to visit (Hadi & Yulianto, 2021). Sports tourism can not only increase people's enthusiasm for sports but also satisfy people's interest in appreciating natural scenery (Qi & Tang, 2022). In the literature, the link between sport and tourism is referred to as the sportification of tourism or the touristification of sport (Malchrowicz-Mosko & Munsters, 2018).

As an economic driver, sports tourism is growing, and industry players are starting to look at it to take advantage of this opportunity, especially because of its contribution to regional development. (Bouchet et al., 2004), Increasing significant economic growth and income of residents surrounding the area used as a sports location (Jiménez-García et al., 2020; Marsudi, 2016), creating jobs and income, profits for local companies, increasing income taxes and increasing the amount of investment in infrastructure and sports facilities (Lupikawaty et al., 2013). This proves that sports tourism brings positive economic benefits that outweigh negative environmental or social impacts for local residents (Ivanov & Ivanova, 2011). The impacts of sports tourism can be positive (e.g., regional economic development), while others may be negative (e.g., sociocultural conflicts and environmental problems) (Wäsche et al., 2013)

The development of sports tourism requires the collaborative involvement of sports, tourism, and various other sectors and stakeholders (Mollah et al., 2021). (Kennelly & Toohey, 2014, 2016; Wäsche, 2015) has suggested collaborative development of sports tourism because sports tourism is very fragmented and involves various stakeholders. The collaboration in question is a joint effort made by stakeholders to achieve common goals. Collaboration in sports tourism provides many benefits, such as developing a sustainable sports tourism industry, increasing tourism volumes, and combining diverse resources and skills (Kennelly & Toohey, 2014; Lim & Patterson, 2008). Stakeholders influence the development, continuation, and success of sports tourism collaborations (Mollah et al., 2021).

Based on Sumedang Regency's tourism policy as outlined in the 2013 Regional Tourism Development Master Plan (RIPPARDA), tourism development is directed at providing adequate tourist attractions in accordance with local resource potential and supported by reliable tourism actors. Sumedang is one of the cities in Indonesia, with an area of 1,559 km², which is in accordance with Sumedang Regency Regional Regulation No. 2 of 2012 concerning Sumedang Regency Spatial Planning for 2011 - 2031.

In Sumedang Regency Regional Regulation Number 10 of 2020 concerning the Sumedang Regency Tourism Development Master Plan for 2021-2025, the government is making serious efforts to develop tourism in several destinations in Sumedang and make Sumedang Regency a tourist city. Access to Sumedang tourism is also supported by the Kertajati International Airport and Cisundawu Toll Road, which makes it easier for tourists to visit Sumedang. This is what makes the Sumedang Regency government even more optimistic about the progress of tourism in Sumedang Regency. However, after four years, the impact of tourism policy in Sumedang has yet to be felt significantly. This is reviewed from various aspects such as tourism growth, economic growth, tourism events, and sports tourism activities.

To see how far the implementation of tourism policies, especially sports tourism, is going, it is necessary to have an evaluation instrument that examines and provides an overview of the level of success in implementing sports tourism policies in Sumedang. Carrying out policy evaluations that are based solely on goal achievement will only provide insight into how effective policy interventions are and what specific factors contribute to achieving policy goals (De Bosscher et al., 2011; Suomi, 2004). There is, therefore, a call to use process evaluations to complement outcome evaluations, as they have particular value for multisite measurements where the same intervention is delivered and received in different contexts (Mansfield et al., 2015). Policy evaluations that focus on process analysis have emerged, especially theory-based process evaluation approaches aimed at informing policy decisions and the allocation of existing resources.

Policymaking is a complex matter, especially in a context where participation is from the public sector, private sector, and civil society. Policy success will depend on the nature of participation and the effectiveness of collaboration between these groups in implementing policy decisions (Andriotis et al., 2018; Krutwayshe & Bramwell, 2010). In an ideal policymaking framework, there is also a mechanism to monitor and evaluate the suitability of the decisions taken and the effectiveness of their implementation (Airey & Ruhanen, 2014).

Tourism policy is an example of public policy created specifically for a country's tourism sector. Tourism policy is 'concrete action in the field of tourism and provides a guiding framework for decision making regarding future tourism governance, development, and promotion of a country' (Hassan et al., 2020). To understand tourism policy implementation, it is important to understand the nature of the institutions involved in achieving policy objectives. At the national level, tourism policy development is closely related to power relations within a country (Bowen et al., 2017).

Tourism policymaking is complex and sometimes contentious, but whatever the political and economic circumstances, it must be directly linked to implementation: the process by which policy ideas and plans are translated into practice (Telfer & Sharpley, 2015). Implementation of tourism policies depends on the effectiveness of local, regional, and national officials in working with the private sector and other stakeholders, including host communities and environmental groups, as well as the third sector (Albrecht, 2017; Dodds & Butler, 2009). Implementation of tourism policies can, in many cases, be challenging (Lai et al., 2006). However, research focusing on the implementation of tourism policy is relatively rare (Albrecht, 2017).

Of these approaches, the 'top-down' and 'bottom-up' approaches are considered useful for implementing tourism policies in developing countries (Andriotis et al., 2018). The 'top-down' approach follows a hierarchical order from top-level policy planners to the regional level, while the "bottom-up" approach refers to implementation originating from the local level (Wang & Ap, 2013). The third approach, 'hybrid and interactional,' has greater explanatory power in developed countries, where there is a shift from governance to more established governance (Bramwell & Lane, 2011).

METHOD

The aim of this research is to evaluate the government's sports tourism policy. Meanwhile, the aim of policy evaluation research itself is to assess the effectiveness of public policies in relation to plans and perceived results (Chen, 2018). Policy evaluation research also aims to provide a better understanding of the success or failure of a policy, as well as to provide recommendations for improvement. Evaluation provides a retrospective analysis of a project, program, or policy to assess how successful or unsuccessful it was and what lessons can be learned for the future (Chen, 2018). The key elements of logic model evaluation include context, input, activity, output, outcome, and impact (Chen et al., 2013). These six elements were developed into several indicators (Table 1).

Table 1. The key elements and indicator of logic model evaluation.

Dimensions	Indicator	Question
Context	1. Policy context	4 Questions
	2. Relevant organizations (Departments involved)	
	3. Program objectives	
Inputs	4. Human resources involved	9 Questions
	5. Several sports tourism in Sumedang?	
	6. Budget	
	7. Time	
	8. Facility	
	9. Promotion	
Activity	10. Training	4 Questions
	11. Material development	
	12. Program implementation	
	13. Event promotion	
Outputs	14. Participant	7 Questions
	15. Total Income	
	16. Increased employment opportunities	
	17. Improved regional image	
Outcomes	18. Knowledge/skills	4 Questions
	19. Behaviour	
	20. Social conditions	
	21. Economic quality	
Impact	22. Social transformation	4 Questions
	23. Improved quality of life	
	24. Improving public health	
	25. Achievement of objectives	
Total	25 Indicators	32 Questions

Research participants include local governments, sports players, tourists, and the public. To collect data from the right participants, this research used a non-probability sampling method (Bell et al., 2022) described as 'purposeful sampling' (Creswell, J.W.; Clark, 2016) to develop an elite sample of interviews with high-level participants in the tourism policy process. Although the use of elite interviews has yet to be widespread in tourism research, it is a commonly used technique in political and policy research, as it has the potential to increase the quantity and quality of data available to researchers in fields where social phenomena are being researched (Hassan et al., 2020).

RESULTS AND DISCUSSION

Context

Sumedang has a policy that regulates the management and administration of regional tourism, namely the regional tourism development master plan (Ripparda). Rippardais is a strategic document prepared by local governments to regulate and manage tourism potential in an area. This document usually covers various aspects, such as analysis of tourism potential, development of tourism infrastructure, promotion and marketing of tourist destinations, environmental preservation, and development of the local tourism industry. Ripparda generally has a certain period, generally every five years. Meanwhile, Ripparda Sumedang has a period of 2021-2025 containing 72 articles. Specifically, those regulating sport tourism in Sumedang regulate seven articles spread across articles 29, 30, 31, 35, 36, 37, and 38. Of the seven articles, six place sports tourism as an alternative tourism or second priority, and only in article 38 is sports tourism made top priority tourism with international standard sports tourism.

Tourism policies are regulations, rules, guidelines, directions, and development/promotion targets, as well as strategies that provide a framework for individual and collective decision-making that directly influence tourism development in the long term as well as daily activities that take place at a destination. Most tourism policies are focused on how to increase revenue from visitors (Joppe, 2018).

To support the implementation of tourism policies, especially sport tourism, there are several agencies involved in sport tourism activities in Sumedang, including the Department of Tourism, Culture, Youth, and Sports (DISPARBUDPORA), Transportation Service (DISHUB), Public Works Service (P.U.), Regional Planning Service (BAPEDA), Village Community Empowerment Service (DPMD), Cooperatives, Small, Medium Enterprises, Trade, and Industry Service. The amount of attention and knowledge explains that there is a need for collaboration in developing sports tourism (Hinch et al., 2018; Weed, 2014). Local governments play an essential role in developing sports tourism as this is a national issue for any destination (Mollah et al., 2021). Exemplary leadership can better coordinate the many stakeholders involved in sports tourism (Mollah et al., 2021). In sports tourism, collaboration or joint efforts are necessary because the development of this tourism market requires the integration of various services, including marketing activities, food, accommodation, transportation, safety, and ticket reservations (Wäsche, 2015).

Inputs

Human resources involved in Sumedang sport tourism activities include sport tourism operators, communities, tourism stakeholders, and associations. A sports tourism operator is a person or company that organizes and manages sports tourism activities or packages. The sports tourism community is a group of people or a network of individuals who have an interest or similarity in promoting, developing, or participating in sport tourism activities. They usually consist of active participants in various types of sports activities, entrepreneurs in the tourism industry, sports event organizers, local governments, sports organizations, and local communities in tourism destinations.

Sports organizations are the main actors in sports tourism collaboration among various stakeholders due to their active influence on the development and promotion of sports tourism (Kennelly & Toohey, 2014). It is also evident that tourism organizations take leadership and initiative for sports tourism collaboration when the sports organization is not an indigenous organization and the tourism organization has a better affiliation with the government (Lim & Patterson, 2008)

Several types of sports tourism that are running in Sumedang include Paragliding, rafting (4 locations), offroad, golf, horse racing, motocross, mountain biking, and BMX. Sumedang has three strategic locations, which are used as paragliding sports locations, while for rafting, Sumedang has 4 locations, which are used as places for sport tourism activities in the water. Three of the eight types of sports tourism that Sumedang has, three have become superior: paragliding, off-road, and rafting. For the last five years, Paragliding Sumedang has held international events, namely the West Java Paragliding World Championship in 2019 and 2021, national events, namely the Sumedang Paragliding Championship, and local events. Then, every week, there are paragliding activities carried out by individuals and paragliding communities.

In implementing the sport tourism policy, the local government allocates funds only to the Disparbudpora. In contrast, other agencies involved in implementing activities need to allocate funds specifically for the sustainability of sport tourism. Other agencies only use funds in accordance with their duties and do not directly support sport tourism activities. For example, the public works department builds and repairs infrastructure, such as roads that support sports tourism activities, so that road access is easy. Diskominfosandistik carries out marketing and promotion of sports tourism activities, and other agencies do not directly help with sports tourism activities in Sumedang.

The local government designed a sports tourism policy specifically, with the overall policy implementation time being five years, namely 2021-2025. This time duration is considered ideal if there are no other disturbances that could hinder the implementation of activities and if several related parties or other agencies support it. However, in its implementation, there are still policies that have yet to be realized, even though the policy has been implemented for four years. Some of the obstacles to implementing the sports tourism policy include refocusing the budget for dealing with COVID-19. Almost all of the dinar service budget in Sumedang and in Indonesia is allocated for the response and recovery from COVID-19. The lack of budget for implementing sports tourism has meant that the relevant agencies have yet to continue several policies, which will be revised in the next period.

In supporting the implementation of sports tourism policies, facilities, equipment, and facilities must be met. So that sports tourism activities can run smoothly. So far, the infrastructure supporting sports tourism activities in several places is excellent and suitable for use, especially in supporting Paragliding. However, the infrastructure of sports tourism rafting locations still needs to be improved. This will undoubtedly disrupt the sustainability of sport tourism itself. Usually, the infrastructure will be repaired if a sports tourism event is held at that location. So, as long as there are no sports tourism events, there will be no infrastructure improvements. Adequate infrastructure, such as transport links and accommodation facilities, can facilitate tourism growth, attract investment, and create jobs in underserved areas (Wissink, 2023). To achieve this, it is critical to allocate appropriate economic resources, increase investment, improve infrastructure, enhance human development, and establish a supportive regulatory framework to ensure economic efficiency (Mishra et al., 2021).

Apart from the infrastructure supporting sport tourism activities, local governments have yet to be able to facilitate sport tourism equipment. So, equipment to support sports tourism activities still relies on personal,

community, and rental equipment. However, in 2025, the regional government plans to allocate funds to facilitate sports tourism activities, especially rafting (rubber boats and rowing) and Paragliding (parachutes and other paragliding equipment).

Activity

Human resources

Human resources are the main actors in organizing sports tourism in Sumedang. These human resources include tourism stakeholders, tourism offices, sports tourism operators, communities, guides, and associations. It is essential for human resources to be able to increase competency and certification to support the ability to manage and develop sport tourism in Sumedang through training activities. So far, the regional government still needs to accommodate increasing H.R. competency and certification. However, H.R. in Sumedang still needs to be certified. Several H.R.s have certifications, including:

- Rescue rafting certification (1 person)
- Paragliding pilot certification (7 person)
- National tour guide certification (1 person)

The competency certificates above were obtained by individual operators and communities without being facilitated by the local government. This certification is not only to ensure the competence of actors or guides. However, it provides a sense of security and comfort to participants or sports tourism fans who need a guide.

Apart from developing human resources, policy materials need to be developed or evaluated in the current period. The aim is to follow up on policies that are not realized immediately or to revise policies if it is not possible to continue in the current period so that the realization of the improved policy can be carried out as soon as possible without having to wait for the policy's validity period to expire.

The realization of policies that have been planned by the regional government is implemented without creating a plan-based timeline. So, the realization of the policy is based on something other than initial scheduling. Timelines can help in planning and organizing tasks that must be completed in policy, help in identifying trends or patterns that may occur over time, analyse data in the context of time, and allocate resources efficiently. Timeline-based planning is a paradigm that models the temporal planning domain as a series of independent but interacting components (Della Monica et al., 2020). By creating a plan-based timeline, it is possible to adapt policy plans more efficiently, reducing computational costs and consequently increasing the overall system's ability to react quickly to unexpected events (De Benedictis et al., 2022).

One way to realize the sports tourism policy is through promotion. The regional government still needs to massively promote sports tourism to increase public interest in becoming part of the sports tourism actors or community. However, community and sports tourism activities such as Paragliding, rafting, and offroad have independently carried out promotions through social media such as Facebook, TikTok, YouTube, and Instagram. This promotion is considered very effective in attracting local and domestic tourists to visit and try sports tourism in Sumedang. Sports tourism marketing via the modern internet, such as Facebook, TikTok, YouTube, and Instagram, plays a vital role in achieving positive results (Prokopenko et al., 2020).

Outputs

Number of participants and economic actors

The output indicators in the logic model refer to instant results that can be seen at the time of the event or shortly after the sport tourism event takes place. The results include the number of participants, income, number of jobs, and regional image. Data from several events that have taken place shows that the number

of participants in the off-road event is 1,500, which will take place in 2023, a major paragliding event with the highest number of participants, 120 participants. For all participants apart from officials and spectators, if calculated roughly, the total number of participants involved can reach 4-5 times the number of core participants. The event here is a competition activity in sports tourism or an event created by the community to gather together to share their hobbies. Apart from during events, the number of participants cannot be calculated with certainty. However, for rafting and Paragliding, the average number of participants ranges from 20-300 participants per month.

During the event, there was an increase in the economy through sales of food, apparel, accessories, and other goods that have selling power. This sale is generally carried out by small traders in the Sumedang area. Unfortunately, there is no data collection on the number of traders trading during the event, so the economic increase cannot be calculated with certainty. This has affected the government's ability to accurately evaluate the impact of sports tourism in Sumedang. However, despite this, the event positively impacted the economic growth of Sumedang residents. There is a large body of literature on the impact of hosting significant events in general [47-50], as well as sporting events are great opportunities for the host country to gain various economic and sociocultural benefits (Mansour et al., 2022).

Economic growth and regional image

Economic growth will, of course, continue to increase if events are scheduled regularly. Unfortunately, sports tourism events in Sumedang cannot be held regularly every year. The regional government still needs to create an annual agenda for sports tourism events. Events that only take place for specific moments or for the benefit of a handful of stakeholders to boost popularity. So, it has yet to be included in the government's annual agenda and has not been able to boost the regional image optimally.

Meanwhile, this is the only offroad event that has a regular agenda every year with up to 1500 participants. This offroad event can trigger other sports tourism to develop through annual events. So that sports tourism in Sumedang can develop evenly, and the regional image will be obtained. The synergy between sports and tourism helps develop the tourism industry by promoting the destination's image through hosting major sporting events (Mansour et al., 2022).

Outcomes

Improved behaviour, culture, and economy

Outcomes refer to outputs that have a broader and often more qualitative impact that occurs as a result of the output. The focus is on changes or impacts experienced by individuals, communities, institutions/agencies, or systems. The role of local government in developing sport tourism through tourism policy is gradually starting to have an impact on community knowledge, especially in the local Sumedang area. Many people are starting to know about sports tourism in Sumedang, both from activities, events, locations, and types of sports. This can be seen from the enthusiasm of the public in seeing sports tourism activities on social media, and the number of visitors to sports tourism locations is starting to get busy. At several events that have been held, public interest can be seen from the large number of visitors and the busyness of several sales stands during the event. Even though the community has yet to take part as a sports tourism actor, community knowledge will promote participation in sports tourism activities in Sumedang for the outside community.

Since the exposure of sports tourism events and several of its activities, many people have come to try to get involved in sports tourism activities. People's behaviour is starting to shift from previously doing sports in general, such as jogging, cycling, futsal, badminton, and sports that are popularly played by people, to sports

that are considered to have more challenges, such as Paragliding and rafting. This change in behaviour does not occur as a whole in society. Generally, this change occurs in upper-middle-class society. This is because the costs of doing sport tourism (Paragliding, rafting, off-roading, and others) are considered expensive. People can use sports tourism facilities by paying rent or packages without owning the equipment.

The changes in behaviour shown by some people in sports tourism activities do not make it a new culture of sports. The sports culture that exists is not due to sports tourism events or activities but rather the impact of sports activities in general, which are starting to become a new trend among young people in Sumedang. This is the impact of social media, where there are lots of posts about sports and many public figures who are trend-centred on carrying out sports activities.

In the economic aspect, there has been no significant increase as a result of the sports tourism policy. This is because event-based sports tourism activities have yet to be held on a scheduled basis and are carried out every year. The economic improvement can only be felt by sport tourism operators, which comes from the packages they sell and a small number of traders who sell around sport tourism locations. Meanwhile, people who support other activities, such as large-scale traders, have yet to feel the impact. The development of quality sports tourism cannot be achieved without the active participation of the community in sports tourism destinations because the role of the community has been proven to have a positive and significant impact on sustainable tourism [52-53]. Regional governments must be able to involve other communities as supporters, even though they are not the main actors in sports tourism activities such as traders.

Impact

Social change, improving quality of life

Improving the quality of life is a concept that does not stand alone or is not a single concept that is stated and accepted universally; this is because the concept of quality of life can cover various scientific domains. In the field of sociology, quality of life is defined as a subjective understanding of ownership (wellbeing); in the field of economics, quality of life is defined as the standard of living, while in the fields of pharmacy and medicine, quality of life is the ratio between healthy and sick times with various influencing factors. Healthy lifestyle. The increase in tourists in sport tourism activities has led to an increase in population income, and this has led to an increase in consumer spending and a gradual reduction in poverty. As population income increases, the quality of life, such as education and health, will improve. In developed countries, economic factors have been found to be associated with many health impacts, including health-related quality of life (Tan et al., 2018). The welfare of the population is determined by the level and quality of life as the most important socio-economic category (Lakomý & Alvarez-Galvez, 2022).

Overall, the impact of sports tourism policies on the quality of life of the community has been felt, especially among the people who live around sports tourism locations. This is because many local people work in trade at tourist locations, so the large number of tourists has a big impact on improving the local economy. Apart from traders, tourism service operators really feel the impact of the sport tourism policy itself. This is proof that tourism can provide various benefits for local communities. Apart from traders, operators are the main actors in this tourism business, and they feel the impact directly and gradually improve the quality of life of sport tourism operators. This is in line with other research findings showing that sustainable tourism has a positive impact on the local economy and employment opportunities in various ways (Wissink, 2023). This encourages economic diversification by encouraging the development of various tourism-related businesses and services, reducing dependence on one industry and creating a more resilient local economy. Sustainable tourism creates job opportunities, such as tour guides, hotel staff, drivers, environmental conservationists, and local guides, leading to increased employment in communities and improved livelihoods.

Additionally, sustainable tourism strengthens local supply chains by promoting the use of local products and resources, thereby providing benefits to local producers and businesses. This empowers local communities through active participation and involvement, enabling them to take ownership of development and improve their skills and knowledge through training and education programs. Sustainable tourism contributes to long-term economic development by creating jobs, diversifying the economy, preserving cultural heritage, empowering local communities, and fostering a more equitable and resilient tourism industry (Wissink, 2023).

