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Identifying the technical and tactical characteristics of Olympic medallists in karate

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ABSTRACT

This study primarily aimed to conduct an observational analysis of Olympic finalists' performance to determine the patterns and characteristics of karate at the highest level of competition. Due to the need for a complete analytical system, we can use this study to create useful information about the planning process based on winning strategies. The research is based on an analysis of athletes who go to the final of the Tokyo Olympic Games. Thirty fights in the male competition were analysed. Prevalence, percentage frequency, and nonparametric tests were used (Fisher's exact test, the likelihood ratio test, and Pearson's chi-square test) for data analysis. Quantity indicators showed that male karate athletes tend to use upper limb karate techniques (53.70%) more than lower limb (35.65%) and a combination (upper and lower or lower and upper limb 10.65%). The difference in scoring by two tactical models of attack and counterattack was significant, and 69.2% of the points were scored by attacking. Moreover, the results suggest a predominant scoring technique using the Kisami-Tsuki model has the highest number of attacks. Considering these characteristics can provide important indicators for technical and tactical coaches and physical trainers to design special training conditions for their athletes.

Keywords: Olympic Games, Kumite match, Combat sport, Performance analysis.

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INTRODUCTION

A performance analysis can aid in understanding the nature and complexity of any sport (O'Donoghue, 2010). Therefore, the technical, tactical, physical, and psychological requirements of the sport should be known prior to the development of a training program (Solé, 2015). Combat sports are of acyclic nature because of their highly intense actions and movements (Silva et al., 2011), and an optimum training plan improves athletic performance (Costa, 2013). This analysis provides a more in-depth understanding of the competition, enabling coaches and participants to optimize training, targeting, and understanding of key points to execute their strategy (Smith et al., 2020). Karate has been transformed from traditional Japanese martial arts to a modern fighting sport. The sport was contested for the first time at the 2020 Olympics, and the two events to be contested are kata and kumite (Frigout et al., 2017). Karate is a martial art with continuous technical and tactical phases involving attacking, counterattacking by punching and kicking to score points, and defending (Chaabène et al., 2014; Ashker, 2011). The athlete assesses his opponent during the competition by obtaining points and to win by applying an appropriate and precise strategy. Thus, to be a successful Kumite exponent, the athlete must make quick decisions about making proper offensive and defensive strokes in response to the opponent's actions (World Karate Federation, 2019). We flag that karate competition rules have changed over time. For instance, in 2000 the WKF changed the rules to make karate competitions more dynamic and attractive and to increase safety. Major changes were introduced to the scoring system, the range of permissible techniques was revised and the degree of contact to the head was restricted. In 2009, the scoring system was simplified (Lystad et al.,2020). Kumite competition is normally disputed individually; however, there is a possibility of team competition. In individual competition, athletes are divided according to sex, age, and weight category. The maximum playing time is 3 min (World Karate Federation, 2019). Subsequently, scores are assigned when specific actions are performed. Three points for ippon, when leg techniques touch the opponent's head or sweeping and throwing techniques lead to the fall of the opponent or hitting the opponent on the field; 2 points for waza-ari, when kicks hitting the trunk are performed; and 1 point for yuko, when a single arm punch hits the head or body. Overcontact during an attack is not allowed. Moreover, it is recommended that athletes perform kicks and striking techniques in a controlled manner or stop the toss just before contact with the opponent's target area (World Karate Federation, 2019).

This study aimed to perform a descriptive analysis by observation that can help determine the most relevant trends and characteristics, information regarding the technical offensive action performed, fist or leg. The reaction to the opponent's attacks, which reactions were performed more compared to the other reactions to the opponent's attacks, what was the most successful type of attack (punches, kicks, or combined) gain more points, and the most intense time of the match for the male category in the 2020 Tokyo Olympic Games. In addition to analysing the preference of certain techniques, whether the fists or legs are used, and their effectiveness in Kumite match. The findings of this study are particularly relevant for technicians, coaches, and researchers involved in kumite match.

MATERIALS AND METHODS

Methodology and design

This study was conducted to determine the technical and tactical performance of the gold and silver medallists of the 2020 Tokyo Olympic Games using dartfish analysis technology. All matches in male group in three categories (under 67 kg; under 76 kg and over 76 kg) were analysed. To support this study, the Iran Karate Federation has given the official video and authorised the analysis of all final matches.