Implication

This research provides implications for policymakers to maximise local governments' role in developing regional tourism, especially sports tourism. Even though sports players are the main drivers of tourism activities, they do not think about the development of sports tourism as a whole because the framework for tourism development is in the hands of local governments. Therefore, the local government must be able to embrace, accommodate, and make policies according to the needs of sports tourism actors to develop sports tourism in Sumedang.

Tourism policy consists of regulations, rules, guidelines, direction, and development/promotion targets, as well as strategies that provide a framework for individual and collective decision-making that directly influences tourism development in the long term, as well as daily activities in Sumedang. This policy is the key to whether regional tourism will develop, in addition to collaboration from all related parties.

Currently, sports tourism is developing and is starting to be looked at by industry players to start taking advantage of this opportunity, especially because of its contribution to regional development, increasing significant economic growth and income of residents around the area used as a sports location, creating jobs and income, profits for local companies, increasing income tax and increasing the amount of investment in infrastructure and sports facilities. This proves that sports tourism can be an economic driver because it brings positive economic benefits that outweigh negative environmental or social impacts for local residents. Therefore, the regional government must begin reformulating its sports tourism policy to prioritise tourism like other tourism offered in Sumedang. With the sports tourism policy becoming one of the tourism priorities, the allocation of funds will be given more attention, and development will be even more rapid.

CONCLUSION

Sports tourism has become a form of special interest tourism in the world of tourism, which is starting to develop in various regions because it can encourage tourists to visit and increase economic growth and regional image. The local government has taken concrete steps by creating several tourism policies to regulate the implementation of sports tourism and welcome potential sports tourism opportunities. Based on the results of an evaluation study of sports tourism policies using a logic model, the results showed that most of the policies have been implemented and have positively impacted the quality of life, economy, and regional image, especially in areas around sports tourism locations. A significant improvement in the quality of life can be felt in people directly involved in sports tourism activities, such as providers of services or tour packages, guides, operators, and traders around sports tourism locations.

AUTHOR CONTRIBUTIONS

Rizal Ahmad Fauzi, serves as the primary leader who develops the conceptual framework and is responsible for the overall writing process of the journal. This includes integrating contributions from other authors and drafting the findings and discussion sections, which provide a comprehensive and in-depth analysis. Yudha

Munajar Saputra focuses on preparing the literature review and theoretical framework sections, as well as contributing to data collection. Amung Ma'mun is responsible for handling data collection and analysis. This role involves processing results from surveys, interviews, or observations. Nuyadi, manages the methodology section, ensuring that the research methods are thoroughly described and meet scientific standards. Sri Rizki Handayani, handles the abstract, conclusion, and bibliography sections, ensuring that all references are properly cited and formatted.

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Impact of substitutions on elite soccer team performance based on player evaluation system

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ABSTRACT

This research aimed to explore the performance characteristics of substitutions and to evaluate the performance of substitutions based on the player evaluation system. Event data of 643 substitutions identified from the Chinese Super League teams in the 2019–2020 season were used. The team ratings, ball possession, and expected threat of four periods (5 minutes per period before and after the substitution) of each substitution were computed. Two-step cluster analysis was performed on the team ratings at different times, and the Scheirer–Ray–Hare test was used for the two-factor design based on the cluster and the substitutions across four periods. The cluster analysis revealed 5 clusters with a Bayesian Information Criterion (BIC) value of 1,360.50. The interactions of team ratings between the periods and the clusters in different groups were detected ($H = 531.96$, $p < .001$, $E_R^2 = 0.47$). The group comparisons suggested that the ratings of Cluster 3 showed a significant decline after substitutions, which was caused by the lower ball possession while showing greater aggressiveness in terms of expected threat. The study shows how player evaluation systems can be used to measure the effectiveness of substitutions in soccer games and provides insight for further analysis of decision-making situations.

Keywords: Performance analysis, Soccer, Match analysis, Substitution, Technical-tactical performance, Player evaluation.

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INTRODUCTION

Decision-making has been an important topic in the study of team sports performance analysis, ranging from the choice of technical actions or movement types made by players on the field, as well as those made by managers and coaches (Nosek et al., 2021). Research on strategic decision-making in football includes a variety of aspects such as substitutions, structures of formations, playing styles, and physical distribution (Castillo-Rodríguez et al., 2023; Gollan et al., 2018; Passos et al., 2016). Among these, substitutions that can influence physical demands and tactics have garnered increasing attention in recent years. This is partly due to the implementation of FIFA's new rules (*International Federation of Association Football*, 2020), which increased the maximum number of substitutions per team from three to five (García-Aliaga et al., 2023; Hills et al., 2020). Not only does the decision of substitution counteract team fatigue to prevent injuries, but it also allows for a change in the game's pace by adjusting the team formations (Bradley et al., 2014; Hills et al., 2018). It might be one of the most direct and effective ways for coaches to get involved and help in the game, which therefore demands more scientific investigation.

The current analysis of substitution performance in soccer matches could be divided into several aspects, namely the timing of substitutions (Myers, 2012; Silva & Swartz, 2016), modifying tactical behaviour through substitutions (Amez et al., 2021; Gómez et al., 2016), exploring the running performance and physical demands of substitutions (Bradley et al., 2014; Carling et al., 2010), assessing the psychological state of substitutions (Woods & Thatcher, 2009). In contrast to earlier academic investigation, which proposed that three substitutions occurring before the 58th, 73rd, and 79th minutes (Myers, 2012), another study that considered team quality and game status suggested that simply evaluating substitution timings in isolation to measure their effectiveness within the game context might be inadequate (Silva & Swartz, 2016). Extensive research has elucidated that trailing teams tend to substitute at an earlier stage in the match compared to their leading counterparts, and such tactical changes often lead to more favourable outcomes (Amez et al., 2021; Gómez et al., 2016). A study based on substitution types has found that different types of substitutions can reflect a team's tactical intention and simultaneously enhance offensive efficiency or reinforce defensive resilience (Lorenzo-Martínez et al., 2021). It seems widely acknowledged that offensive substitutions increase the probability of goal-scoring (Wittkugel et al., 2022), yet the effectiveness of defensive substitutions in preventing goal-scoring opportunities remains a subject of ongoing debate (Conte et al., 2016; Del Corral et al., 2008; Gómez et al., 2016). When it comes to running performance, there have been various studies showing that the total distance and the high-intensity runs by midfield substitutes in the second half are greater than those covered by the replaced players or teammates of the same position (Bradley et al., 2014; Bradley & Noakes, 2013; Coelho et al., 2012). Meanwhile, the interval between their high-intensity runs is shorter (Carling et al., 2010).

These studies consider the effects of various contextual variables, including scoreline, home advantage, and team rankings, thereby elucidating more profound insights derived from practical experiences. Nonetheless, it is worth noting that a substantial portion of these substitution studies tends to overlook the on-field position and behaviours of players. The criteria employed to assess the impact of substitutions are often confined to goal differences or changes in the scoreline (Leeuwen, 2020). As a consequence, the scope is relatively limited when it comes to providing comprehensive evaluation of substitutions made for the diverse tactical objectives of teams.

Therefore, adopting a multivariate approach could be a potential solution for the research topic. Specifically, advanced or hybrid performance indicators were proposed and could be used to evaluate the effect of substitution. For instance, the ball possession, which is widely known for assessing the team's performance

in soccer, suggests that the high percentage of ball possession in the penalty box may contribute to goals scored (Link & Hoernig, 2017; Parziale & Yates, 2013; Wang et al., 2022). Recently, expected threat (xT) was introduced as an aggregated metric of the expected goal (xG) (Eggels et al., 2016; Rathke, 2017) and ball possession to evaluate individual actions related to attacking (Singh, 2019). Following this development, several innovative frameworks were put forward to achieve a more comprehensive evaluation of match performance. Decroos et al. (2019) estimated the probability of goals and concedes and used it as a value to rate single action. Other researchers combined the value of multiple players to evaluate team performance (Bransen & Van Haaren, 2020). Moreover, some studies further refined the on-ball value of attacking and organizing behaviours (Li et al., 2020), and adopted performance indicators of both competing teams to determine the defensive effectiveness (Ruan et al., 2022). These models offer specific references for coaches and players and are the main components of the player evaluation approach selected in this research.

Given the above rationale, the purpose of this study was to explore the effectiveness of substitutions from the perspective of team evaluation and analyse the timing of substitutions and offensive performance metrics before and after substitutions. The hypothesis was that differences in team performance ratings, xT, and ball possession percentages before and after substitutions would be statistically significant, and that ratings could be affected more by the period of substitutions than by the other two evaluation methods. Meanwhile, it is expected that the findings could provide a practical framework that applies a player evaluation system to the decision-making scenario of substitutions, offer insights into team dynamics during different phases of the match, and inform coaches and players about the impact of different evaluation methods on substitution decisions.

METHOD

Sample

The study considered 643 substitutions from 240 matches played by 16 Chinese Super League (CSL) teams during the 2019 season. Match event datasets were retrieved from the public-access football statistics website named “*whoscored.com*”, whose data were provided by the international sports data provider OPTA Sports with verified reliability (ICC ranging from 0.88-1.00) (Liu et al., 2013). Originally, there were a total of 1368 substitutions, and 725 of them failing to meet the following criteria were excluded: i) The time segment contains 5 minutes prior to and 15 minutes posterior to each substitution, e.g. if a match ended at 90 minutes, any substitutions made after the 75th minute were excluded; ii) Substitutions resulting from unexpected injuries and dismissals (red card) (Gómez et al., 2016); iii) Players entering as substitutes had to have appeared in at least one game in the previous season. Ethical approval for this study was granted by the local ethics committee and conformed to the recommendations of the Declaration of Helsinki.

Variables and procedures

According to the scientific literature that analysed substitutions during soccer matches (Hills et al., 2018), 4 contextual and 15 individual indicators were chosen from the raw data as independent variables in the analysis. The description and definitions of these two types of performance indicators are presented in Table 1. Since the study does not focus on comparisons in match behaviour between substitutes and starters, these variables were selected to describe both contextual factors and team performance.

Instead of using potentially biased goal scores to assess substitution effects, the study considered several approaches of on-the-ball action rating during the match after comprehensively comparing their characteristics. Firstly, the percentage of ball possession was included as it could provide intuitive and

understandable information about the rhythm and momentum of the match (Wang et al., 2022). Additionally, the study incorporated Expected Threat (xT), which quantifies the threat associated with on-the-ball events based on ball possession data (Singh, 2019; Sumpter, 2021; Van Roy et al., 2020). The study has undertaken the selection of pertinent features, encompassing the three-dimensional coordinates of the ball within the goal area, shot locations, the length and angle between the goal and the ball, the body parts involved in player actions, assist types, and the ultimate outcomes of shots. These features collectively form the foundation of the expected goal (xG) model. The approach adopted involves the allocation of xG values to distinct regions on the football pitch, contingent upon the likelihood that possessing the ball in each area will culminate in a goal during a possession phase. Furthermore, the effectiveness of these actions is assessed by calculating changes in grid values before and after ball movements, thus quantifying the expected threat associated with these actions.

Table 1. Description and definition of the performance indicators.

Variables	Description
<i>Contextual</i>	
Match location	The team making the substitution playing home or away
Match status	The goal difference between the team making the substitution and the opponent
Ranking	The substitution team's ranking
Opponent Ranking	The opponent team's ranking
<i>Individual</i>	
Number of minutes remaining	Time remaining in the current match
Number of substitutions remaining	The number of substitutions remaining in the current substitution team
Substitution type	Three types of substitutions constructed according to the position the player is replaced, which are offensive substitution, neutral substitution and defensive substitution; Positions were categories in 5 by player vector last season, including strikers, central midfielders, wing forwards, fullbacks and central backs
Rating/Possession/Expected threat within 5 minutes before substitution	Team rating/possession/expected threat of the game performance in the first 5 minutes before the substitution based on the player evaluation system
Rating/Possession/Expected threat within the first 5 minutes after substitution	Team rating/possession/expected threat of the game performance in the first 5 minutes after the substitution based on the player evaluation system
Rating/Possession/Expected threat within the second 5 minutes after substitution	Team rating/possession/expected threat of the game performance in the second 5 minutes after the substitution based on the player evaluation system
Rating/Possession/Expected threat within the third 5 minutes after substitution	Team rating/possession/expected threat of the game performance in the third 5 minutes after the substitution based on the player evaluation system

Moreover, the study employs Li's (2022) player assessment system, which relies on four key individual player attributes to formulate rating models: shot, organization, skill, and defence, each considering event types and qualifiers. These models integrate the risk-reward paradigm (Goes et al., 2022) and yield two distinct models per attribute. For shot ratings, the model calculates the value of a shot by subtracting xG_2 (considering only on-target shots) from xG_1 (considering all shots), normalized relative to the player's total number of shots per match. In organization and skill ratings, threatened situations encompass events like shots, penalties, crosses, opponent clearances, opponent goalkeeper strikes, and the opponent's own goals. The models differentiate between situations arising after 5 and 3 events, respectively. Ratings for organization and skill are derived from the difference between threatened and lost values of a player's total actions (e.g., passes and dribbles per match). Defence ratings are determined by comparing the probability of maintaining possession after 3 defensive actions and the probability of conceding a shot after 5 defensive actions. All models use XGBoost, LightGBM, and CATboost, which are three Gradient Boosting Decision Tree-based frameworks. After training and optimization, the LightGBM model was selected as optimal due to its superior

performance. Player and team ratings are then calculated by summing ability ratings after min-max normalization, offering a precise measure of individual and team performance during matches.

Statistical analyses

The two-step cluster analysis was suitable for handling both ordinal and nominal data based on the distance measure (Chiu et al., 2001), which was performed accordingly on the team ratings at various times before and after substitutions. The time intervals included 5 minutes prior to substitutions and three subsequent 5-minute periods following each substitution. The Bayesian Information Criterion (BIC) and the Ratio of Distance Measures were the statistical measures of fit in a two-step cluster analysis (Bacher et al., 2004; Kent et al., 2014) for assessing team ratings. The Scheirer–Ray–Hare test, a nonparametric test (Scheirer et al., 1976), was used for the two-factor design when the hypothesis of sphericity and normality was not satisfied ($p < .05$) based on the cluster and the substitutions over four periods (5 minutes per period before and after the substitution). The variables of team ratings, ball possession, and the expected threat during the four periods of the substitutions were analysed using the Scheirer–Ray–Hare test. Post-hoc multiple comparisons were conducted with the Mann-Whitney U test with the significance level adjusted. The effect size estimations for the Scheirer-Ray-Hare test were computed using epsilon-squared (E_R^2) whose thresholds of magnitude: negligible, <0.01 ; weak, $0.01-0.04$; moderate, $0.04-0.16$; relatively, $0.16-0.36$; strong, $0.36-.64$ (Tomczak & Tomczak, 2014). In addition, the value of the correlation coefficient (r) was computed as the effect size estimations for the post-hoc Mann-Whitney U test with thresholds of magnitude: negligible, <0.1 ; weak, $0.1-0.39$; moderate, $0.39-0.69$; strong, $0.69-0.89$; and very strong, >1.00 (Hopkins et al., 2009; Schober et al., 2018). The level of significance was set at $p < .05$. All analyses were performed using the statistical software R version 4.2.2 and Python 3.

RESULTS

According to the descriptive statistics, the ratio of home (48.1%) and away (51.9%) games was nearly equal in all samples. The proportion of samples ranked higher (50.4%) than their opponents was roughly equivalent to those ranked lower (49.6%). The distribution of the frequency of substitutions of different types and numbers during the game period is shown in Figure 1. The stacked column diagram represents the type of substitution, and the area diagram represents the number of substitutions.

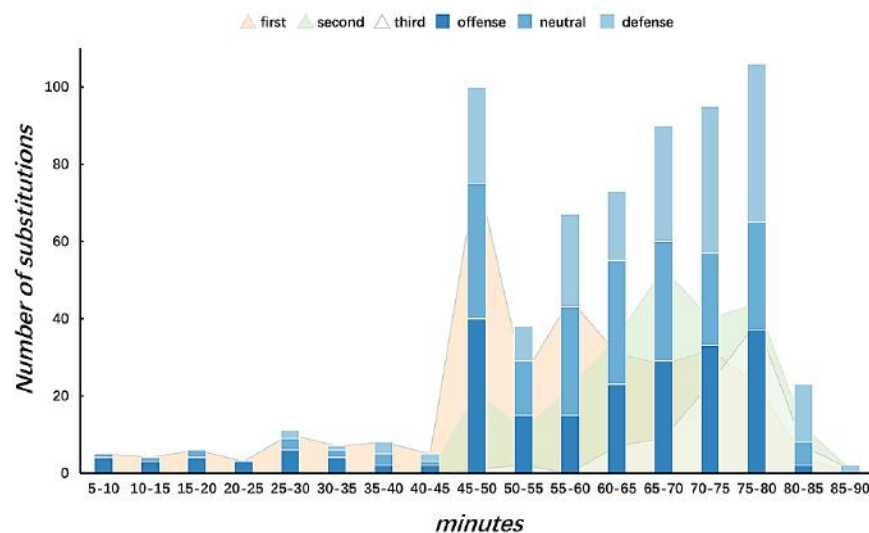


Figure 1. Stacked diagram of the substitution types and numbers during different match periods.

The two-step cluster revealed five groups according to the ratings in different periods before and after substitutions. Clusters 1, 2, 3, 4, and 5 comprised 15.2, 17.3, 18.5, 22.9, and 26.1% of the sample size, respectively. The BIC value of the cluster analysis was 1,360.50, and the ratio of distance measures was the maximum (1.70). The cluster analysis showed the Predictor Importance (PI) of the four periods in descending order: the first 5 minutes after substitutions (PI = 1), the third 5 minutes after substitutions (PI = 0.91), 5 minutes before the substitutions (PI = 0.85), and the second 5 minutes after substitutions (PI = 0.55). The clusters of team ratings according to the periods are shown in Figure 2. Each cluster is represented by a coloured polyline, with cluster 1 scoring relatively high and cluster 5 relatively low. Additionally, in cluster 3 there were about 35% of substitutes with a drawn match status, and over 40% of all clusters substituted with a negative goal differential.

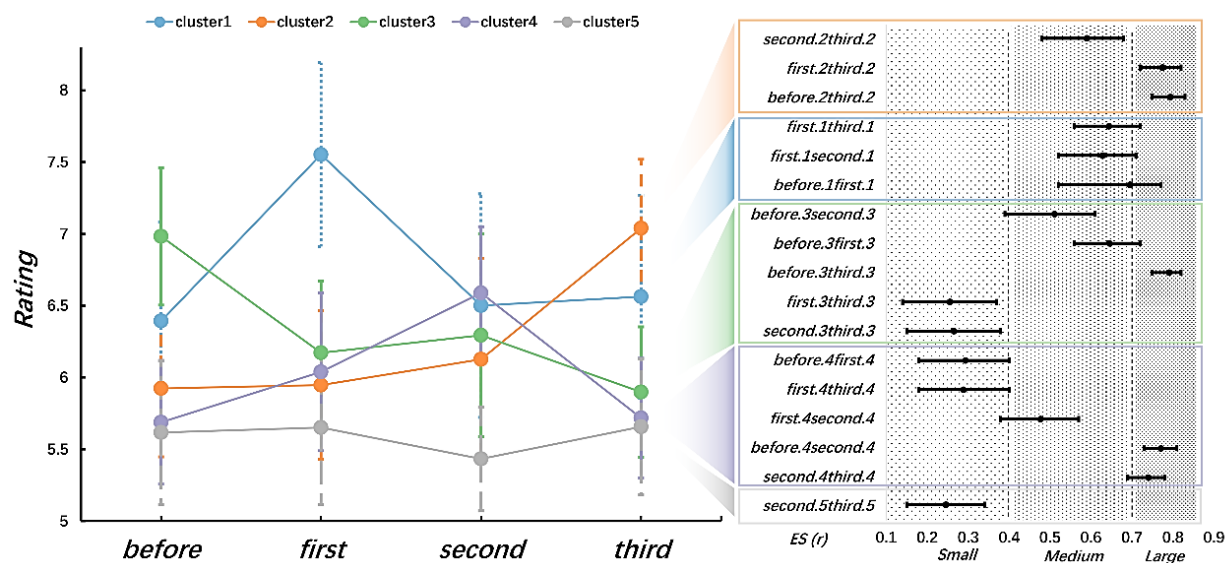


Figure 2. Line diagram of the clusters during periods before and after substitutions and the forest diagram of the interactions' main effect sizes.

As shown in Figure 2, the mean and standard deviation of team ratings and the interactions ($H = 531.96, p < .001, E_R^2 = 0.47, 95\%CI = [0.44,0.49]$) between the two factors of the periods and the clusters in different groups were detected (see Supplementary Table 1 for detailed interaction analysis results). The main effects of team ratings were statistically significant ($H = 662.06, p < .001, E_R^2 = 0.26, 95\%CI = [0.23,0.29]$). The interaction between clusters and periods of substitutions in expected threat did not show any statistically significant differences, and neither did ball possession.

The main effects of expected threat showed on the two factors (clusters: $H = 13.56, p < .05, E_R^2 = 0.001, 95\%CI = [0.002,0.013]$; periods: $H = 203.02, p < .001, E_R^2 = 0.08, 95\%CI = [0.06,0.11]$), and the main effects of ball possession only showed on the clusters ($H = 45.41, p < .001, E_R^2 = 0.02, 95\%CI = [0.01,0.03]$). The post-hoc Mann-Whitney U test on clusters of expected threat and ball possession showed that group comparisons revealed significant differences ($p < .05$) with specific results in Figure 3. Moreover, the pairwise comparisons of expected threat on periods of substitutions were as follows: before-first ($p < .001, r[95\%CI] = 0.35[0.30, 0.41]$), before-second ($p < .001, r[95\%CI] = 0.29[0.24, 0.35]$), before-third ($p < .001, r[95\%CI] = 0.31[0.26, 0.37]$).

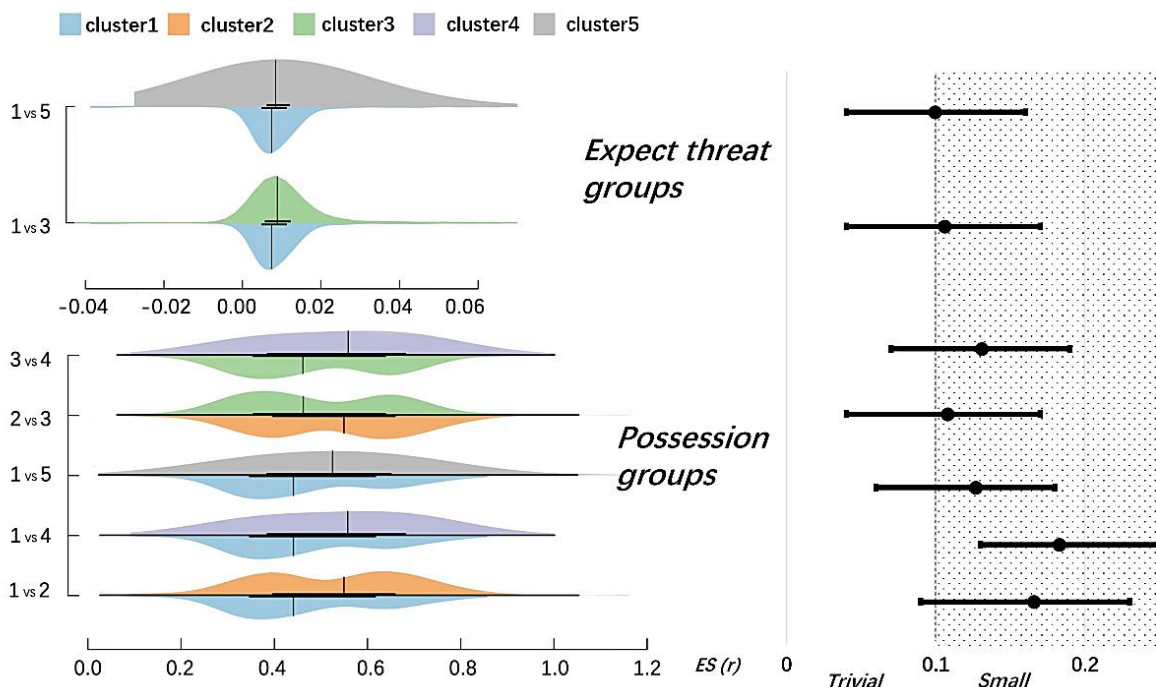


Figure 3. Violin and forest diagrams of Expected Threat and ball possession group comparisons on clusters.

DISCUSSION

The primary objective of the present study was to investigate the effectiveness of substitutions through the lens of team assessment, with a particular focus on analysing the temporal and match performance dynamics before and after substitutions. As previously mentioned, this research delved into team performance using diverse evaluation methodologies, seeking to discern performance fluctuations attributable to the strategic implementation of substitutions.

The study found that substitutions were made with around 28 minutes remaining in the match. The finding is consistent with previous literature (Del Corral et al., 2008) that reported most of the substitutions were made at half-time and in the second half. In contrast to previous research (Gómez et al., 2016; Myers, 2012), this study's substitution periods are earlier, with a heavier focus on the 45-50 minutes and 75-80 minutes intervals. Regarding substitution types, offensive types were often introduced at halftime more than others. This situation might suggest that coaches often adopt an aggressive tactical approach during halftime substitutions (Amez et al., 2021). The neutral and defensive substitutions were observed to increase in frequency in the second half of the games, which may align with the notion that defensive substitutions become more prevalent when a team is leading, aiming to maintain lineup stability (Lorenzo-Martinez et al., 2022).

The ratings of all the clusters fluctuate after substitutions. Notably, except for cluster 3, which experienced a significant decline, the ratings of the remaining clusters either remained unchanged or exhibited an upward trend. Accounting for the expected threat and ball possession, Cluster 3 demonstrated great offensive intention with poor possession in pairwise comparison. Cluster 2 indicated a gradual increase in ratings after substitutions and had high ball possession relative to Clusters 1 and 3, which implies that the teams were capable of converting possession into goals (Lago-Peñas & Dellal, 2010). They may be trailing in score but

have the upper hand in the game momentum. Both Cluster 1 and Cluster 4 rose and then stabilized within 15 minutes after substitutions. However, Cluster 4 has a higher ball possession than Cluster 1, which might be the reason why it can keep the ratings high for longer. For Cluster 5, its rating is the lowest and the steadiest among the clusters, with a small effect size.

In general, a player coming on as a substitute may have a longer high-intensity running distance than their colleagues who are already on the field (Bradley & Noakes, 2013; Carling et al., 2010), indicating that substitutes typically possess more physical energy and stronger ambition to get better performance. However, the distinctions must be specific about the players' positions or roles (Bush et al., 2015; Tierney et al., 2016). Physical information can be a fundamental reference of the physiological and fatigue of players which still need the events and positions to obtain a comprehensive team performance. Combined with the analysis of events and player positions (see Supplementary Table 2 for detailed results), it was found that the change in Cluster 3 might be attributed to the wingers being replaced and the tactics being similar to the counterattack (Lago-Peñas et al., 2017) to get more ball recoveries but ignore the scoreline or the opponent's strength. For Cluster 2, ratings did not start to rise until the third five-minute interval after the substitutions, revealing that these substitutes could take time to adapt to the game tempo (Dancy, 2009). According to events and positions, possession, crosses, and long passes are vital for creating better attacking opportunities with these midfield substitutes. The ratings decline of Cluster 1 may be in line with earlier research (Amez et al., 2021) in that making substitutions enhances the likelihood of goal-scoring, with less fluctuation during the first five minutes and a gradual decline after that. It can be hypothesized that the substitutions involve the insertion of playmakers, individuals known to encourage their teammates to receive and engage with the ball, as highlighted by prior research (Bush et al., 2015; Li et al., 2022). The observed alterations in the ratings within Cluster 4 might be attributed to defensive player replacements, potentially fortifying the defensive line, especially during closely contested ball possession scenarios. However, both clusters suggest that the resulting rating improvements may prove transient, potentially owing to the team's overall suboptimal physical condition (Tierney et al., 2016). The low ratings of Cluster 5 might be related to the ranking, which might replace the defensive centres to guard the goals. In the meantime, these substitutions showed a decent expected threat that might depend on the defenders who transfer the ball to create shots for teammates (Singh, 2019; Van Roy et al., 2020).

Interestingly, the subtle changes in team performance were easier detected on ratings than ball possession or the expected threat of teams. The evaluation framework of player or team ratings may distinctly explain the match report in a given scenario, although the other two approaches are more suited to summarize the overall momentum of the game or monitor team playing styles (Singh, 2019; Van Roy et al., 2020; Wang et al., 2022).

Even though the study provides novel knowledge about the assessment of substitutions, there are some limitations to be acknowledged. Firstly, the research did not consider factors such as fitness status and internal load of players (Aquino et al., 2022; Hills et al., 2020), although the changes in substitution rules could introduce more physically prepared players into the pitch and increase more possible tactical adjustments (García-Aliaga et al., 2023; Meyer & Klatt, 2023). At the same time, specific match scenarios were not integrated into the analysis to inspect the influence of different substitutions on their teammates. Finally, the counteracting tactics adopted by opposing teams from team and individual perspectives were unable to be included, which also limits the generalizability of the findings.

The current study provides practical information at two different levels. At a team tactical level, the research can provide references for coaches on substitution decisions and lineup setting when deciding players who

can bring instant benefits to the team's counterattack or defence. It is acknowledged that most coaches prefer offensive substitutions with strong explosiveness or more consistent performance when the team is trailing in the score (Wittkugel et al., 2022), and the current findings could further help them to evaluate how effective these players are and their impact on teammates. From a match scouting perspective, coaches and analysts could estimate the meaningful effects of opponents' substitution tactics and their span at the rest of the game.

CONCLUSION

This study has elucidated 5 distinct substitution clusters employed across various assessment methods within association football competitions. A further exploration of the effectiveness of substitutions was undertaken by leveraging a player evaluation system. The findings indicated that the ratings of Cluster 3 showed a significant decline after substitutions, attributed to low ball possession despite high aggression in terms of expected threat. The ratings of Cluster 2 showed a significant rise after substitutions caused by the possession play and midfielder substitutes. The remaining clusters displayed varying ratings within a 15-minute window post-substitution. Furthermore, the player evaluation system was employed for substitution analysis to verify the compatibility of ratings, ball possession, and expected threat in this regard.

AUTHOR CONTRIBUTIONS

Each author contributed individually and significantly to the development of the manuscript. Jiale Wu: writing, statistical analysis and preparation of the entire research project. Yuesen Li: data collection, statistical analysis. Changjing Zhou: writing and revision. Xiuyuan Xiong: data collection and analysis. Xiaoru Qin: data collection and analysis. Yixiong Cui: intellectual concept, writing and revision.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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The effects of dynamic stretching performed before and between the sets of exercises on vertical jump performance

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ABSTRACT

The purpose of this study was to investigate the effects of dynamic stretching (DS) performed before and between the sets of exercises on vertical jump performance. Twelve healthy adult males performed DS on their lower limb muscles, with 10 repetitions on each side before and between four sets of three repetitions of vertical jumps. Vertical jump height was measured. Additionally, the percent change in jump height for each set was determined based on the baseline score from set 1. Heart rate was also measured at rest, before exercise, and before each set of vertical jumps. Vertical jump height was significantly higher in the latter half of the sets ($p < .05$) compared to the condition in which DS was only performed before exercise and to the control condition in which the participants were refrained from performing DS throughout. In addition, when DS was only performed before exercise, vertical jump height was significantly lower in set 4 compared to set 1 ($p = .001$). These findings suggest that DS performed between sets, in addition to performing before the exercise, produces a higher power output in vertical jump performance in the latter half of multiple sets.

Keywords: Performance analysis, Inter-set stretching, Power, Jump height, Plyometrics, Athletic performance.

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INTRODUCTION

Dynamic stretching (DS) is widely used as part of the warm-up phases of competition and resistance training. DS is a method to improve dynamic flexibility related to actual sports motion by simulating the motion (Yamaguchi et al., 2007). DS which involve controlled movement through the active range of motion for each joint (Fletcher, 2010) is currently replacing static stretching in warm-up (Behm & Chaouachi, 2011). It has been reported that DS performed before exercise increases heart rate (Fletcher, 2010; Fletcher & Monte-Colombo, 2010a) and core temperature (Fletcher & Jones, 2004; Fletcher & Monte-Colombo, 2010b), induces post-activation potentiation in the stretched muscle caused by voluntary contractions of the antagonist (Hough et al., 2009; Torres et al., 2008), and increases activation of motor units (Fletcher, 2010; Herda et al., 2008). Previous studies have shown that such DS associated factors improve vertical jump (Kurt et al., 2023; Meerits et al., 2014; Smith et al., 2018) and sprint (Lopez-Samanes et al., 2021; Malek et al., 2024) performance, and leg extension power (Yamaguchi et al., 2007). However, it has been suggested that the effects of DS before exercise last only about 5 minutes (Kruse et al., 2013; Smith et al., 2018). Smith et al. (2018) investigated the effects of DS, foam rolling, and their combination for the lower muscles on vertical jump height. As a result, the vertical jump height was higher immediately and 5 minutes after DS compared to baseline values (before DS). However, they found that the effect disappeared after 10 minutes.

In training programs that focus on vertical jump performance and leg extension power, it is common to include multiple sets in the program. In fact, in traditional resistance training, multiple sets of force production with rest between sets are more effective than single set of force production in improving muscle strength (Peterson et al., 2005). Additionally, during the training to improve power production, such as plyometrics, it is common to have long rest periods between sets to ensure adequate recovery (Haff & Triplett, 2016). However, considering the duration of the effects of DS mentioned above, in the case of multiple-set program with long rest periods between sets, it is possible that the effects of DS before exercise disappears in the latter half of the sets. It has been shown that rest between sets affects performance on subsequent sets (Kraemer, 1997), therefore, inter-set strategies are considered important. Considering this, in a multiple-set program, implementing DS before exercise as well as between the sets may be effective in sustaining the effects of DS.

The effects of DS between sets (Arazi et al., 2015; Nasiri et al., 2011; Nasiri et al., 2013) are not widely studied. In a study by Arazi et al. (2015), the participants performed 64 seconds of DS for each of the four muscle groups between the sets of bench press or leg press. As a result, no significant difference was found in the number of repetitions for each set compared to a control condition in which the participants were at rest between sets. On the other hand, in a study by Nasiri et al. (2011), the participants performed 50s of DS for four muscle groups between the sets of bench press. As a result, the average number of repetitions in each set significantly increased compared to the control condition in which the participants rested between sets. Previous studies (Arazi et al., 2015; Nasiri et al., 2011; Nasiri et al., 2013) have focused on the effects on muscular endurance using traditional resistance training exercises and have not reached consensus in their findings. Furthermore, these studies did not consider the effects of DS before exercise. Considering the actual coaching situations, verifying the effects of performing DS not only before exercise but also between sets may provide more beneficial recommendations for strength and conditioning professionals in creating training programs. In addition, by verifying whether the effects of DS are sustained by performing DS between sets, as in plyometrics, it may provide useful suggestions for practical inter-set strategies during plyometric exercises. The purpose of this study was to investigate the effects of DS performed before and between sets of exercises on vertical jump performance, one of the popular plyometric exercises.

METHODS

Experimental design

A randomized crossover trial was conducted to investigate the effects of DS performed before and between sets of exercises on vertical jump performance. The trial consisted of one condition per day, and participants participated in the experiment for 3 days at approximately the same time each day to control for the circadian variation. The intervals between these 3 days were 1-2 weeks. Temperature and humidity were recorded on each experimental day ($20.8 \pm 0.9^\circ\text{C}$, $45.7 \pm 9.6\%$). The protocol consisted of three conditions: the FULL condition (FULL), in which DS was performed before as well as between the sets of exercises, the PREcondition (PRE), in which DS was only performed before exercise, and the control condition (CON), in which participants remained at rest and did not perform DS before nor between the sets of exercises. The participants rested in a chair for 5 minutes before their resting heart rates were measured (Fletcher & Monte-Colombo, 2010a; Otterstetter et al., 2013). After a 3-minute warm-up run and warm-up jumps, vertical jump measurements were performed in four sets of three repetitions. In addition, heart rate was measured before each set. In FULL, DS was performed on the three lower limb muscle groups before set 1 and during the intervals between sets. In PRE, the same DS as in FULL was performed only before set 1, and the participants were asked to remain in the seated rest position for the subsequent intervals. In CON, participants were asked to rest in a seated position and did not perform any DS throughout the experiment. The time between the warm-up jumps and set 1 (240 seconds) and the rest intervals (240 seconds) were set to be the same for all three conditions.

Participants

Twelve healthy adult males (35.8 ± 8.0 years, $174.1 \pm 5.7\text{cm}$, $74.5 \pm 8.4\text{kg}$) who regularly performed strength training including plyometrics participated in the experiment. The study conformed to the Declaration of Helsinki and was approved by the Ethics Review Committee of the National Institute of Fitness and Sports in Kanoya (23-1-49). All participants were fully informed of the purpose and content of the study as well as the risks associated from participating in the study, and their written informed consent was obtained.

Procedures

Vertical jump

Vertical jump was assessed using the Vertec (West Warwick, RI, USA) vertical jump apparatus. Participants first had their standing reach measured by raising their dominant arm and touching the highest vane possible with their middle finger (Stroiney et al., 2020). The participants were then instructed on the proper form for jumping and were allowed three warm-up jumps. After each treatment, their heart rate was measured. Then, participants performed four sets of three vertical jumps with 240 seconds (Haff & Triplett, 2016) of rest between sets. Participants rested for 10-20 seconds between each jump. The participants jumped from both feet with no step in an attempt to touch the highest vane possible (Holt & Lambourne, 2008). Jump height was calculated by subtracting the standing reach height from the vane height reached by the participant from each jump. The average of three jumps in each set was calculated and used for analysis. The jump height of set 1 was used as the baseline measurement, and the percent change in jump height for each set was also calculated. The intraclass correlation coefficient for vertical jump was 0.977.

Heart rate

Heart rates at rest and before each set were assessed using a Polar H10 HR Monitor (Polar Electro Oy, Finland). The heart rate before each set was recorded within 30 seconds of the completion of DS in FULL (Fletcher & Monte-Colombo, 2010a). In PRE and CON, heart rates were recorded at the same timing as they were recorded during FULL.

Dynamic stretching

The muscle groups that performed DS were gluteus muscles, quadriceps femoris, and hamstrings. These muscle groups are the predominantly active muscle groups in vertical jump (Bobbert & Casius, 2005; Sugisaki et al., 2013). Prior to each routine, the correct stretching techniques were demonstrated and each participant was monitored to ensure that the stretching was conducted properly. Each participant was instructed to intentionally contract the antagonist of the targeted muscles (Holt & Lambourne, 2008) and performed DS once every 2 seconds (Holt & Lambourne, 2008) for 10 times (McMillian et al., 2006) on each side. A digital metronome was used to standardize the timing of each repetition. The total duration of the DS procedure was approximately 2 minutes. Below, is a detailed description of the stretching exercises.

Gluteus muscles: the participant was placed in a drop lunge position, with one leg crossing behind the other leg from an upright position, the foot placed diagonally behind the other leg, and bending the hip joint and knee to lower the body (Figure 1a).

Quadriceps femoris: in the upright position, the participant bent his knee to bring the heel to the buttocks and grabbed the ankle the same time. (Figure 1b).

Hamstrings: in the upright position, the participant kicked a leg forward with a straight knee. (Figure 1c).



Figure 1. Stretching exercises. (a) Gluteus muscles (b) Quadriceps femoris (c) Hamstrings.

Statistical analysis

The sample size was calculated using GPower (version 3.1.9.7, University of Kiel, Germany) with a target effect size (ES) = 0.25, α error probability = 0.05, power (1- β err prob) = 0.80, resulting in an estimated sample of 10 participants per group. A 2-way repeated-measure analysis of variance (ANOVA; set [set 1 or set 2 or set 3 or set 4] \times condition [FULL or PRE or CON]) was used to analyse vertical jump height. A 2-way repeated-measure analysis of variance (ANOVA; time [Rest or Before set 1 or Before set 2 or Before set 3 or Before set 4] \times condition [FULL or PRE or CON]) was used to analyse heart rate. The assumption of sphericity was confirmed using Mauchly's test. Greenhouse-Geisser epsilon corrections were used when the assumption of sphericity was violated. The effect sizes for main effects and interactions were determined by partial eta squared (η^2_p) values. Partial eta squared (η^2_p) values were classified as small (0.01), moderate (0.06), and large (0.14). Post-hoc analyses of significant main and interaction effects were conducted where appropriate using the Bonferroni correction. The effect sizes (ES) were determined for pairwise comparison using Cohen's d . The ES were defined as small ($d = 0.2-0.5$), moderate ($d = 0.5-0.8$), and large ($d > 0.8$).

95% confidence intervals (CIs) were calculated. Differences were considered statistically significant at $p < .05$. Statistical analyses were performed using SPSS version 28.0 (IBM SPSS Statistics Inc, Chicago, IL). All results are presented as mean and SD.

RESULTS

Vertical jump

There was a significant 2-way interaction between set and condition for vertical jump height ($p = .002$, $\eta^2_p = 0.268$). Post-hoc testing with Bonferroni-corrected revealed that the jump height in FULL for set 3 was significantly higher than that in PRE ($p = .036$, $d = 0.276$), and the jump height in FULL for set 4 was significantly higher than that in PRE ($p = .004$, $d = 0.318$) and CON ($p = .021$, $d = 0.233$). In PRE, the jump height for set 4 was significantly lower than set 1 ($p = .001$, $d = 0.196$) (Table 1).

Table 1. Table 1 Comparison of vertical jump height between conditions.

	Vertical Jump Height (cm)			
	set1 (95%CI)	set2 (95%CI)	set3 (95%CI)	set4 (95%CI)
FULL	56.6±8.4 (51.3-62.0)	56.7±8.5 (51.3-62.1)	57.0±8.6 (51.6-62.5)*	57.0±8.6 (51.6-62.5)*****
PRE	56.0±7.9 (51.0-61.0)	55.6±8.0 (50.5-60.7)	54.7±8.0 (49.6-59.8)	54.5±7.6 (49.6-59.3)#
CON	55.5±8.6 (50.0-60.9)	55.4±8.3 (50.1-60.6)	54.9±8.6 (49.4-60.3)	55.1±8.4 (49.8-60.4)

Note. FULL = FULL condition; PRE = PREcondition; CON = control condition. Data are presented as mean ± SD and 95% confidence interval (95% CI). * $p < .05$ vs PRE, ** $p < .01$ vs PRE, *** $p < .05$ vs CON, # $p < .05$ vs set1 at PRE.

There was a significant 2-way interaction between set and condition for the percent change in jump height from the baseline score ($p = .003$, $\eta^2_p = 0.253$). Post-hoc testing with Bonferroni-corrected revealed that the percent change in FULL for set 3 ($p = .009$, $d = 1.215$) and set 4 ($p = .002$, $d = 1.708$) were significantly higher than those in PRE. In PRE, the percent change for set 4 was significantly lower ($p = .001$, $d = 2.240$) (Figure 2).