Data acquisition and performance measures

The case study items included hand techniques, feet techniques, combination techniques, number of attacks, and number of defensive reactions. Additionally, the techniques were characterised according to good form, enough speed, timing, suitable distance, and power control of the hit to the head and face in order to gain points (World Karate Federation, 2019).

Table 1. Observation tool.

Tactics	
Attack	Direct and indirect attack
Counterattack	Direct response after the end of opponent attack
Blocking	Direct and indirect block
Dodge	Dodge opponent attack
Technique	**Punching techniques**
Upper limb	Kizami-Zuki (punch with forward anterior hand) Gyaku-zuki-jodan and chudan Kizami-gyaku-zuki-jodan Kizami-gyaku-zuki-chudan.
Lower limb	Kicking techniques: Uko-geri (leg kick in lateral direction) Mawashi-geri-jodan (circled exterior leg kick pointed to the head) – Mawashi-geri-chudan (circled exterior leg kick pointed to the body) Ura-mawashi-geri (circled interior leg kick pointed to the head) – Ushiro-geri (direct leg kick from turn in back direction)
Combination	Combination of punching and kicking techniques
Throwing	Grappling technique that involves off-balancing an opponent, and throwing them to the ground
Techniques on head	Techniques movements pointed to head
Techniques on body	Techniques movements pointed to the body

The study observed four types of hand attacks: kizami tsuki (straight punch), Gjaku tsuki (reverse punch), kizami tsuki gjaku tsuki Judan (straight punch and reverse punch to the face), and kizami tsuki gjaku tsuki Chudan (straight punch and reverse punch to the face to the trunk). The five kick technique models, Mavasi geri (roundhouse kick); Ura mavasi geri (inside circular leg); Usiro ura mavasi geri (reverse roundhouse kick); Ushiro geri (back kick); and Kekume geri (lateral leg technique), and the ten combination attack models.

Scoring strategy

During official karate competition, matches are disputed between two competitors under strict rules, but athletes are free to move, kick and punch in defensive and offensive manners. There are several ways to earn points in karate, such as offensive and defensive. Based on the technical and tactical ability, the athlete chooses the right method for each competition according to their opponent. In the offensive method, the athlete attempts to score points with a single direct attack, a double direct attack, or combined attacks. While in the defensive method, the player chooses the best reaction to the opponent's attack. In this method, we can refer to techniques such as a direct counterattack, blocking the opponent's attack, defending, or emptying the opponent's attack and attacking from the player's side. The second method has its own dimensions, and the player must choose the most accurate response in the most accurate time possible compared to the opponent's activity. Sports fight rules in karate set the following values: 1 point (Yuko); 2 points (Waza-ari); and 3 points (Ippon). Ippon is scored for leg kicks to the head and the techniques of throwing, which result in a final fall of the opponent or a final punch. Waza-ari is scored for kicks to the trunk. Finally, Yuko is awarded for single arm punches to the head and body (world karate Federation, 2019).

Data analysis

Video analysis methods using actual data that can be recorded with the ability to analyse slow movements were used to precisely distinguish between techniques. The statistical sample consisted of six karate athletes who reached the finals in the Olympic Games (-67, -75, and +75 categories), and the different techniques used by the silver and gold medallists were evaluated using Dartfish software along with Excel 2015.

Statistical analyses

In order to analyse the data, in addition to using descriptive statistic indicators (prevalence and percentage frequency), nonparametric tests were used (Fisher's exact test, the likelihood ratio test, and Pearson's chi-square test) for data analysis.

RESULTS

Numeral and percent analysis for each one of the technical and tactical factors was conducted in actual combat, and the results are presented in Tables (2,4,6,8,10,12).

Comparison of hand techniques

Table 2 illustrates the difference of the 116 attacks carried out using hand techniques, in 25 instances (21.6%) the athlete succeeded in getting points and in 91 instances (78.4%) failed to get points. Among the four implemented models, kizami tsuki (front hand punch) has the highest score with 15 successful attacks (32.2%) out of 48 executed moves. Furthermore, kizami tsuki (41.4%) was the most used method among four hand technique models in the 116 executed hand techniques.