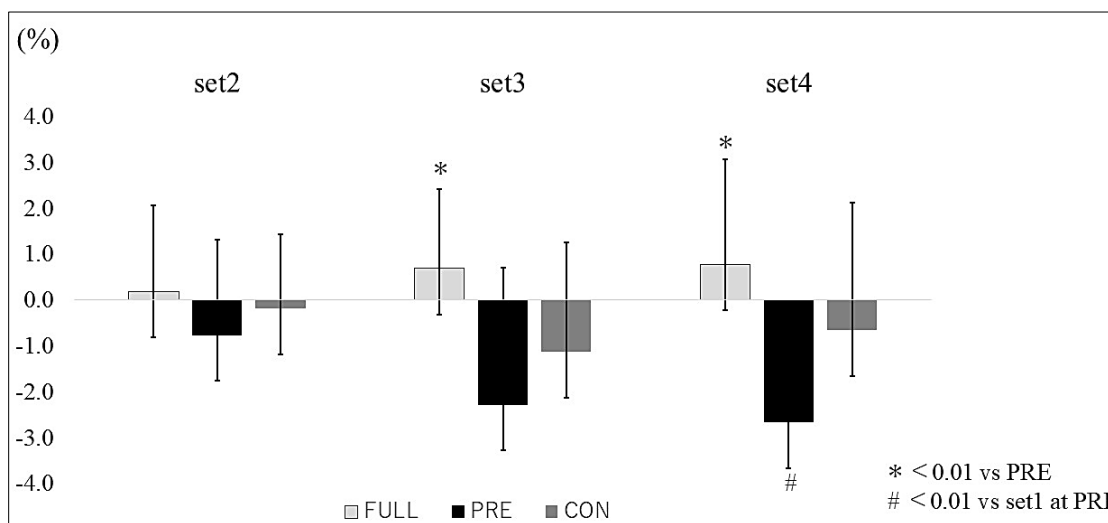


Figure 2. Average percentage change in vertical jump height from set 1.

Heart rate

There was a significant 2-way interaction between set and condition for heart rate ($p < .001$, $\eta^2_p = 0.821$). Post-hoc testing with Bonferroni-corrected revealed that heart rates in FULL (Before set 1 [$p < .001$, $d =$

1.795], Before set 2 [$p < .001$, $d = 2.298$], Before set 3 [$p < .001$, $d = 2.493$], Before set 4 [$p < .001$, $d = 2.603$]) and PRE (Before set 1 [$p < .001$, $d = 1.981$], Before set 2 [$p = .024$, $d = 0.651$], Before set 3 [$p = .012$, $d = 0.646$], Before set 4 [$p = .001$, $d = 0.845$]) were significantly higher than those in CON from Before set 1 to Before set 4, and that heart rates in FULL were significantly higher than those in PRE from Before set 2 to Before set 4 (Before set 2 [$p < .001$, $d = 1.892$], Before set 3 [$p < .001$, $d = 2.070$], Before set 4 [$p < .001$, $d = 2.227$]). Additionally, in FULL, heart rates from Before set 1 to Before set 4 were significantly higher than Rest (Before set 1 [$p < .001$, $d = 3.161$], Before set 2 [$p < .001$, $d = 3.058$], Before set 3 [$p < .001$, $d = 3.089$], Before set 4 [$p < .001$, $d = 3.071$]), and heart rates Before set 3 (Before set 1 [$p = .009$, $d = 0.453$], Before set 2 [$p = .003$, $d = 0.181$]) and Before set 4 (Before set 1 [$p = .009$, $d = 0.493$], Before set 2 [$p = .021$, $d = 0.223$]) were significantly higher than Before set 1 and Before set 2. In PRE, heart rates from Before set 1 to Before set 4 were significantly higher than Rest (Before set 1 [$p < .001$, $d = 2.918$], Before set 2 [$p < .001$, $d = 1.329$], Before set 3 [$p < .001$, $d = 1.168$], Before set 4 [$p = .001$, $d = 1.221$]), and heart rates from Before set 2 to Before set 4 were significantly lower than Before set 1 (Before set 2 [$p < .001$, $d = 2.008$], Before set 3 [$p < .001$, $d = 2.088$], Before set 4 [$p < .001$, $d = 2.307$]). Additionally, in CON, heart rates from Before set 1 to Before set 3 were significantly higher than Rest (Before set 1 [$p < .001$, $d = 1.192$], Before set 2 [$p = .003$, $d = 0.918$], Before set 3 [$p = .006$, $d = 0.824$]) (Table 2).

Table 2. Comparison of heart rate between conditions.

	Heart Rate (bpm)				
	Rest (95%CI)	Before set1 (95%CI)	Before set2 (95%CI)	Before set3 (95%CI)	Before set4 (95%CI)
FULL	71±8.4 (66-77)	112±16.3 (102-123)*†	117±19.4 (105-129)**‡	121±21.0 (107-134)**‡§	122±21.6 (108-135)**‡§
PRE	74±10.9 (68-81)	115±16.5 (105-126)*†	88±9.6 (82-94)#‡	87±10.1 (80-93)#‡	86±7.3 (81-90)#‡
CON	73±9.4 (67-79)	86±12.6 (78-94)†	82±9.8 (76-88)†	81±9.0 (75-86)†	79±8.0 (74-84)

Note. FULL = FULL condition; PRE = PREcondition; CON = control condition. Data are presented as mean ± SD and 95% confidence interval (95% CI). * $p < .01$ vs CON, ** $p < .01$ vs PRE, # $p < .05$ vs CON, ‡ $p < .01$ vs CON, † $p < .05$ vs Rest, § $p < .05$ vs Before set1, ¶ $p < .05$ vs Before set2.

DISCUSSION

The purpose of this study was to investigate the effects of DS performed before and between sets of exercises on vertical jump performance. The results revealed that when the DS was performed before and every interval, the vertical jump performance was higher in the latter half of the sets compared to the condition in which DS was only performed before exercise or to the control condition. Furthermore, when DS was only performed before exercise, the vertical jump performance decreased from the baseline in the latter half of the sets.

Previous studies have shown that performing DS before exercise improves vertical jump performance (Hough et al., 2009; Kurt et al., 2023; Meerits et al., 2014; Smith et al., 2018). In a study by Meerits et al. (2014), the participants performed three sets of 20 seconds of DS on the hamstrings. The results revealed that squat jump height was significantly improved compared to the jump before DS. Hough et al. (2009) also had healthy males perform 15 DS on each of the lower limb muscles. They found that the vertical jump performance after DS was significantly higher than that of a control condition in which the participants remained at rest instead of DS, and a condition in which static stretching was performed. However, it has been suggested that these effects of DS before exercise last only about 5 minutes (Kruse et al., 2013; Smith et al., 2018). In this study, vertical jump performance also decreased in the latter half of sets during the PREcondition in which DS was only performed before the exercise. In set 4 of PRE, where performance decreased, at least 12 minutes had passed since the implementation of DS, and therefore it was considered that the effects of DS had disappeared, as in previous studies (Kruse et al., 2013; Smith et al., 2018). On the other hand, in the FULL

condition, in which DS was performed before and between sets of exercise, the vertical jump performance was significantly higher in the latter half of the sets compared to the other conditions. Factors that may have contributed to the effects of DS on subsequent performance improvement include increased heart rate (Fletcher, 2010; Fletcher & Monte-Colombo, 2010a) and core temperature (Fletcher & Jones, 2004; Fletcher & Monte-Colombo, 2010b), post-activation potentiation in the stretched muscle caused by voluntary contractions of the antagonist (Hough et al., 2009; Torres et al., 2008), and increased activation of motor units (Fletcher, 2010; Herda et al., 2008). The increased heart rate caused by DS may affect blood flow and core temperature, which in turn may cause an increase in sensitivity of nerve receptors and speed of nerve impulses, therefore enabling muscle contraction to be more rapid and forceful (Fletcher & Monte-Colombo, 2010a). Previous research has shown that DS performed before exercise increased the heart rate, which in turn improved vertical jump and sprint performance (Fletcher & Monte-Colombo, 2010a). However, this study only investigated performance on a single set. In our study, multiple sets of force production were performed. In the PREcondition, in which DS was only performed before exercise, the heart rate and the vertical jump performance significantly decreased in the latter half of the sets. On the other hand, in the FULL condition, the heart rate before each vertical jump was maintained at a high value even in the latter half of the sets. In addition, the subsequent vertical jump performance was also higher than other conditions. In other words, maintaining a high heart rate was thought to result in high vertical jump performance, and therefore it was suggested that changes in heart rate may be related to the effect of DS between sets on performance. On the other hand, this study did not investigate other factors that may affect performance. Nasiri et al. (2011), who investigated the effects of DS between sets on the bench press, a traditional resistance training exercise, noted that increased waste metabolite removal and substrate delivery promoted the recovery of energy sources between sets. Thus, further investigation is needed in future studies because factors other than heart rate may be affected by DS.

In this study, there were no significant differences in vertical jump performance in set 1 across the conditions, indicating no effect of DS before exercise in the FULL and PREconditions. This may have been because the number of repetitions of DS performed before exercise was inadequate. Christensen et al. (2008) used eight DS exercises for the lower limb muscles, performing the same number of repetitions as in our study, and examined the effect on subsequent performance. The results showed that DS did not improve performance. Thus, the number of repetitions of DS before exercise in our study may have been insufficient to improve performance. However, in our study, the number of repetitions of DS was determined considering two factors; the rest duration between the sets is limited, and the recommended the number of repetitions in competitive and training settings (Gil et al., 2019). A study has shown the performance-enhancing effects of DS with the same number of repetitions used in our study (McMillian et al., 2006). In addition, a review by Oppler et al. (2018) noted that there is not yet any clear indicator for the number of repetitions of DS should be performed to enhance performance. Therefore, it is considered necessary to further examine the adequate repetitions of DS in future studies; however, it has been suggested that if the number of repetitions of DS is increased, the effect of fatigue may not only cancel out the subsequent improvement in performance, but may even decrease performance (Turki et al., 2012). Furthermore, it has also been suggested that the effects of DS last only about 5 minutes (Kruse et al., 2013; Smith et al., 2018). Considering these factors and the results of this study, it would be useful and practical to conduct future investigations to determine the optimal number of repetitions of DS to be performed, keeping in mind that DS should be performed not only before exercise but also between sets.

Finally, there is still a lack of research on the effects of DS performed before and between the sets of exercises. Thus, future research is suggested to examine both the factors that contribute the performance enhancing effect of the DS performed between the sets of exercises, and the more effective number of

repetitions of DS to enhance performance. In addition, further investigation will be needed for the effects of DS on sprint performance, maximum muscle strength, power production using other jump exercises or weightlifting exercises, or other performance indicators that simulate competitive situations. Furthermore, with further investigation, the effects of DS may be expected to be applied not only in training but also in team sports. In team sports, some athletes may have to wait on the bench for a long time after warm-up before getting a chance to perform. In some sports, such as basketball, volleyball, and futsal, the athletes may sub in and out repeatedly. Considering the duration of the effects of DS, performing DS while waiting on the bench may improve subsequent performance.

CONCLUSION

Performing some DS for 10 repetitions between the sets of exercises, in addition to performing them before exercise, can produce higher power output in vertical jump performance in the latter half of multiple sets. This may result in a greater training effect than passive rest between sets. Thus, performing DS between sets may be an effective inter-set strategy when performing plyometric training.

AUTHOR CONTRIBUTIONS

Study concept and design, drafting the article and its critical revision: Yuji Iida. Data collection, English editing, final approval of the version to be published: Ichiro Watanabe. Data collection, final approval of the version to be published: Naoto Yoshida. Data collection, final approval of the version to be published: Kohei Iijima. Data collection, final approval of the version to be published: Hiromu Sato. Conception and design of the study, final approval of the version to be published: Akira Maeda. All co-authors have contributed to the published work and agree to its publication in *Journal of Human Sport and Exercise*.

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Imagery vividness and perspectives in women's artistic gymnastics training

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ABSTRACT

This study aimed to examine imagery vividness and different modalities and perspectives in women's artistic gymnastics. It explored athletes' imagery use in training practice and how vivid imagery is developed for different motor tasks. Forty-seven female athletes (age 19 ± 3 years), with women's artistic gymnastics expertise (12 ± 4 years) participated in this study. The *Vividness of Movement Imagery Questionnaire* (Dahm et al., 2019) was used to determine the imagery vividness of the participants for the different imagery modalities and perspectives respectively: external–visual, internal–visual, and kinaesthetic. The ANOVA results showed no differences between the most vivid imagery for age ($F[3] = 0.724, p = .54$) and expertise ($F[4] = 0.091, p = .97$). T-test results revealed differences in the imagery vividness of the kinaesthetic imagery depending on the gymnasts' activity as a coach ($F[45] = 5.280, p < .05$). To benefit from imagery use in training (e.g. to adjust coaching), the most vivid imagery modality and perspective must be determined individually. These results emphasise the need for skill-specific assessments of imagery modalities and perspectives to benefit from individualised imagery-adapted instructions.

Keywords: Physical education, Visual imagery, Kinaesthetic imagery, Motor tasks.

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INTRODUCTION

Psychological strategies for enhancing performance are widely used in various sports. In training and competition practices in artistic gymnastics, it is common to imagine important skills or the entire exercise program before performing them. In general, motor and visual imagery is widely accepted as a strategy to enhance learning and is effective in improving motor skill performance (Cumming & Williams, 2013; Moran et al., 2012; Simonsmeier et al., 2020). This is because, in addition to the conditional, coordinative, and sports-technical performance requirements, individual imagery use enhances performance in different sports settings (Munzert & Lorey, 2013). Research has shown that imagery is used and improves skill acquisition in (artistic) gymnastics (Moran et al., 2012; Munzert & Lorey, 2013; Simonsmeier & Frank, 2016). In artistic gymnastics, the athlete's performance depends not only on motor abilities and technical skills, but also on psychological abilities (Berisha, & Mosier, 2020).

Imagery use as one of the psychological abilities includes various strategies and is categorised differently in literature. Researchers distinguish at least two imagery modalities in which the visual and kinaesthetic aspects of movement execution were imaged. The visual modality is further separated into two visual imagery perspectives. On the one hand visual imagery can be generated from internal (first-person perspective: internal visual imagery) on the other hand from external (third-person perspective: external visual imagery) perspectives (Callow et al., 2013; Moran et al., 2012; Roberts et al., 2008). Furthermore, imagery from the internal perspective does not automatically imply a combination of the visual and kinaesthetic modalities (Roberts et al., 2008), and subjects are equally able to perform visual and kinaesthetic imagery (Guillot et al., 2004). Both visual perspectives are also described in action observation, in which movements of one's self or those of other people are usually observed by video (Moran et al., 2012). Due to the concurrence of the perspectives, a combination of action observation and visual imagery is used to improve performance (Wright et al., 2022). While observing someone performing an action that is within our motor repertoire, our brain simulates the execution of the movement (Moran et al., 2012).

The imagery modalities and perspectives can affect skill development and performance in various ways (Callow et al., 2013; Simonsmeier et al., 2020). Different sports-specific settings play important roles in imagery use. Previous research provides evidence imagery use depending on the skill level, for different sports and skills. Elite athletes tend to use mental imagery more frequently for skill rehearsal than novice counterparts (Arvinen-Barrow et al., 2007). A study with U.S. track and field athletes reported that successful athletes used more external imagery than non-successful athletes (Ungerleider & Golding, 1991). It looks different for a U.S. Olympic artistic gymnastics team, where results revealed that successful qualifiers used internal imagery more than non-qualifiers (Mahoney & Avenir, 1977). According to this, for the learning of a simple gymnastics skill an external imagery perspective is considered to be effective (Hardy & Callow, 1999). In addition to the skill level, the effectiveness of the different imagery modalities and perspectives depends on the age of the athletes. Expertise and age could necessarily be related to each other (Munzert & Lorey, 2013). A study that focused on imagery in children and adolescents suggested an age effect (Dhouibi et al., 2021) and supposed that age and competition level can affect imagery use (Simonsmeier et al., 2020). However, it remains to be elucidated which aspects are decisive and whether age and competition level interact.

Different imagery modalities and perspectives can be graded in terms of their vividness. These grades can be used to observe which modality or perspective is rated as the most vivid. Studies have reported different results in imagery vividness using the *Vividness of Movement Imagery Questionnaire* comparing young and older subjects. A transfer from a visual to kinaesthetic imagery ability was observed in older subjects

compared to younger ones (Subirats et al., 2018). It can be observed that individuals differ in their vividness of the modalities and perspectives, like a trend from more internal to more external imagery perspective with aging (Liu et al., 2019).

Taking differences in skill-specific characteristics into account, Munzert and Lorey (2013) emphasised the differentiation of open and closed skills for the classification of the effects of imagery in sports. Unlike open skills which require the ability to imagine external events and environmental conditions, closed skills differ in the predictability of the environment (Schmidt & Lee 2005). However there are sports that approach both, open and closed skills. Coelho colleagues (2007) investigated the effects of imagery on performance in tennis in both the closed skill of the serve and the open skill of returning a serve. Athletes in artistic gymnastics, a sport with typically closed skills, reported kinaesthetic imagery more often than athletes in open skills sports (Munzert & Lorey, 2013).

For artistic gymnastics practice, the question concerns whether athletes use different imagery modalities and perspectives, also because imagery is suggested to use in combination with action observation to improve performance (Wright et al., 2022). With regard to gymnastics skills requiring the use of a particular technique for successful performance, the third-person visual perspective is described as beneficial for action observation because it provides a visual representation of the desired technique (Wright et al., 2022). Thus, when transferring the effects of action observation to gymnasts who are also coaches, it seems reasonable that action observation could have an effect on the imagery of the gymnast with a coaching role.

The influence of imagery on performance can also be attributed to other psychological factors. The results of a gymnastics-related study showed that internal and external visual imagery exercises improved self-confidence in performing wheel motion skills, whereas the internal visual imagery training method was preferred (Prastyawan et al., 2023). Therefore, improved performance can be achieved through the imagery perspective or increased self-confidence. At best, the image use of an athlete adapts individually (Cumming & Williams, 2013). But the current practice of imagery is often not systematised and is based on experience (Ladda et al., 2021).

Coach instructions such as “*visualise the skill in your mind before executing*” are part of everyday training. However, no attention has been paid to how this skill can be imagined. Therefore, the present study investigates whether a specific modality and perspective of imagery are more vivid, and how gymnasts’ imagery use in training is characterised. The questions were whether age and expertise have an impact on the modality and perspective of imagery, and which training-specific characteristics should be considered.

Based on the effects of different modalities (visual and kinaesthetic) and visual perspectives (external and internal), the aim was to investigate if gymnasts evaluate a specific imagery modality and perspective (in the following referred to as imagery “*type*”) more vivid, depending on athletes age, expertise or training specific characteristics like action observation and own coaching activities. We assumed more vivid imagery for athletes who used imagery more frequently in training. The following hypotheses were examined:

- 1) Imagery types differ in their rated vividness.
- 2) The most vivid type of imagery depends on the gymnasts’ characteristics (age and expertise).
- 3) Gymnasts with own coaching activities differ in imagery vividness from those without.
- 4) Gymnasts with more frequent imagery use in training rated imagery more vivid.

MATERIALS AND METHODS

Participants

Forty-seven female athletes aged between 12 and 24 years (mean 19 ± 3 years), with women's artistic gymnastics expertise for at least 5 years (mean 12 ± 4 years) in German clubs, voluntarily participated in this study. The participants were limited to female athletes because their performance would not be comparable to that of male artistic gymnastics athletes owing to different evaluation and execution criteria. All participants competed, at least in regional competitions. Twenty of them had their own coaching activities and 27 did not. All participants were informed of the procedures and tasks before starting the experiment. All participants agreed to participate voluntarily and were informed that they could drop out at any time without providing a reason. For participants who were under 18 years old, consent was obtained from their parents. This study was conducted in accordance with the Declaration of Helsinki and was approved by the ethics committee of our university (No. 138/2021).

Measures

For data collection, an online survey was chosen to capture sociodemographic data, followed by the *Vividness of Movement Imagery Questionnaire* (VMIQ-2, Dahm et al., 2019) and sports-specific questions. The VMIQ-2 assesses the ability to form mental images of 12 motor tasks (i.e. running, kicking a stone, jumping sideways) for three imagery types: external-visual imagery (EVI), internal-visual imagery (IVI), and kinaesthetic imagery (KI). For this study, one item on artistic gymnastic-specific skills (i.e. stretched jumps with turns) was added. Participants were asked to imagine each of the 13 items in three different ways (also listed in German for the literal use of the VMIQ-2):

- EVI: "Imagine if you are watching yourself performing the movement."
- "Sie sehen sich wie auf einem Video bei der Bewegungsausführung."
- IVI: "Imagine if you are looking out through your own eyes."
- "Sie sehen bei der Bewegungsausführung durch Ihre eigenen Augen."
- KI: "Imagine feeling yourself doing the movement."
- "Sie fühlen wie Sie die Bewegung ausführen."

For each motor task, they rated the vividness of movement imagery on a five-point Likert scale, (1 = perfectly clear and vivid; 5 = no image at all, I only know that I am thinking about the movement). The following sport-specific part included questions about specific experiences in gymnastics. It was queried the expertise in gymnastics (current and past activity in gymnastics), the imagery use frequency and timing in training, and athlete's own coaching activity in artistic gymnastics. And all participants had to answer the question if she is or was able to perform a stretched jump with turn.

Procedure

Female gymnasts who were at the required competition level, in the appropriate age range and able to perform the stretched jump skill were asked to take part in the study. They were sent all necessary information and a link to the survey by email. They were asked to take a calm and undisturbed place. After answering the sociodemographic part, before answering the individual items of the VMIQ-2, they were asked to imagine the motor tasks. The sports-specific questions completed the survey. In total the online survey took approximately 20 minutes to complete.

Analysis

Data from 47 participants were analysed. Fifty-two of them completed the survey, but five were excluded because of prolonged inactivity in artistic gymnastics for too long. The collected data were analysed by

performing descriptive and inferential statistical analyses using the statistical analysis software SPSS (Version 29.0). Descriptive data in the figures and tables are presented as means (M) and standard deviations (SD). For inferential statistics, the significance criterion was set at $p < .05$. The assumptions for conducting analyses of variance were checked. To determine any statistical group differences for imagery vividness types, group assignment was dependent on the most vivid rated imagery type (EVI, IVI, or KI). If participants made equally pronounced ratings for two or three imagery types, they were assigned to “Mix” group.

To test Hypothesis 1, a one-way analysis of variance (ANOVA) was conducted to test for group differences between the imagery types regarding the vividness of the images. To verify Hypothesis 2, an ANOVA was performed to determine differences in the most vivid imagery type depending on the gymnasts’ age or expertise. For hypothesis 3, T-tests were completed to determine imagery vividness differences, depending on the own coach activity (group “coach” $n = 20$; group “no coach” $n = 27$). Pearson’s correlation coefficient was used to determine the possible correlations between imagery vividness and age. Spearman’s rho correlation coefficient was used for correlations between imagery vividness and imagery use frequency in training (Hypothesis 4), as well as between action observation frequency in training and the vividness of external imagery.

RESULTS

This study aimed to investigate whether gymnasts rate a specific imagery type more vividly depending on age, experience, or training-specific characteristics. Further questions concerned whether imagery vividness was different for the imagery types and whether it was related to imagery use frequency in training.

Descriptive statistic

All 47 participants imagined movements before performing them during training; however, they reported different frequencies of imagery use: 12.8% (6) *always*, 48.9% (23) *most of the time*, 34.0% (16) *now and then*, 4.3% (2) *rarely*. After execution, different behaviours were reported. Descriptive statistics revealed a reduced number of gymnasts using imagery and a reduced frequency of imagery use: 39 participants imagined movements in training after they had performed them (8.5% *always*, 29.8% *most of the time*, 36.2% *now and then*, 8.5% *rarely*). They all carried out action/movement observations of themselves doing gymnastics, but with varying frequencies: 29.8% (14) *regularly*, 48.9% (23) *now and then*, 21.3% (10) *rarely*, and 0% never.

The VMIQ-2 ratings indicated similar vividness for the three imagery types surveyed (Table 1). A low score reflected a high level of vividness.

Table 1. Participants’ ratings for external visual imagery (EVI), internal visual imagery (IVI) and kinaesthetic imagery (KI) vividness.

	EVI (M ± SD)	IVI (M ± SD)	KI (M ± SD)
Participants (amount)	47	47	47
Vividness (five-point scale)	1.96 ± 0.78	1.74 ± 0.59	1.81 ± 0.68

The 47 participants show varying degrees of vividness for the three imagery types. Based on the most vivid rated type, participants were assigned to the imagery type group (Table 2). Descriptive statistics show that the imagery type was most vivid rated by participants who rated EVI as the most vivid (VMIQ-2 = 1.38), and the least vivid rated when participants rated KI as the most vivid (VMIQ-2 = 1.62).

Table 2. Participant's characteristics listed all and distributed to the most vivid rated imagery type.

	All (M ± SD)	EVI (M ± SD)	IVI (M ± SD)	KI (M ± SD)	Mix (M ± SD)
Participants (amount)	47	8	12	17	10
Age (years)	18.81 ± 3.22	19.75 ± 3.41	17.75 ± 3.19	18.82 ± 3.32	19.30 ± 3.06
Expertise (years)	11.95 ± 3.79	12.13 ± 4.55	11.92 ± 3.96	11.62 ± 3.45	12.40 ± 4.06
Vividness (five-point scale)	1.55 ± 0.54	1.38 ± 0.32	1.55 ± 0.34	1.62 ± 0.43	1.57 ± 0.95

Inferential statistic

Considering the participants' ratings for all three imagery types, the ANOVA results showed no differences between the three imagery types for imagery vividness ($F[2] = 1.294$, $p = .28$). Also, if including just the vividness of the most vivid rated type groups, ANOVA results revealed no differences between the most vivid imagery type for variable "vividness" (Welch's $F[3, 20.57] = 0.839$, $p = .49$). That is, the vividness did not differ between the most vivid rated imagery type groups.

The ANOVA results indicated no differences between the most vivid imagery types for age ($F[3] = 0.724$, $p = .54$), expertise ($F[4] = 0.091$, $p = .97$). This implies that the participants in the study cannot be said to rate a particular imagery type as more vivid depending on their age or expertise.

The t-test results revealed differences in the vividness of the KI imagery types depending on athletes coaching activity ($F[45] = 5.280$, $p < .05$). Participants without coaching activity rated KI as more vivid (VMIQ-2 = 1.63) than did those with coaching activity (VMIQ-2 = 2.06). No differences were observed for external imagery vividness ($F[45] = 1.012$, $p = .65$), or internal imagery vividness ($F[45] = 2.389$, $p = .42$) depending on coaching activity. The most vivid rated imagery type groups are also compared here; t-test results revealed no differences for imagery vividness based on own coach activity ($F[45] = 1.526$, $p = .68$).

There were no correlations between imagery vividness of the most vivid imagery type and age ($r = .14$; $p = .93$; $n = 47$) or expertise ($r = -.16$; $p = .30$; $n = 47$), and no correlations between imagery vividness of the most vivid rated imagery type and frequency of imagery use in training ($r = .20$; $p = .18$; $n = 47$). There was no correlation between action observation and the vividness of the external imagery ($r = .05$; $p = .74$; $n = 47$).

DISCUSSION

This study aimed to consider the interrelation between imagery types and vividness and athletes' age, expertise, or training-specific characteristics, such as action observation or coaching activities in women's artistic gymnastics. Overall, the present results indicated no fundamental differences depending on imagery modality, perspective, or vividness. The results did not verify the assumption that imagery type or vividness differed according to age or expertise. Previous studies have indicated that the experience of imagery is unique to each individual, and athletes can emphasise certain aspects or manipulate the content of their images for specific cognitive functions. The data showed several differences between athletes' uses of imagery, reflecting the different task demands of each sport (Hardy & Callow, 1999). Corresponding to Munzert and Lorey (2013), open-skill sports require the ability to imagine externally; for gymnastics, assuming it involves predominantly closed skills, it could be concluded that internal imagery use is more vivid. Callow and colleagues (2013) explain the inconsistent results concerning previous concepts which eventually did not differentiate between internal and kinaesthetic imagery. The results of the present study indicate that imagery type and vividness are individual for gymnasts and may be determined by various aspects. Overall, no differences in the frequency of imagery use in training, action observation, or gymnast's coaching activities were observed in the present results.

Results from other studies on closed-skill sports, which were also conducted in gymnastics, are only partially transferable. As different skills were investigated, there might be differences in various studies. Some describe EVI as more effective than IVI for learning a static gymnastics skill (White & Hardy, 1995) or learning a basic gymnastics floor sequence (Hardy & Callow, 1999). A crucial difference was that the participants were randomly assigned to the groups and instructed to imagine a certain imagery type. Participants were selected based on the most vivid imagery type. Both studies examined the learning of skills, which makes them different from the present study because different levels of expertise can result in different imagery use (Arvinen-Barrow et al., 2007). The assumption, that action observation could influence the imagery type and vividness of the gymnast's imagery because it provides a visual representation of the desired technique (Wright et al., 2022), could not be observed in the present results. In gymnastics, studies suggest differences in imagery use and performance depending on competition level and age (Simonsmeier & Frank, 2016). These results include not only skill-related imagery but also general, motivational, and emotional imagery. In the present study, in which each participant was used to imagery in training, a lack of differences depending on age or expertise was observed. This is even though the age range was chosen to be wide. Considering that few studies that have focused on imagery in children and adolescents have proposed an age effect (Dhouibi et al., 2021), this investigation included participants aged 12 to 24 years. The results indicated no differences in imagery type or vividness depending of age. The imagery vividness was similar despite the wide range of ages and expertise. Alternatively, imagery use is individual and in training often not guided, which means that athletes use it individually, and a few is unclear and unstructured. Further research is required to understand the imagery used by athletes better.

The missing differences in imagery type and vividness in the present study can be explained by deficiencies in the self-reported vividness ratings of the questionnaire. It may not be reasonable to transfer VMIQ-2 with general movements to gymnastic-specific behaviours. Similarly, results showing similar imagery vividness in the VMIQ-2 for all participants could be evaluated. Perhaps the participants would rate vividness of gymnastic movements differently. Everyday movements being rated similarly vivid do not necessarily mean that all would also elicit similar results for imagery vividness in gymnastic movements. For the participants examined, it is assumed that everyone is familiar with imagery because all gymnasts use imagery in training before performing a skill, and only a few athletes show imagery use with low frequency. Therefore, there is a need for a validated sports-specific tool. Perhaps, it is purposeful to replace everyday movements with different gymnastic movements in the VMIQ-2, and not only, as in the present study, supplemented with one gymnastic-specific skill. Perhaps the missing vividness differences for the imagery types in the present results can be explained by the fact that, despite different ages and expertise, the gymnasts all used imagery in training. If the results are considered for the coaching activity, small differences can be observed. Gymnasts without coaching activity rated KI vividness as more vivid. Gymnasts with coaching activities may be used to observe movements from a third-person perspective, which is why KI may not be as vivid.

CONCLUSION

The vividness of the imagery modality and perspective seem to be very individual. In the present study, all three imagery types exhibit similar vividness. Some gymnasts do not show higher vividness for one imagery type but have equally strong ratings for two or three types. For the most vivid imagery types, gymnasts can be found with a wide range of ages, different levels of expertise, varying frequencies of imagery use, and action observation in training. The imagery modality and perspective may depend on a variable that we did not consider, and a validated sports-specific tool for imagery could be useful for training practice. Therefore, coaches should pay more attention to imagery used by gymnasts. If imagery is to be considered for training, the sports-specific imagery modality and perspective must first be tested individually to be adequately used.

Thus, improving performance through imagery-adapted instructions becomes possible. Instruction can direct attention towards the execution of a movement or one aspect of a movement. Therefore, the question arises as to whether vivid visual imagery is necessary for instruction that directs attention to movement to be effective. Can athletes direct the focus of attention internally if no internal visual imagery is developed? Do internally focused instructions make internal visual imagery more vivid? In future research, it would be interesting to determine whether a particular focus of attention is appropriate for a certain imagery modality and perspective. For imagery interventions, the athletes' imagery type should be considered and matched with the desired imagery modality for skill. Derived from this, instructions could be used to achieve the desired focus of attention, which is matched with the individual imagery preference. This could make the instructions more effective during training practice.

AUTHOR CONTRIBUTIONS

Juliane Veit. Study concept and design, data collection, statistical analysis, manuscript preparation and writing. Tobias Vogt. Study concept and design, writing and critical revision.

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No potential conflict of interest was reported by the authors.

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Optimizing the potentials of field hockey players through complex and contrast training on physiological and biochemical responses

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ABSTRACT

In the current scenario of field hockey, players are continuously looking for new ways to improve their performance on the field, particularly in terms of power moves. Throughout this exploration, the current study examined the specific effects of complex and contrast training on field hockey player's physiological and biochemical responses. A total of 45 male field hockey players (mean (SD); weight: 63.62 (4.54) kg, height: 1.67(0.06) cm, and age: 19.42(1.18) yrs.) were randomly assigned to three equal groups namely complex training group (COM), contrast training group (CNST) and control group (CON). All the selected physiological and biochemical outcome measures have been tested baseline (T1) and after 12- weeks of training intervention (T2) assessments. Since the CON group was practicing field hockey every day, they were regarded as an active CON group. The intervention in the given period significantly improved VC and VO_{2max} , positively impacting respiratory function. However, no notable changes were observed in RHR, HDL, and LDL levels. Forthcoming research may emphasize the refining of intervention protocols to address these areas and further understand the underlying mechanisms for optimal cardiovascular health and performance enhancement for field hockey players.

Keywords: Sport medicine, High-density lipoprotein, Low-density lipoprotein, Training intervention, Vital capacity, VO_{2max} , Resting heart rate.

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INTRODUCTION

A long-standing sport, field hockey has experienced significant and quick transformation in recent years. The introduction of artificial turf (Young, 2019), changes in the free hit rule (Tromp and Holmes, 2017), one versus one tie-breaker from sport penalty stroke (Hoskens et al., 2023), elimination of the offside rule (Asembo et al., 1998), and changes in the duration and period of the match from 35 minutes two half to 15 minutes four quarters has altered the technical, tactical, and physiological demands of the players at every level, but especially at the professional level. Playing field hockey requires brief bursts of vigorous running, which may demand an equal amount of anaerobic and aerobic energy to cover longer distances (Kusnanik et al., 2018). Field hockey looks to be aerobically demanding due to its constant motion (McGuinness et al., 2017), but it also demands regular anaerobic exertion for power movements (Lemmink and Visscher, 2006). Modern field hockey is heavily reliant on physiology as it directly affects players' performance and endurance. Besides strength and agility (Krishnan and Rajawadha, 2020), the sport requires a high level of cardiorespiratory (Fedotova, 2001) as well as cardiovascular fitness (Lin et al., 2023) and endurance. To maintain the intense running, sprinting, and quick changes of direction throughout the game, players must possess excellent aerobic capacity (15 minutes of each quarter). In exercise physiology research, the development of physical fitness has been linked with the improvement of basic biochemical processes in exercise metabolism (White and Ismail, 1978). On-field performance is optimized by the biochemical composition of the athlete (Seshadri et al., 2019). By monitoring these variables on a regular basis, field hockey players can gain valuable insight into their health, metabolism, and cardiovascular system (Manna et al., 2011). Several training interventions have been proven to be effective on the physiological aspects of field hockey players (Hanjabam and Kailashiya, 2014; Roberts, 2016; Sarkar et al., 2019; H. B. Sharma and Kailashiya, 2018). However, some of the training interventions have explored positive results in biochemical variables (Hazar et al., 2015; Manna et al., 2009, 2016). Those interventions include plyometric training (Rangaraj and Ganapathy, 2024) and strength training (Hanjabam and Kailashiya, 2014).

Plyometrics involves high-intensity movements that combine rapid eccentric and concentric muscle contractions. It is one of the most important components of modern athletic conditioning programs. This program should be tailored to an athlete's position and sport to enhance its specificity and imitate its assigned sport-specific activities. It can be specific in terms of movements, weights, angular velocities, and metabolic demands (Davies et al., 2015). Plyometric exercise is beneficial for a variety of health and sports-related issues as of yet. Plyometric exercise, for instance, has been shown to improve bone mass in addition to improving muscle strength, endurance, agility, and running (Grgic et al., 2021). Resistance training has the potential to improve general health and well-being by improving bone, muscle, tendon, and ligament strength and toughness; strengthening joints; preventing injuries; increasing bone density; improving metabolism; improving cardiac function; and raising the good cholesterol (Azeem and Mohammed, 2019). The term strength training is often used synonymously with resistance training (Stricker et al., 2020). Some of the previous studies reported that combined resistance and plyometric training intervention had explored positive effects when compared to isolated training (Ahmad dar and Kalimuthu, 2021; Allégue et al., 2023). Complex training (COM) is a broad, efficient approach to physical training that combines a number of methods to maximize an athlete's physical fitness and performance. In order to improve power, speed, and overall athletic ability, strength training exercises are usually combined with explosive movements or stretch-shortening cycles. In order to increase the power output during the plyometric activity, COM mixes biomechanically identical plyometric activities with heavy resistance exercises in the same program. For instance, squats jump right after heavy-weight squats (Bevan et al., 2009). Furthermore, as would happen in the absence of the previous heavy resistance set, this results in an improved performance of the next lighter set (Matthews et al., 2009). Contrast training (CNST) is described as integrating the use of heavy loads and

lighter load exercises in the same training session (Alves et al., 2010). These modes employ the same exercise technique, but at different intensities, to take advantage of the PAP effect. CNST is particularly described as a collection of exercises that uses contrasting heavy and light loads. All high-load strength exercises are performed at the start of the session, and all lower-load power activities are performed at the second half (Cormier et al., 2020b). For instance, during the first half of the training session (beginning); weight training activities like hard squats and bench presses, can be practiced. During the second half of the session (at the end); plyometric workouts like medicine balls throw can be practiced. COM and CNST are both forms of high-intensity training that combine resistance training with plyometrics to enhance explosive power and athletic performance. In COM, plyometric exercises are performed after a strenuous resistance workout with the goal of enhancing power output through the use of post-activation potentiation. It is necessary to carefully manipulate training variables, including intensity, volume, and frequency, in order to achieve maximal benefits from the intervention (Murlasits et al., 2012).

Several studies focused on the acute effectiveness of COM as well CNST among various trained populations (Clark et al., 2006; Liossis et al., 2013; Matthews et al., 2009; Smilios et al., 2005). Some of the studies focused on the long-term effectiveness of COM as well CNST among different sports populations such as football (El-Shafee, 2017; Garcí'A-Pinillos et al., 2014; M. Hammami et al., 2017; M. Hammami, Gaamouri, Shephard, et al., 2019; M. Z. Hammami et al., 2017; Spinetti et al., 2019), handball (M. Hammami, Gaamouri, Aloui, et al., 2019), basketball (Román et al., 2017; Santos and Janeira, 2008), rugby (Argus et al., 2012; Bevan et al., 2009), and volleyball (Umaran et al., 2020). However, few studies explored the induced effect of COM and CNST among field hockey players (Rathi et al., 2023; Thapa et al., 2023). Thus far, limited studies have observed the effect of COM and CNST on vital capacity, VO_{2max} , and resting heart rate (Kanniyan and Syed, 2013) under physiological variables (Rajeshkumar and Muralitharan, 2023) among trained athletes, especially on field hockey players. Only a few studies have explored the influence of various training on HDL and LDL under biochemical variables among trained athletes (Bal et al., 2012; Manna et al., 2010; Ouerghi et al., 2014). For evaluating training and assessing the health, metabolism, and cardiovascular status of field hockey players, physiological and biochemical variables play a key role. Coaches may benefit from regular monitoring of physiological and biochemical variables during training at various stages of growth and development for the purpose of training and selecting players at different ages (Manna et al., 2010). Thus, the focus of the current study is to determine how COM and CNST affect field hockey player's vital capacity, VO_{2max} , resting heart rate, and levels of HDL and LDL.

METHODS AND MATERIALS

Participants

The required sample size for the study was determined using G*Power 3.1.9.6 (Kang, 2021), developed by Franz Faul from the University of Kiel, Germany. The following variables were included in the a priori: compute required sample size - given, power, and effect size for within-between interaction in repeated measures ANOVA: three groups, two measurements, alpha error < .05, desired power (1-β error) = 0.80 (Park et al., 2020), Non-sphericity correction = 1, the correlation between repeated measures = 0.5, and effect size (f) of 0.25 (Cohen, 1992). The computed sample size indicated that a minimum of 42 participants would be required to achieve statistical significance in the study (Figure1). A slightly larger sample size of 50 male participants was recruited in order to account for potential participant dropout. This approach was taken to ensure the study's strength and reliability, allowing for a margin of safety in case of unexpected participant withdrawal. According to the exclusion and inclusion criteria, 50 field hockey players agreed to participate in the present study from Union Christian College, Aluva, India, who had six years of playing experience in the field hockey. Prior to the recruitment of the all-field hockey players the researcher had given the whole ideas

and objectives of the study verbally as well as written sheet. All the field hockey players completed the informed consent sheet prior to the start of any procedure. However, completing the remaining phases of the study, five field hockey players were excluded due to their pre-existing injury record. While collecting the T1 assessment 45 participants (mean (SD); weight: 63.62(4.54) kg, height: 1.67(.06) cm, and age: 19.42(1.18) yrs.) were considered as study sample (n = 45). The selected samples had no history of Musculo skeletal injuries. According to the Helsinki Declaration, the study was approved by the Institutional Ethical Committee at Pondicherry University, India. After twelve weeks of COM and CNST intervention, T2 was completed for the study samples (n = 45). There were no dropouts after the commencement of the training program.

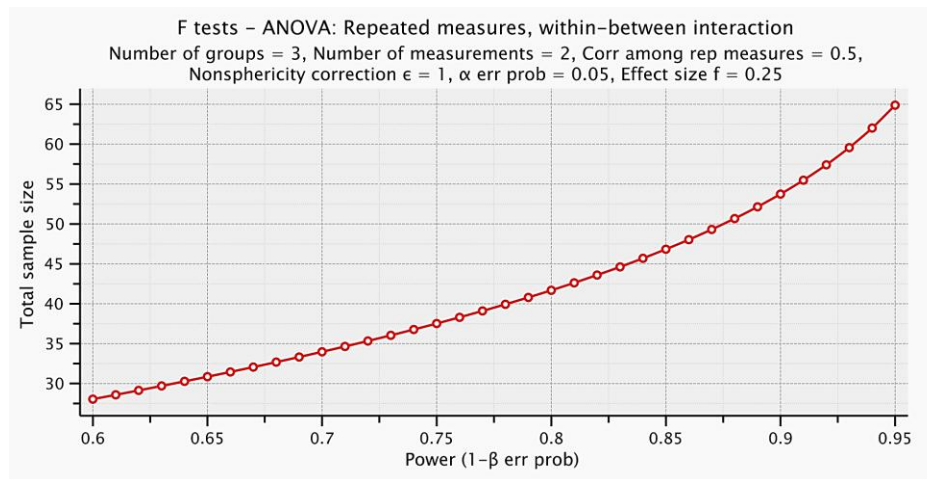


Figure 1. Sample size estimation through G*Power software.

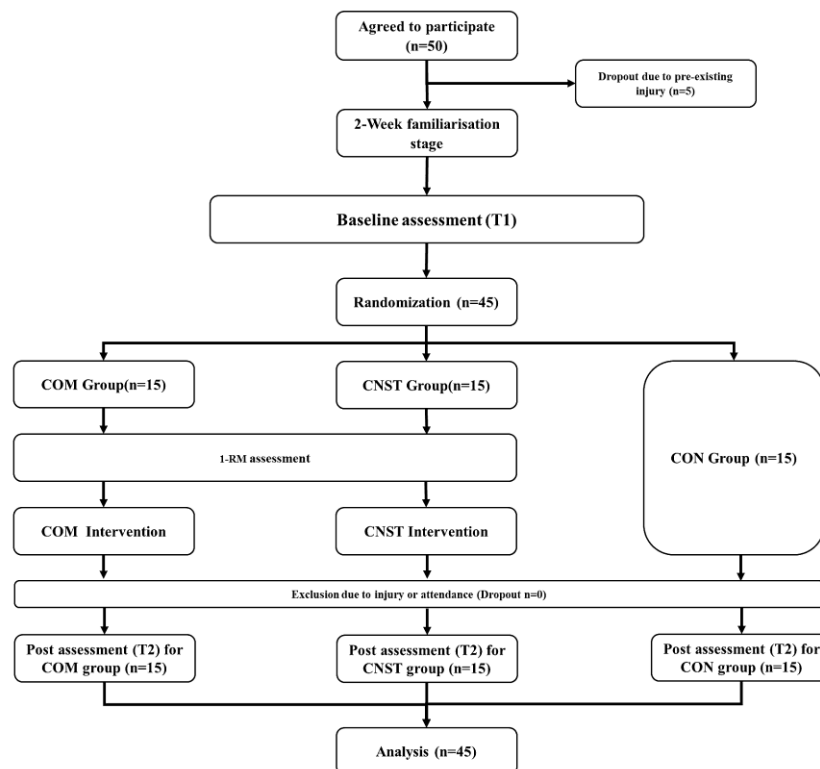


Figure 2. Sampling size in different stages of research.

Study design

A 3x2 mixed model design (group x time) was used in this current study, and the purposive sampling technique was implemented to assign inclusion criteria for the sample selection. After the T1 assessment, 45 field hockey players were randomly allocated to the two experimental (COM = 15 and CNST = 15) groups and the control group (CON = 15). Before the 12-weeks of COM and CNST intervention, the participants of the two experimental groups had two weeks of familiarisation stage, and the CON group underwent regular activity. Training interventions were done using the proper progressive load method, which was based on the one-repetition maximum for each individual. The outcome measures of vital capacity, resting heart rate, VO_{2max} , HDL, and LDL were tested in T1 (before intervention) and T2 (after intervention) assessments. Following the randomization of the research samples ($n = 45$), no participant was dropped for any reason. Finally, a total of 45 field hockey players were included in the T2 assessment. The whole process and sampling sizes in different stages are presented in Figure 2.

Intervention

At Union Christian College Aluva, 12-weeks of complex and contrast training intervention were held for the field hockey players, with each training session for 60 minutes, which included the general and specific warming up, training intervention, and cooling down and three sessions in a week (Monday to Saturday) were conducted with proper resting periods. For the two training intervention groups (CON and CNST), two weeks of familiarisation were conducted before the study intervention to ensure the participants were well-adapted to the training. The training intervention began with an intensity of 60–70% for each participant and each training group.

Table 1. COM training program.

Indicator	Exercise	Set	Repetition
Week 1-3 60-70% 1RM	Chin-ups	1-2	8-10
	Medicine ball overhead pass	1-2	6-8
	Leg curl	1-2	8-10
	Single-leg lateral hop	1-2	6-8
	Chest press	1-2	8-10
	Box jump	1-2	6-8
Week 4-6 65-75% 1RM	Chin-ups	2-3	8-12
	Medicine ball overhead pass	2-3	6-10
	Leg curl	2-3	8-12
	Single-leg lateral hop	2-3	6-10
	Chest press	2-3	8-12
	Box jump	2-3	6-10
Week 7-9 70-80% 1RM	Chin-ups	2-3	10-12
	Medicine ball overhead pass	2-3	8-10
	Leg curl	2-3	10-12
	Single-leg lateral hop	2-3	8-10
	Chest press	2-3	10-12
	Box jump	2-3	8-10
Week 10-12 75-85% 1RM	Chin-ups	3-4	10-12
	Medicine ball overhead pass	3-4	8-10
	Leg curl	3-4	10-12
	Single-leg lateral hop	3-4	8-10
	Chest press	3-4	10-12
	Box jump	3-4	8-10

Note. 1 RM = 1 repetition maximum.

Table 2. CNST training program.

Indicator	Exercise	Set	Repetition
Week 1-3 60-70% 1RM	Half squat	1-2	8-10
	Bench press	1-2	8-10
	Calf press or leg press	1-2	8-10
	Vertical jump	1-2	6-8
	Medicine ball standing side wall throw	1-2	6-8
	Zig zag hops	1-2	6-8
Week 4-6 65-75% 1RM	Half squat	2-3	8-12
	Bench press	2-3	8-12
	Calf press or leg press	2-3	8-12
	Vertical jump	2-3	6-10
	Medicine ball standing side wall throw	2-3	6-10
	Zig zag hops	2-3	6-10
Week 7-9 70-80% 1RM	Half squat	2-3	10-12
	Bench press	2-3	10-12
	Calf press or leg press	2-3	10-12
	Vertical jump	2-3	8-10
	Medicine ball standing side wall throw	2-3	8-10
	Zig zag hops	2-3	8-10
Week 10-12 75-85% 1RM	Half squat	3-4	10-12
	Bench press	3-4	10-12
	Calf press or leg press	3-4	10-12
	Vertical jump	3-4	8-10
	Medicine ball standing side wall throw	3-4	8-10
	Zig zag hops	3-4	8-10

Note. 1 RM = 1 repetition maximum.

The intensity was implemented based on the one-repetition maximum test conducted for each participant. Both COM and CNST training were a combination of plyometric and resistance training. In COM training, biomechanically similar weight training exercises are alternated with lighter-load power exercises, set-for-set (e.g., chin-ups followed by medicine ball overhead pass) (Cormier et al., 2020a). CNST training is described as a combination of training that incorporates the utilization of contrasting heavy and light loads, with all high-load strength exercises done at the beginning of the session and all low-load power activities at the conclusion (Cormier et al., 2020a). Detailed information about the COM and CNST training intervention can be found in Table 1 and Table 2, respectively.

Load measurement

Individualized training intensity was designed using the frequently used one-repetition maximum test. Prior to the commencement of the familiarization stage, 1RM evaluations were performed using the procedures described in prior research (Atalag et al., 2021). Before each evaluation, a 10-15-minute general warm-up was performed, which included jogging, strides and dynamic stretching, followed by full-body freehand squats, whole-body walking lunges, and whole-body push-ups. A quick warm-up included five to ten repetitions with a load of 40-50%, followed by three to five repetitions at 50-60% of the anticipated 1RM. During the specified warm-up and test, trained spotters assured safety. The weight was then gradually raised in increments of 5 kg or less to reach the 1RM in a maximum of five tries. The time between 1RM efforts was four minutes. For the CON group, there was no 1RM data available.

Outcome measures

Based on the outcome measures used in this study, solid evidence for the conclusions could be drawn. VC, VO_{2max} , and RHR were used in the physiological outcome measures in this study. HDL and LDL levels were determined using a blood sample lab test, which falls under the category of biochemical outcome measures. For this study, all outcome measures were examined using a T1 evaluation and T2 assessment in the morning following 12 weeks of intervention. The spirometer was a viable measure for assessing vital capacity, as was the Queen's College step test, and the palpating technique was also a reliable measure for assessing resting heart rate. To identify the characteristics of the participant's height and weight measured through a standard stadiometer (MCP 2m/200CM Roll Ruler Wall Mounted Growth Stature Meter) and weighing machine (HD-93 Digital weighing machine).

Physiological outcome measures

VC was assessed with a valid tool, namely a spirometer (litters)(Singh and Mitra, 2020). Participants received verbal information prior to taking the test. The participants were asked to shut their noses with clips and inhale deeply before exhaling forcefully into the opening of the spirometer. During the test, participants ensured a tight bond around the mouth and opening of the spirometer. Each participant had three attempts. The best one out of three was selected as a VC score. After each try, the spirometer was carefully examined for the next attempt. RHR was recorded using the palpation technique (Mishra et al., 2023; S. H. Sharma and Singh, 2020) in the early morning before the daily routine. VO_{2max} was assessed indirectly by using the valid test of the Queens College step test procedure(Bandyopadhyay, 2007; Nabi et al., 2015). The step test was carried out at a height of 41.275 cm. The stepping was accomplished for a total of three minutes, with a number of twenty-four steps per minute specified. After completing the task, the carotid pulse rate was measured from the fifth to the thirtieth seconds of recovery. The 30-second pulse rate was converted to beats per minute. Finally, VO_{2max} score was converted using the equation of:

$$VO_{2max} = 111.3 - (0.42 \times \text{pulse rate beat/min}).$$

Biochemical outcome measures

Blood samples were collected from the participants in the morning session after 12 hours of fasting period (Ayob et al., 2023). All blood samples (HDL and LDL) collections were performed by nurses with all safety requirements and biochemical analyses were carried out in an ISO 9001:2015 certified private laboratory. Fasting biochemical analyses were performed using the automated procedure on EM200 technology.

Statistical analysis

All data were tabulated using Microsoft Excel, and the normality of the data was determined using the Shapiro-Wilks test (Sanpasitt and Apanukul, 2023). The characteristics of the participants (baseline assessment) were calculated using one-way ANOVA to ensure that there was no significant difference between the groups. Three groups were compared, as well as all outcomes, with a baseline 12 weeks after intervention with a paired sample t-test (Thapa et al., 2023). The magnitude of changes between T1 and T2 assessment was calculated using Cohen's d values, which were described as trivial: 0 to 0.2; small: 0.2 to 0.6; moderate: 0.6 to 1.2; large: 1.2 to 2.0; very large: 2.0 to 4.0; nearly perfect: >4.0 (Ndlomo et al., 2023). To compare the changes of three groups for all outcome measures, a 3x2 (group x time) mixed design analysis of variance for repeated measures test to measure the time (pre-test and post-test), group (COM, CNST, and CON) and interaction (group x time) effects (Alhamad et al., 2023). Bonferroni post hoc test was used to identify specific differences between the groups (Alhamad et al., 2023). Additionally, the partial eta-square (PES) was taken from the two-way repeated measures ANOVA test. Effect size (partial eta-square) was used to determine the magnitude of the difference. A large is interpreted as (≥ 0.14), a medium is

interpreted as (0.06-0.14), and a small is interpreted as (≤ 0.06) (Pramanik et al., 2023). to indicate the statistically significant .05 level was fixed. Jeffrey's Amazing Statistics Program (JASP) 0.18.3.0 open-source software was used to perform all the statistical analysis (Ağduman and Daşkesen, 2023; Jannah et al., 2023).

RESULTS

Table 3 presented the characteristics of the participants of two intervention groups (COM and CNST), and the control group (CON) did not show any significant difference in weight ($p = .464$), height ($p = .258$), and age ($p = .941$). The normality of the participant's characteristics was determined using Shapiro-Wilks tests.

Table 3. Characteristics of participants.

Characteristics	COM	CNST	CON	p
	Mean (SD)	Mean (SD)	Mean (SD)	
Weight	64.73(4.33)	63.47(5.47)	62.67(3.72)	.464
Height	1.70(0.075)	1.66(0.061)	1.67(0.040)	.258
Age	19.47(1.19)	19.47(1.06)	19.33(1.34)	.941

Table 4 shows the normality of the outcome measures (vital capacity, resting heart rate, VO_{2max} , HDL, and LDL) data that was determined using the Shapiro-Wilks test. All the data of the outcome measures were normally distributed in Kolmogorov-Smirnov as well as the Shapiro-Wilks test.

Table 4. Tests of Normality.

Outcome measures	Group	Shapiro-Wilk		
		Statistic	df	Sig.
VC	COM	0.907	15	.123
	CNST	0.921	15	.201
	CON	0.897	15	.084
RHR	COM	0.930	15	.276
	CNST	0.920	15	.191
	CON	0.908	15	.126
VO_{2max}	COM	0.948	15	.491
	CNST	0.943	15	.418
	CON	0.884	15	.055
HDL	COM	0.886	15	.057
	CNST	0.961	15	.716
	CON	0.946	15	.469
LDL	COM	0.957	15	.637
	CNST	0.951	15	.537
	CON	0.939	15	.371

Table 5 Repeated measure analysis of variance reveals that VC had significant changes between the groups ($p < .01$, PES = 0.448) with large effect, between the time ($p < .01$, PES = 0.713) with large effect, and interaction between the group x time ($p < .01$, PES = 0.520) with large effect. RHR did not show any significant difference between group, time and group x time. VO_{2max} did not show significant changes between the

groups ($p = .066$, PES = 0.121) with moderate effect, but significant changes between the time ($p < .01$, PES = 0.520) with large effect, and interaction between the group x time ($p < .01$, PES = 0.315) with large effect.

Table 5. Repeated Measures ANOVA.

Outcome measures	Group	T1 (SD)	T2 (SD)	Group (effect)	Time (effect)	Group x time (interaction)
VC	COM	3.83(0.243)	4.51(0.194) †▲ #	0.00** (0.448)	0.00** (0.713)	0.00** (0.520)
	CNST	3.87(0.258)	4.45(0.262) †▲			
	CON	3.77(0.263)	3.81(0.252)			
RHR	COM	74.27(2.49)	73.73(2.25)	0.379 (0.045)	0.803 (0.002)	0.228 (0.068)
	CNST	74.13(2.20)	74.00(2.42)			
	CON	74.53(3.07)	75.47(2.33)			
VO _{2max}	COM	39.31(2.51)	43.94(1.81) †▲ #	0.066 (0.121)	0.00** (0.520)	0.00** (0.315)
	CNST	39.15(2.68)	42.88(1.45) †▲			
	CON	39.76(3.05)	40.04(2.80)			
HDL	COM	43.13(3.48)	48.33(2.79)	0.141 (0.089)	0.008** (0.154)	0.415 (0.041)
	CNST	42.93(4.65)	47.93(2.94)			
	CON	42.40(2.72)	42.93(3.01)			
LDL	COM	120.40(9.03)	103.53(8.24)	0.051 (0.132)	0.008** (0.156)	0.97 (0.001)
	CNST	119.27(13.97)	104.33(10.79)			
	CON	120.93(11.13)	119.60(10.11)			

Note. # Significant difference with training protocol .05, † significant difference with baseline .05. ▲ Significant difference with control .05, η^2_p partial et square, * $p < .05$, ** $p < .01$.

High-density lipoprotein (HDL) level had no significant changes between groups ($p = .141$, PES = 0.089) with moderate effect, and in the interaction between groups and time ($p = .415$, PES = 0.041) with small effect but over time had significant change ($p < .01$, PES = 0.154) with moderate effect. Similar to low-density lipoprotein (LDL), no significant changes were observed between groups ($p = .51$, PES = 0.132) with moderate effect, and in the interaction between groups and time ($p = .97$, PES = 0.001) with small effect but over time had significant change ($p < .01$, PES = 0.156) with moderate effect for LDL level also.

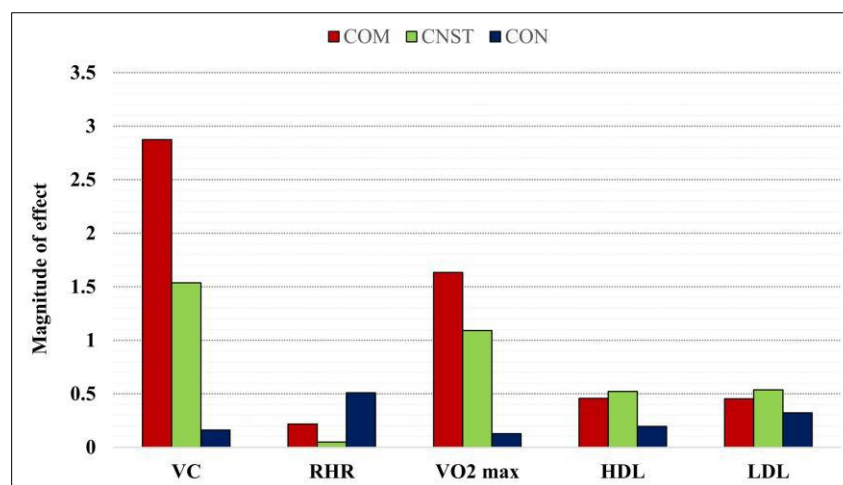


Figure 3. Magnitude of effects in outcome measures between T1 and T2 assessments for COM, CNST and CON groups.

When considering the paired sample t-test, VC had a significant difference between COM ($p < .05$) with a nearly perfect effect and CNST ($p < .05$) group with a large effect, but the CON group did not show any significant difference ($p > .05$) with trivial effect. VO_{2max} had a significant difference between COM ($p < .05$) with a large effect and CNST ($p < .05$) group with a moderate effect, but the CON group did not show any significant difference ($p > .05$) with a trivial effect. Despite this, RHR, HDL and LDL were not significantly different among the three groups (Magnitude of effects presented in Figure 3).

When considering the one-way analysis of variance, the T1 assessment of all the outcome measures did not show any significant difference at the .05 level. VC, VO_{2max} significantly improved in both training interventions (COM and CNST). However, neither the CON group nor the training interventions (COM and CNST) demonstrated significant changes in RHR, HDL, or LDL. When considering the Bonferroni post hoc test, the COM group showed significantly higher improvement in VC and VO_{2max} when compared to CNST as well as the CON group.

DISCUSSION

A number of studies have previously examined the impact of COM on VC and RHR among football players (Rozario and Vallimurugan, 2020) as well as CNST on handball players (Rajkumar, 2020). However, a few authors explored the impact of COM versus CON training on VC, RHR, and VO_{2max} among soccer players (Kanniyan and Syed, 2013), but few of the authors examined the field hockey population. According to these results, VC and VO_{2max} were significantly different between the COM group and the CON group at the end of the 12 weeks of training intervention. In comparison with the two-intervention group, the COM group showed significant improvements. There was no significant difference in the variable RHR between the experimental and control groups. Some of the previous study's results are in line with the current study results (Anitha et al., 2018; Gómez-molina et al., 2018; Kanniyan and Syed, 2013; Manna et al., 2016; Rajeshkumar and Muralitharan, 2023; Sarkar et al., 2019; H. B. Sharma and Kailashiya, 2018). In the study by H. B. Sharma & Kailashiya (2018), sprint-strength and agility training improved aerobic (VO_{2max}), cardiovascular parameters, and performance of male field hockey players after six weeks. Sarkar et al. (2019) assess the impact of an eight-week high-intensity interval training program on anaerobic threshold level VO_{2max} and associated cardio-respiratory parameters. The athlete can eventually exercise at a higher burden with improved cardiac proficiency after completing the 8-week HIIT regimen. One study Indranil Manna et al. (2016), found that RHR did not change significantly after eight weeks of aerobic, anaerobic, and skill development training in field hockey players. The young hockey players in this study had increased their maximum aerobic capacity (VO_{2max}) following six and twelve weeks of training (Manna et al., 2009). Indian players may not achieve the same level of success at the international level as their European counterparts due to their lower VO_{2max} (Manna et al., 2009). This is mostly because increased duration of activity and intensity raises the muscle's myoglobin content since it causes the worked muscles to hypertrophy. Thus, more muscle mass also results in an increased blood flow, which eventually improves the muscle's ability to perform for extended periods of time. Based on the results of the study by Kanniyan & Syed (2013), there are significant differences between the complex training group, contrast training group, and the control group in all cardio-respiratory endurance tests. During a 12-week period of an intervention study, Rajeshkumar & Muralitharan, (2023) found a significant increase in vital capacity and forced vital capacity following the concurrent training program including aerobic and resistance training. Anitha et al. (2018) found that plyometric training significantly improved vital capacity and anaerobic capacity in male volleyball players over the course of 12 weeks. According to study Gómez-molina et al. (2018) novice runner's VO_{2max} was enhanced by 8 weeks of concurrent plyometric training. Some of the previous studies results are not in a line with the current study results (Hanjabam and Kailashiya, 2014; Roberts, 2016). According to Roberts (2016), sports-specific

training significantly affected VO_{2max} in field hockey players after six weeks of training, but not after 12 weeks, in the same population, the resting heart rate was significantly reduced over 6 weeks of sprint, strength, and agility training which revealed by Hanjabam & Kailashiya, (2014). Moderate intensity plyometric training had significant decline in RHR among Badminton Players (Rangaraj and Ganapathy, 2024). A study by Indranil Manna et al. (2016) found that elite field hockey players did not experience any significant changes in VO_{2max} after four and eight weeks of aerobic anaerobic and skill training. considerable reduction in training volume, load, and intensity during the course of the program, that might be the possible reason for getting contrary results in these past studies (Gil-rey et al., 2015).

The development of athlete profiles, the evaluation of training adaptations, and the investigation of program effectiveness are fundamental elements of physiological assessment in the laboratory and in the field (Reilly et al., 2009). In the current study, results state that over 12 weeks of COM and CNST training on biochemical variables such as HDL and LDL, there was no significant difference among field hockey players. However, a trivial increase in HDL and a trivial decline in LDL over the 12-week course training intervention (COM and CNST). Some of the previous study results are in line with the current study results (Bal et al., 2012; Farsani and Rezaeimanesh, 2011; Koh and Miller, 2012; Ouerghi et al., 2014). According to the study by Bal et al. (2012) Indian jumpers' total cholesterol levels did not alter significantly after a six-week plyometric training program. The study by Ouerghi et al. (2014) stated that, after 12 weeks, total and low-density lipoprotein cholesterol levels and High-density lipoprotein cholesterol levels had no significant difference in high-intensity interval training addition with regular soccer training; only regular soccer training and control group who did not participate any physical activity. In addition to regular soccer training, low-density lipoprotein cholesterol levels decreased by about 2% in the high-intensity interval training group. There was a minimal increase in High-density lipoprotein cholesterol levels for the high-intensity interval training addition with regular soccer training and regular soccer training. Based on a meta-analysis conducted by Kelley & Kelley (2009), it was concluded that aerobic training improved HDL-C while progressive resistance training did not. According to the research by Koh & Miller, (2016) after six weeks of power-based resistance training for collegiate athletes that includes weightlifting and plyometrics, the lipoprotein parameters were unaffected. Farsani & Rezaeimanesh, (2011) explored the six weeks of aerobic interval training affected certain blood lipids; LDL remained constant in female athletes and students. Some of the previous studies are not in line with the current study results (Kelley and Kelley, 2009; Manna et al., 2010; Sarkar et al., 2023). The study by Indranil Manna et al. (2010) investigates how Indian soccer players' lipid profiles varied according to their training regimen, which included aerobic, anaerobic, and skill development. Also, similar results have been revealed for high-intensity training in team game athletes (Sarkar et al., 2023). Kelley & Kelley, 2009 also suggest that progressive resistance training reduces LDL levels.

Limitations

The study is not without its limitations. Limitations include various characteristics that could impact the generalizability and strength of the findings. Only minimal or slightly above-minimal sample sizes were obtained to determine the study's power value. A 12-week intervention period provides insight into short-term effects, while a duration beyond 12 weeks may provide more robust information. The study focused on the physiological and biochemical variables and inattention to the various relevant performance evaluation measures. There was no control over the diet, socioeconomic status, psychological factors, or environmental factors in all of the three groups, as the study did not control for these factors.

Practical application

In evaluating training and assessing the health, metabolism, and cardiovascular status of field hockey players, physiological and biochemical variables play a key role. Coaches may benefit from regular

monitoring of physiological and biochemical variables during training at various stages of growth and development for the purpose of training and selecting players at different ages. Future research should examine the training duration beyond 12 weeks or adjust the intensity and volume of the training to enhance the effect on lipid profile and cardiovascular parameters.

CONCLUSIONS

In conclusion, both training intervention groups resulted in substantial improvements in VC, suggesting better respiratory function than the CON group. However, RHR was unaltered across all three groups, suggesting that neither the treatments nor the control condition had an effect on RHR. VO_{2max} went up considerably in both the COM and CNST groups as compared to CON, demonstrating better aerobic capacity. Furthermore, compared to CON, the COM and CNST groups showed no better lipid profiles, with higher HDL and lower LDL. However, trivial changes were made in two experimental groups. T1 tests verified the initial comparability of groups. Furthermore, the Bonferroni post hoc test showed superior effectiveness of the COM training, showing substantially higher increases in VC and VO_{2max} when compared to CNST and CON. Overall, our data highlight the efficacy of personalized complex training programs in improving numerous physiological parameters linked to cardiovascular health and fitness in field hockey players but no potential effectiveness on lipid profile. Future studies should look at the long-term effects of complex and contrast training on field hockey players, taking into account injury prevention, recovery, and sustained performance over the course of an entire season. Coaches and trainers can use individualized sophisticated training regimens to improve respiratory function, aerobic capacity, and lipid profiles in field hockey players. Coaches may help athletes achieve peak performance and maintain optimal health by incorporating evidence-based treatments into their training regimens. Continuous monitoring of physiological indicators of the athletes can help to guide the training plan revisions, assuring long-term progress and injury avoidance.

AUTHOR CONTRIBUTIONS

Conceptualization, I.N.K.V. and G.V.; methodology, I.N.K.V. and G.V.; software, I.N.K.V. and S.B.; formal analysis, I.N.K.V., G.V. and S.B.; investigation, I.N.K.V.; resources, I.N.K.V.; data curation, I.N.K.V.; writing—original draft preparation, I.N.K.V. and G.V.; writing—review and editing I.N.K.V., G.V. and S.B; project administration, I.N.K.V. All authors have read and agreed to the published version of the manuscript.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

ETHICAL STATEMENT

An ethical clearance and informed consent were obtained prior to the start of the study. The study received approval from the institutional ethical committee at Pondicherry University (Approval No. HEC/PU/2023/05/07-08-2023). Written/verbal informed consent was taken from all participants. The study was carried out in accordance with the principles enunciated in the Declaration of Helsinki.

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Heart rate variability-guided aerobic training without moderate-intensity enhances submaximal and maximal aerobic power with less training load

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ABSTRACT

This study aims to clarify the effects of heart rate variability (HRV)-guided aerobic training on submaximal and maximal aerobic power. Twelve active men participated in a 5-week intervention and were divided into two groups: a block periodization training group (BP, n = 6) and a HRV-guided training group (HRV-G, n = 6). All participants underwent the same aerobic training during week one. In weeks 2–5, the training load for the HRV-G was adjusted based on the HRV of an individual on waking. The BP underwent 2 weeks of overload training followed by 2 weeks of taper training. To determine the submaximal and maximal aerobic powers, an incremental load test was performed at baseline and once a week. The internal load during the training sessions was derived from the heart rate. The monotony and strain were calculated from the internal load. TRIMP and the strain were lower in the HRV-G than BP. The HRV-G had a greater relative distribution of time spent at low-intensity and a lower relative distribution of time spent at high-intensity than BP. The change in the maximal and submaximal aerobic power was greater in the HRV than in BP. The current findings indicate that combined low- and high-intensity HRV-guided training enhance increases the submaximal and maximal aerobic power, regardless lower training load than BP.

Keywords: Sport medicine, Cardiac-autonomic nervous system, Aerobic training, Periodization, Training adaptation.

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INTRODUCTION

Aerobic training increases submaximal and maximal aerobic power, and its effect on aerobic power depends on the intensity, frequency, and duration of the prescribed exercises (Wenger & Bell, 1986). A aerobic training program is generally supervised and predetermined. Block periodization (BP) is a popular method for optimizing maximal aerobic power by focusing on a targeted ability for a given period of time (Issurin, 2010). One aspect of BP is tapering following overload, which has been shown to increase maximal aerobic power (Thomas & Busso, 2005). There is an interindividual variation in the change in aerobic power, even when the relative training load is the same. In fact, 5% of all participants exhibit little or no effect, while another 5% show an increase in effect by 40–50% (Skinner et al., 2001). Aubry et al. (2014) (Aubry et al., 2014) also revealed that individuals who responded better to a 3-week overload training exhibited greater gains in maximal aerobic power after a 2-week tapering period compared to those who responded less or did not respond to the overload training. A magnitude of aerobic adaptation is influenced by internal load from heart rate than external load (MORINAGA & TAKAI, 2024; Taylor et al., 2018). Therefore, it is necessary to focus on internal load and design an aerobic training program that reduces individual variations in adaptation to aerobic training.

Heart rate variability (HRV) derived from R-R intervals (RRi) such as the high-frequency domain (HF), root mean squared differences of successive RRi transformed by natural logarithm (LnRMSSD), and coefficients of covariance in LnRMSSD ($CV_{LnRMSSD}$) can be a valid and reliable tool for assessing the cardiac-autonomic regulation of parasympathetic activity (Camm et al., 1996). Changes in parasympathetic activity indices may reflect positive or negative adaptations to aerobic training (Buchheit et al., 2010; Da Silva et al., 2014; Hautala et al., 2003; Le Meur et al., 2013; Nummela et al., 2009; Plews et al., 2012). Da Silva et al. (2014) (Da Silva et al., 2014) demonstrated a positive relationship between increases in LnRMSSD and increases in 5-km running time after a 7-week endurance training intervention (6 days per week) in trained endurance runners. After 3 weeks of overload training for trained triathletes, the LnRMSSD value attenuates with decreasing running distance until exhaustion (Le Meur et al., 2013). Furthermore, 7 weeks of aerobic training simultaneously reduces $CV_{LnRMSSD}$ and increases the distance of the Yo-Yo intermittent recovery test level 1 (Boullousa et al., 2013). Hautala et al. (2003) (Hautala et al., 2003) demonstrated that the magnitude of individual cardiac parasympathetic activity is associated with changes in the maximal oxygen uptake and independent of the training volume. Considering the earlier studies, a potential factor for interindividual variation in aerobic adaptation is the adjustment of the automatic cardiovascular regulation of parasympathetic activity (Hautala et al., 2003). However, the relationship between the changes in HRV and aerobic performance gain remains unclear.

Based on the above studies, it has been recommended that individualized aerobic training guided by HRV, in which the training load is adjusted by monitoring the daily HRV of the individual, may be more effective than predetermined aerobic training for improving maximal oxygen uptake and aerobic power (Javaloyes et al., 2019; Kiviniemi et al., 2010; Kiviniemi et al., 2007; Vesterinen et al., 2016). Compared to predetermined aerobic training, HRV-guided training reduces the number of moderate- and high-intensity training sessions (Carrasco-Poyatos et al., 2022; Vesterinen et al., 2016) and the proportion of moderate intensity training (Javaloyes et al., 2019). Daily variation in LnRMSSD is also lower with HRV-guided training than with predetermined aerobic training (Javaloyes et al., 2019). Regarding aerobic power, HRV-guided training produces greater increases in aerobic peak power and power at moderate and high intensities than predetermined training (Javaloyes et al., 2019). Furthermore, HRV-guided training is as effective as or more effective at maximizing aerobic power than the BP strategy (Javaloyes et al., 2020; Nuutila et al., 2017). For example, Javaloyes et al. (2020) (Javaloyes et al., 2020) demonstrated that training-induced changes in the

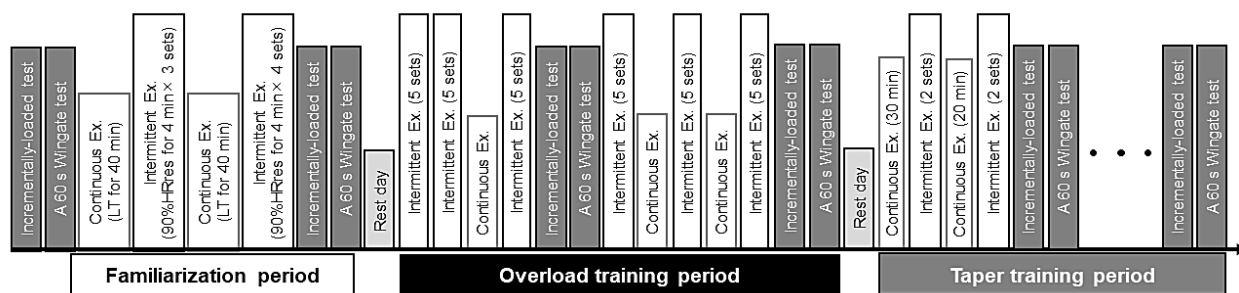
maximal aerobic power and submaximal power output at first ventilatory threshold were greater with HRV-guided training compared to BP training.

Exercise beyond the lactate threshold (LT) intensity facilitates sympathetic nerve activity and delays fatigue recovery (Seiler, 2010). Therefore, aerobic training programs for endurance athletes should consist of exercises that combine an intensity below the LT with an intensity above the onset of blood lactate accumulation (OBLA) (polarized training) (Stöggl & Sperlich, 2015). Furthermore, Esteve-Lanao et al. (2007) (Esteve-Lanao et al., 2007) divided sub-elite runners into two groups: one consisting of a higher volume of low-intensity training and the other consisting of less low-intensity training and moderate-intensity training and found that the first group timed better in a 10.4-km cross-country than the second group. The HRV-guided training program in the earlier study included moderate-intensity training, which may have reduced the effect on maximal and submaximal aerobic power. This study tested the hypothesis that the HRV-guided aerobic training, consisting of low- and high-intensity, enhanced maximal and submaximal aerobic power adaptation compared to BP training programs, regardless of the training load.

METHODS

Participants

Twelve active men (20.4 ± 1.8 years, 177.9 ± 4.4 cm, 73.4 ± 7.1 kg) were divided into two groups: a BP training group (BP, $n = 6$) and a HRV-guided training group (HRV-G, $n = 6$). The performance level of all subjects, as classified by training time and frequency and maximal aerobic power, were levels 2 (De Pauw et al. 2013). The participants had been running for 1 to 2 h, at least five times a week for over five years. None of the participants reported any illness or were prescribed medications for cardiovascular, metabolic, or orthopaedic disorders. We explained the purpose and methods of the study in detail and obtained informed consent from the participants before they participated in the experiment. This study was approved by the National Institute of Fitness and Sports in Kanoya (No. 11-101).



Note. Ex, exercise; HRres, heart rate reserve.

Figure 1. Training program in experimental and control groups for familiarization and experimental period referenced by Morinaga and Takai (2023, in press).

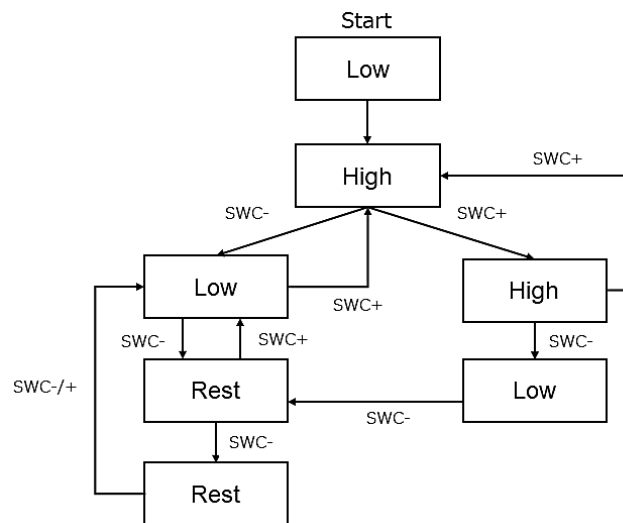
Experimental design

According to the training modality reported by Morinaga and Takai (2023) (MORINAGA & TAKAI, 2024), the BP group participated in a 5-week aerobic training intervention (Figure 1). Two protocols of aerobic training were prescribed using a bicycle ergometer (Aerobic 75X III, COMBI, Japan). One included low-intensity aerobic training of 40 min of continuous exercise at the intensity of LT, and the other included high-intensity aerobic training with 4 min x 4 sets of high-intensity intermittent exercise at an intensity of 90% of the heart

rate reserve (HR_{res} , $HR_{res} = (HR \text{ in a training session} - HR \text{ at rest}) / (\text{maximal HR} - HR \text{ at rest})$) with a 3-min active recovery period at an intensity of $50\%HR_{res}$. The heart rate was measured during the prescribed training to determine the internal load of training sessions. During the first week (familiarization period), all the participants performed an identical aerobic training program to familiarize themselves with the exercises. The experimental period was set to four weeks, corresponding to the period between 2nd to 5th week. For BP, during the period from 2nd to 3rd week, the training duration was increased such that the external load increased by 40% compared to that of the familiarization period (Le Meur et al., 2013), which was we expected to induce above moderate intensity (Halson et al., 2002). During weeks 4 and 5, the external load was decreased by 50% by shortening the training duration compared to the familiarization period (Bosquet et al., 2007). For HRV-G, the participants were prescribed low- or high-intensity training based on individual HRV scores measured upon awakening. To adjust for the training intensity, an incremental load test was conducted at baseline and once a week.

HRV-guided training

All participants had their HRV measured as prescribed below, from a week before to the end of the intervention. Participants recorded their RRI using HRV analysis software (MCsoftware, Hosanad, Italia). RRI was recorded every morning immediately after waking up and emptying the bladder. Participants were in the supine position for 5 min. The obtained data were log-transformed to reduce bias due to non-uniformity of the error (LnRMSSD). After performing a 7-day moving average of the daily LnRMSSD_{7d} (Plews et al. 2012) values, we calculated the weakly mean (LnRMSSD_{7d}) and coefficient of variance in LnRMSSD ($\text{CV}_{\text{LnRMSSD}_{7d}}$). From power spectral analysis, components in the frequency band from 0.03 to 0.15 Hz were considered low frequency (LF), and those in the range of 0.15 to 0.4 Hz were considered high frequency (HF). The use of normalized units $\{\text{HF or LF components} / (\text{the total power} - \text{very LF component}) \times 100\}$ is crucial to obtain values for the autonomic cardiac modulation, because the high interindividual variation in RRI total variance and direct current noise (Manzi et al., 2009) and computed as the ratio of LFnu and HFnu (LF/HF). All HRV parameters were calculated for the familiarization period and weekly during the experimental period.



Note. When $\text{LnRMSSD}_{rollave}$ remained inside SWC (+), high-intensity interval training sessions was prescribed. If $\text{LnRMSSD}_{rollave}$ fell outside SWC (-), low intensity or rest were described. $\text{LnRMSSD}_{rollave}$, 7-day moving average of the natural logarithm of the root-mean squared differences of successive RR intervals; SWC, smallest worthwhile change. Low: continuous pedalling exercise; High, high intermittent interval pedalling exercise.

Figure 2. Heart Rate Variability-guided training decision-making schema. Modified from Vesterinen et al., 2019.

To detect the variability of LnRMSSD_{7d} to the prescribed training, the smallest worthwhile change (SWC) was derived from the mean and standard deviation (SD) of LnRMSSD in the familiarization period $\{\text{mean} \pm 0.5 \times \text{SD}\}$ for each participant (Vesterinen et al., 2016). For HRV-G, the morning value of LnRMSSD_{7d} was used to prescribe the training to be performed in a given training session. This procedure is illustrated in Figure 2. For example, if the LnRMSSD_{7d} was within the SWC, the participant continued to perform high-intensity intermittent exercise. If the LnRMSSD_{7d} value deviated from the SWC, the participant performed low-intensity exercise or took a day off.

Incremental load test

The participants performed an incremental load test on a bicycle ergometer (Aerobike 75XL III, COMBI, Japan), and the results were used to quantify their maximal aerobic power (W_{max}), power at LT (W_{LT}), and power at OBLA (W_{OBLA}) (Manzi et al., 2009). The participants adjusted the handlebar and saddle heights of the ergometer before the test, followed by a 5-min standardized warm-up, in which they pedalled the bicycle with an initial load of 50 W. The load was increased by 25 W every 3 min until exhaustion. The pedalling frequency was held constant at 70 rpm using an audible metronome. The heart rate was measured using a telemetric sensor (RC3 GPS, Polar, Finland). Blood lactate concentration (Bla) was measured from the fingertip using a blood lactate meter (Lactate Pro2, Arkray, Japan) 30 s before the end of each stage. The Bla level measured at the stage when exhaustion was reached was defined as the maximal Bla (Bla_{max}). We also assessed the rate of perceived exertion (RPE) using the Borg scale (6–20 points) (Borg, 1973) at the end of each stage. We calculated the maximal aerobic power (W_{max}) using the following equation based on the method proposed by Halson et al. (2002) (Halson et al., 2002).

$$W_{\text{max}} = W_{\text{final}} + \left(\frac{t}{180} \right) \times 25$$

Here, W_{max} is the maximal aerobic power (W); W_{final} is the pedalling power of the final stage (W); t denotes the time at the incomplete stage (s); the exercise time at each stage is 180 s; and the incremental load is 25 W. We computed the maximal heart rate (HR_{max}) after calculating the moving average of the time-series data for 30 s. We defined W_{LT} and W_{OBLA} as the pedalling power at 2 and 4 $\text{mmol}\cdot\text{l}^{-1}$, respectively, which were derived from the relationship between Bla and the pedalling power in the incremental load test ($y = a \cdot e^{bx}$) (Manzi et al., 2009). The aerobic power was normalized to body mass ($\text{W}\cdot\text{kg}^{-1}$).

Sixty-second Wingate test

The participants pedalled with maximal effort for 60 s on an electrical brake bike (POWER MAX V III, KONAMI, Japan), with a load set at 7.5% of the body mass of the participant (Vandewalle et al., 1987). Before the test, we adjusted the handlebars and saddle and fixed both feet to the pedals with non-elastic belts. The position of one pedal was measured using a potentiometer (AO-PMA2, Applied Office, Japan), and the analogue signal was amplified using an amplifier (DPM-912A, Kyowa, Japan) and recorded in a personal computer via an A/D converter (PowerLab 16/35, ADInstruments, Australia) at a sampling frequency of 100 Hz. The number of rotations (rpm) was calculated from the data obtained using an analysis software (Labchart 7, ADInstruments, Australia). We calculated the pedalling power (W) by multiplying the workload (kp) by the number of rotations $\{\text{workload (kp)} \times \text{number of rotations per minute (rpm)} \times 0.98 \text{ (constant)}\}$. The mean power for 60 s (W_{60}) was calculated as the index of aerobic work capacity (Gastin, 2001) and normalized to body mass ($\text{W}\cdot\text{kg}^{-1}$).

Internal load

To quantify the training load in the training and test sessions, we calculated the training impulse (TRIMP) from the exercise HR_{res} and the weighting factor and training duration for each individual {training duration (min) \times HR_{res} \times weighting factor} (Manzi et al., 2009). The weighting factor was obtained from the regression equation ($y = a \cdot e^{bx}$) of the $Bla-HR_{res}$ relationship in the incremental load test. Training intensity distributions were classified into three categories based on the HR_{res} at the LT and OBLA. As indices of the training load (Foster, 1998), the monotony and strain of the TRIMP were also calculated as the sum of the TRIMP, mean, and standard deviation weekly of the experimental period. The monotony was then calculated by dividing the mean by the standard deviation, and the strain was calculated by multiplying the sum of the TRIMP by the monotony.

Statistical analysis

All variables are presented as means and SDs. The independent variables are submaximal and maximal aerobic power, internal loads, and HRV parameters before (PRE) and after (POST) the experimental period. We calculated the relative changes in aerobic power using the following equation: (POST values – PRE values) / PRE values \times 100. Additionally, to demonstrate the consistency of adaptations in aerobic power, the coefficient of variation (CV) for the rate of change in aerobic power between subjects was calculated.

All variables were analysed using the R software (version 4.4.0). To confirm the differences between groups at the PRE stage for all variables, Mann-Whitney U test was conducted. Subsequently, the differences in internal loads between groups during the experimental period, Mann-Whitney U test was performed. Given the non-normality and heteroscedasticity of the aerobic powers and HRV parameters, the Aligned Rank Transform (ART) was applied using the ARTool package (Wobbrock et al., 2011). This allowed for nonparametric ANOVA to be conducted on the data, which included group and time as independent variables. An ANOVA was then conducted to examine the main effects and interaction effects. When significant effects were detected, Bonferroni *post hoc* comparisons were performed using the emmeans package to provide detailed pairwise comparison (Elkin et al., 2021). All significance was set at $p < .05$.

We evaluated the data using magnitude-based inference for practical significance (Hopkins et al. 2009). We used qualitative inference to assess differences in the independent variables between groups over time (Hopkins 2006). Standardized changes and 90% confidence limits (CL) were calculated as the following thresholds: ≤ 0.2 (*trivial*), > 0.2 (*small*), > 0.6 (*moderate*), > 1.2 (*large*), > 2.0 (*very large*), and > 4.0 (*extremely large*). We rated the qualitative changes in the higher or lower independent variables as: $< 0.5\%$ (*almost certainly not*), $0.5-5\%$ (*very unlikely*), $5-25\%$ (*unlikely*), $25-75\%$ (*possible*), $75-95\%$ (*likely*), $95-99.5\%$ (*very likely*), and $> 99.5\%$ (*most likely*). If the chance of a higher or lower difference is $> 5\%$, then the true difference is considered *unclear* (Hopkins et al. 2009).

RESULTS

A total of 12 subjects completed the whole study. No significant difference observed in the indices of internal load, submaximal and maximal aerobic power, and HRV parameters in PRE values.

Internal load for the intervention period

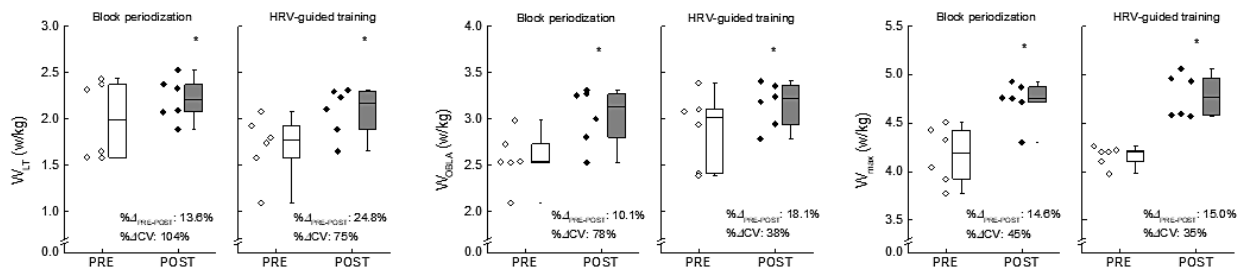
Table 1 presents the descriptive data on the internal load for the experimental period. Training duration was 486 min for BP and 465 ± 89 min for HRV-G. TRIMP was significantly lower in HRV-G ($p < .05$, ES = -1.54; *very likely*) than in BP. Strain was significantly lower in HRV-G than in BP ($p < .05$, ES = -1.70; *very likely*). Monotony was no group different between the groups ($p = .43$, ES = -0.62; *unclear*).

Table 1. Descriptive data on indices of training load for the experimental period.

	BP	HRV-G	ES	Qualitative inference
TRIMP (a.u.)	1472 ± 234	1015 ± 347*	-1.54	very likely
Monotony (a.u.)	1.13 ± 0.09	1.02 ± 0.22	-0.62	unclear
Strain (a.u.)	1644 ± 161	1048 ± 470*	-1.70	very likely
Time spent at each intensity (min)				
<LT	128 ± 20	205 ± 85	1.29	likely
LT-OBLA	189 ± 35	174 ± 58	-0.30	unclear
>OBLA	169 ± 44	85 ± 59*	-1.61	very likely
Relative distribution of time spent at each intensity (%)				
<LT	26 ± 4	44 ± 19	1.33	very likely
LT-OBLA	39 ± 7	37 ± 9	-0.19	unclear
>OBLA	35 ± 9	18 ± 13	-1.45	very likely

Note. The values are expressed as means and SDs. BP: block periodization training group; HRV-G: heart rate variability-guide training group. TRIMP: training impulse. *: significantly different compared to BP ($p < .05$).

The time spent below the LT tends to be longer in HRV-G than in BP ($p = .06$, $ES = 1.25$; *likely*). The time spent above the OBLA was significantly shorter in the HRV-G than BP ($p < .05$, $ES = -1.61$; *very likely*), and the time spent in the intensity between the LT and OBLA was tend to shorter in HRV-G than in BP ($p = .48$, $ES = -1.25$; *likely*). In regard to the proportion of time spent in each intensity zone to training duration, the intensity below the LT was tend to greater in HRV-G than in BP ($p = .09$, $ES = 1.33$; *very likely*), and the intensity above the OBLA in HRV-G tend to lower than in the BP ($p = .09$, $ES = -1.45$, *very likely*). The proportion of the intensity between the LT and OBLA was no group different between the groups ($p = .37$, $ES = 0.19$; *unclear*).



Note. W_{max} : maximal aerobic power, W_{LT} : aerobic power at lactate threshold; W_{OBLA} : aerobic power at onset of blood lactate threshold. Blank circle: PRE-value; black circle: POST-value-a: significantly different compared to PRE.

Figure 3. The submaximal and maximal aerobic power before and after experimental period.

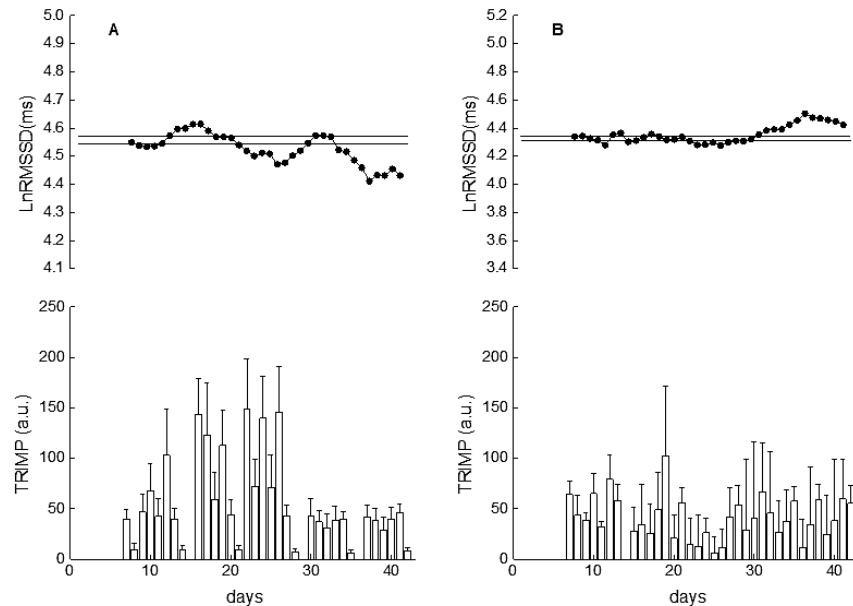
Training-induced changes in maximal and submaximal aerobic power

For the experimental period, submaximal and maximal aerobic power significantly increased (Figure 3). Within-group degree of changes are in HRV-G (W_{LT} : $25 \pm 19\%$, $ES = 1.17$, *likely*; W_{OBLA} : $18 \pm 7\%$, $ES = 1.50$, *very likely*; W_{max} : $15 \pm 5\%$, $ES = 3.40$, *most likely*), in BP (W_{LT} : $14 \pm 14\%$, $ES = 0.40$, *unclear*; W_{OBLA} : $10 \pm 8\%$, $ES = 0.44$, *unclear*; W_{max} : $14 \pm 6\%$, $ES = 2.04$, *very likely*). Additionally, the coefficients of covariance in the relative changes in submaximal and maximal aerobic power was lower in HRV-G group than in BP group (W_{LT} : HRV-G vs. BP, 75% vs. 143%; W_{OBLA} : 38% vs. 121%; W_{max} : 35% vs. 49%).

Training-induced changes in the indices of parasympathetic activity

Figure 4 shows the longitudinal changes in TRIMP and LnRMSSD for each training group throughout the intervention, and Table 2 presents the descriptive data on the indices of cardiac-parasympathetic activity for

the experimental period. No significant change in HRV parameters was found for the experimental period ($p = .56$ to $.92$, $ES = 0.01$ to 0.55 , *unclear*). HFnu was significantly higher ($p < .05$, $ES = 1.54$, *very likely*) and LFnu and LF/HF were significantly lower ($p < .05$, $ES = -1.59$ to -1.89 , *very likely*) in HRV-G than in BP for experimental period.



Note. The time course data are expressed as means of subjects each group. Black circle, 7-day moving average of LnRMSSD; blank bar: daily Training impulse; A: block periodization group, B: heart rate variability-guided training group.

Figure 4. Time course data on LnRMSSD and TRIMP throughout the intervention.

Table 2. Descriptive data on heart rate variability parameters for the intervention period.

	BP			
	PRE	POST	ES	Qualitative inference
RRi (ms)	1140 ± 130	1125 ± 129	-0.46	<i>unclear</i>
LnRMSSD (ms)	4.56 ± 0.47	4.44 ± 0.44	-0.17	<i>unclear</i>
LnRMSSD/RRi (a.u.)×10 ⁻³	4.02 ± 0.18	3.98 ± 0.25	-0.36	<i>unclear</i>
CV _{LnRMSSD} (%)	1.66 ± 1.10	1.74 ± 1.12	-0.04	<i>unclear</i>
LFnu	66.4 ± 7.8	66.7 ± 9.8	0.04	<i>unclear</i>
HFnu	33.9 ± 7.8	33.7 ± 9.4	-0.02	<i>unclear</i>
LF/HF	2.42 ± 0.78	2.66 ± 0.79	0.31	<i>unclear</i>
	HRV-G			
	PRE	POST	ES	Qualitative inference
RRi (ms)	1122 ± 141	1139 ± 144	0.08	<i>unclear</i>
LnRMSSD (ms)	4.43 ± 0.34	4.46 ± 0.38	0.18	<i>unclear</i>
LnRMSSD/RRi (a.u.)×10 ⁻³	3.99 ± 0.23	3.98 ± 0.32	-0.26	<i>unclear</i>
CV _{LnRMSSD} (%)	1.14 ± 0.35	0.94 ± 0.45	-0.50	<i>unclear</i>
LFnu	57.0 ± 10.7	51.1 ± 10.3	-0.56	<i>unclear*</i>
HFnu	43.0 ± 10.7	48.9 ± 10.3	0.56	<i>unclear*</i>
LF/HF	1.99 ± 1.01	1.37 ± 0.59	-0.43	<i>unclear*</i>

Note. Values are expressed as means and SDs. BP: block periodization training group; HRV-G: heart rate variability-guide training group. RRi: R-R interval; LnRMSSD: 7-day moving average of the root mean squared differences of successive RRi transformed by natural logarithm; LnRMSSD/RRi: ration LnRMSSD to RRi; CV_{LnRMSSD}: coefficients of covariance in LnRMSSD. *: significantly main group different compared to BP ($p < .05$).

DISCUSSION

The main findings obtained here were that the HRV-guided training increased the submaximal and maximal aerobic power to the same extent as BP even when strain was lower in HRV-guided training than in BP, and interindividual variation was lower in HRV-guided training than BP, and HRV-guided training enhanced cardiac-parasympathetic activity.

Comparison of the HRV-G training and the regular training in the training-induced changes in the maximal and submaximal aerobic power

In the HRV-G, the relative changes in submaximal and maximal aerobic power were 24.8% for W_{LT} , 18.1% for W_{OBLA} , and 15.0% for W_{max} . In the earlier studies, the relative changes in aerobic power induced by HRV-guided training ranged from 2.8 to 37.6% for aerobic power at the LT level (Javaloyes et al., 2019; Javaloyes et al., 2020; Nuuttila et al., 2017; Vesterinen et al., 2016), from 2.6 to 22.9% for aerobic power at the OBLA level (Javaloyes et al., 2019; Javaloyes et al., 2020; Nuuttila et al., 2017; Schmitt et al., 2018; Vesterinen et al., 2016), and from 5.1 to 10.4% for maximal aerobic power (Javaloyes et al., 2019; Javaloyes et al., 2020; Kiviniemi et al., 2010). The submaximal aerobic power obtained in this study was similar; however, the maximal aerobic power was greater than that reported in previous studies. The greater gain in the maximal aerobic power might be due to differences in the HRV-G prescription, training load, and initial LnRMSSD. Further, aerobic training which combines intensity below the LT with intensity above the OBLA is prescribed in this study. However, previous studies have designed training programs that include moderate intensity (Carrasco-Poyatos et al., 2022; Javaloyes et al., 2019; Javaloyes et al., 2020; Vesterinen et al., 2016). Esteve-Lanao et al. (2007) (Esteve-Lanao et al., 2007) found that for sub-elite runners, the gain in a 10.4-km run was greater in the training below the ventilation threshold (VT) 1 than in the training ranging from VT1 to VT2, when the amount of the training above VT2 was equal between groups. Neal et al. (2013) (Neal et al., 2013) showed that increases in the maximal aerobic power were significantly greater with polarized training combined with low- and high-intensity training than with low- and moderate-intensity training. Aerobic training above moderate intensity evokes sympathetic activity (Chwalbinska-Moneta et al., 1998; Robinson et al., 1966) and delays recovery time (Seiler et al., 2007). In this study, the proportion of time spent below LT-OBLA intensity was similar between the groups, but the proportion of time spent below the LT intensity tended to be greater ($p = .09$, $ES = 1.33$, *very likely*) in HRV-G than in BP. In addition, when the LnRMSSD was within the SWC, they trained continuously at high intermittent aerobic training prescription, which may have allowed them to spend time training at high intensity even during the short training time. When the LnRMSSD was within the individuals SWC, aerobic power was higher within the SWC than without the SWC (DeBlauw et al., 2021). Therefore, in this study, the HRV-guide training where high-intensity training was prescribed during better physiological states and low-intensity training was conducted to promote adequate recovery, may have led to improvements in maximal aerobic power despite the lower training load.

Regarding the initial level of LnRMSSD, individuals with high cardiac-parasympathetic activity exhibit high aerobic adaptations (Buchheit et al., 2010; Hautala et al., 2003). The LnRMSSD (4.43 ± 0.34) value in this study is equivalent to that reported in previous studies (4.20 to 4.61) (Carrasco-Poyatos et al., 2022; Javaloyes et al., 2020; Nuuttila et al., 2017). Furthermore, no group-related differences in LnRMSSD were observed in this study. Therefore, the effect of the initial LnRMSSD on the gain in maximal aerobic power may have been less in this study.

Regarding the training load, TRIMP and strain in the HRV-G was lower than in BP. TRIMP and strain were lower in HRV-G than in the BP because there was no period of intensive high-load training. To optimize aerobic power, intensive training period are necessary (Issurin, 2010; Thomas & Busso, 2005); however,

intensive training may lead to increased training load (volume, monotony, and strain) (Figueiredo et al., 2019), resulting in training maladaptation for some individuals (Meeusen et al., 2013), thereby causing interindividual variation in the magnitude of training effects (Aubry et al., 2014; MORINAGA & TAKAI, 2024). Aubry et al. (2014) (Aubry et al., 2014) found that individuals who positive response to the 3-week intensive training exhibited greater gains in maximal aerobic power after the 2-week tapering than those who responded less or did not respond to the intensive training. The interindividual variation of training effects occurring such intensive training was dependent on the strain obtain from heart rate (MORINAGA & TAKAI, 2024). In this study variation of changes in aerobic powers was lower in HRV-G than BP. The magnitude of the strain depends not only on training volume but also on monotony, and lower monotony reduces strain, which can mitigate these risks (Foster, 1998). In this study, throughout the experimental period, there was no group difference in monotony between HRV-G and BP. Both groups having low monotony may be attributable to the fact that in the BP, intensive training periods and tapering periods were set, whereas in the HRV-G, it could be due to the training prescription at either low or high intensity. Therefore, HRV-training, which consists of both low-intensity and high-intensity components, allows for maintaining low monotony, thereby potentially maximizing aerobic power and reducing the variability of training effects.

The effect of submaximal aerobic power in this study was greater in HRV-G than in BP. HRV-guided training might have a greater impact on submaximal aerobic performance compared to predetermined aerobic training, as observed in recreational (da Silva et al., 2019; Vesterinen et al., 2016), trained (Javaloyes et al., 2019), and well-trained (Javaloyes et al., 2020) subjects. Above moderate-intensity exercise enhances sympathetic activity (Chwalbinska-Moneta et al., 1998; Robinson et al., 1966) and delays the time required for parasympathetic activity to return to resting levels (Seiler et al., 2007). Given that cardiac parasympathetic activity has been observed day to day variation (Carrasco-Poyatos et al., 2022; da Silva et al., 2019; DeBlauw et al., 2021; Kiviniemi et al., 2010; Nuutila et al., 2017; Vesterinen et al., 2016), it is conceivable that even with the same external training load, a decrease in parasympathetic activity and an increase in sympathetic activity may be promoted. Therefore, it is suggested that the control of changes in over-activity of the autonomic nervous system by imposing a training load adapted to the fluctuating parasympathetic activity may affect the improvement of submaximal aerobic powers.

Training-induced changes in the indices of parasympathetic activity

$\ln\text{RMSSD}_{7d}$ did not change before and after the experimental period both groups. Javaloyes et al. (2020) (Javaloyes et al., 2020) demonstrated that while $\ln\text{RMSSD}$ did not change with 8 weeks of aerobic training, it decreased more in BP compared with HRV-guided training. In aerobic training with the block periodization strategy, as the training volume decreased, the indicator of cardiac-parasympathetic activity decreased, whereas sympathetic activity increased, leading to a shift in the valance of parasympathetic and sympathetic activity toward sympathetic dominance (Manzi et al., 2009). Many earlier studies have demonstrated no change in $\ln\text{RMSSD}$ after <8-week of HRV-guided training (Carrasco-Poyatos et al., 2022; Da Silva et al., 2014; Javaloyes et al., 2019; Javaloyes et al., 2020; Nuutila et al., 2017). A 12-week aerobic training program increases the cardiac-parasympathetic activity (Melanson & Freedson, 2001). However, Nuutila et al. (2017) (Nuutila et al., 2017) showed that for an 8-week HRV-G training, RMSSD changed in the last four weeks, although it was unchanged in the first 4 weeks. In this study, the ratio of LF to HF, indicative of the valance of parasympathetic and sympathetic activity, increased in HRV-G and decreased in BP. Additionally, there were an inverted U-shaped relationship between training load and cardiac-parasympathetic activity. Considering these findings, HRV-guided training without moderate-intensity might be a training method that enhances cardiac-parasympathetic activity.

Limitations in this study

This study has some limitations. First, the classification of the participant groups in this study only level 3 based on the criteria defined by De Pauw et al. (2013) (De Pauw et al., 2013). The participants examined in this study were non-high-performing athletes ($W_{\max} < 4.6$ W/kg, < level 3). Aerobic adaptation in high-performing athletes may differ from that in non-athletes (Skinner et al., 2001). Therefore, it is unknown whether the current results apply to elite athletes ($W_{\max} > 4.9$ W/kg, levels 4-5) (De Pauw et al., 2013). Secondly, in this study, the low-intensity training was set at the LT intensity. Therefore, it is possible that the duration of exercise at moderate-intensity was not significantly reduced due to the increased heart rate during low-intensity training. Finally, the sample size of this study was small. Therefore, we used non-parametric analysis and magnitude-based inferences, which enables looking at small changes.

Practical applications

Aerobic training, designed as a predetermined program with BP, has an inter-individual variation in aerobic adaptation (Aubry et al., 2014; Skinner et al., 2001). In fact, the coefficient of variation of the relative change in maximal aerobic power is 49% for BP. The value for HRV-G is 35%. Therefore, HRV-G training showed less interindividual variation in aerobic power adaptation. Furthermore, HRV-G training combining low- and high-intensity, such as polarized training (Stöggl & Sperlich, 2015) decreases the time spent between moderate- and high-intensity training and the strain derived from the internal load. Earlier studies reported the effects of HRV-guided training of more than moderate intensity corresponding to the intensity from the LT to OBLA combined with a rest day in the case of two consecutive days of high-intensity training. In this study, high-intensity intermittent training was conducted when the LnRMSSD values were within the SWC of an individual. This may have resulted in a greater gain in maximal aerobic power.

CONCLUSION

The Heart rate variability-guided training without moderate-intensity training reduces training volume and uniformly enhances maximal and submaximal aerobic power.

AUTHOR CONTRIBUTIONS

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by HM. YT participated in study design, coordinated research activities. The first draft of the manuscript was written by HM and YT commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

ETHICAL APPROVAL

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of the National Institute of Fitness and Sports in Kanoya (No. 11-101).

CONSENT TO PARTICIPATE

Informed consent was obtained from all individual participants included in this study.

CONSENT TO PUBLISH

The authors affirm that human research participants provided informed consent for the publication of the images in Figure 1–4.

DATA AVAILABILITY STATEMENT

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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