Table 2. Frequency of hand attacks and success rate.

Hands Technique	Frequency Success				Total	
	Yes		No			
Kizami tsuki	15	32.2 %	33	68.8 %	48	41.4 %
Gjaku tsuki	6	23.1 %	20	76.9 %	26	22.4 %
Kizami tsuki gjaku tsuki Judan	2	6.2 %	30	93.8 %	32	27.6 %
Kizami tsuki gjaku tsuki Chudan	2	20 %	8	80 %	10	8.6 %
Total	25	21.6 %	91	78.4 %	116	100 %

Table 3. Test results of the success rate of hand technique attack.

	Value	df	Sig	Monte Carlo		
				Sig	99% Confidence Interval	
					Lower Bound	Upper Bound
Pearson's Chi-Square	7.152	3	0.047	0.048	0.045	0.056
Likelihood Ratio	8.227	3	0.042	0.047	0.044	0.055
Fisher's Exact Test	7.606			0.046	0.040	0.051
Linear-by-Linear Association	4.758	1	0.029	0.035	0.030	0.040

Table 3 illustrates the difference in the effectiveness of scoring points among the four models is statistically significant, with Fisher's exact test = 7.606, likelihood ratio = 8.227, and Pearson chi-square = 7.152 (p =

.047). Therefore, it can be concluded that among the four manual technique models, the kizami tsuki model has the highest number of attacks and is the most successful model for gaining points.

Comparison of kick techniques

What percentage of the various kick attacks used by the top six athletes in the Olympic games in 30 competitions were scoring attacks? (Table 4).

Table 4. Frequency of kick attacks and success rate.

Kick attack	Frequency of Success				Total	
	Yes		No			
Mavasi geri	8	15.7 %	43	84.3 %	51	66.2 %
Ura mavasi geri	1	7.7 %	12	92.3 %	13	16.9 %
Kekume geri	2	22.2 %	7	77.8 %	9	11.7 %
Usiro ura mavasi geri	1	25 %	3	75 %	4	5.2 %
Ushiro geri	0	0 %	0	0 %	0	0 %
Total	12	15.6 %	65	84.4 %	77	100 %

Of the total attacks, 21.6% of cases succeeded in scoring and 91 cases (78.4%) failed, as seen in Table 4. Out of 77 attacks executed using five-foot techniques, 12 equivalent cases (15.6%) succeeded in scoring and 65 equivalent cases (84.4%) failed. Among the five implemented models, the most used method among the five-foot technique models was Mavasi geri (66.2% of 77 executed movements).

Table 5 details the difference in the success of scoring among the five models, p = .756, Fisher's Exact test = 1.692, likelihood ratio = 1.242, Pearson's chi-square = 1.187, is not statistically significant. Therefore, it can be concluded that among the five-foot technique models, Mavasi geri was the most used method of attack by the six athletes; However, there was no significant difference in the number of attacks leading to scoring using these techniques.

Table 5. Success rates of the kick attack techniques.

	Value	df	Sig	Monte Carlo		
				Sig	99% Confidence Interval	
					Lower Bound	Upper Bound
Pearson's Chi-Square	1.187	3	0.756	0.774	0.763	0.785
Likelihood Ratio	1.242	3	0.743	0.882	0.874	0.890
Fisher's Exact Test	1.692			0.639	0.627	0.651
Linear-by-Linear Association	0.207	1	0.649	0.730	0.718	0.741

Combination techniques

We examined the combined attacks executed by the winning players in the Olympic tournament (Table 6).

Combination technique (Table 6), 7 instances (30.4%) succeeded in scoring and 16 cases (69.6%) failed. Among the 10 implemented models, Throwing & tsuki was had the highest number with 3 successful attacks (60% out of five executed moves), and was the most used method among the 10 combination technique models (21.74% of 23 executed moves).

Table 7 illustrates the difference in the success of scoring among the models, p = .748, Fisher's Exact test = 6.172, likelihood ratio = 7.674, Pearson's chi-square = 5.918, is not statistically significant. Therefore, it can be concluded that among the 10 combination technique models, throwing & tsuki had the highest score with three successful performances; however, the number of attacks leading to scoring using these techniques did not have a significant difference.

Table 6. Frequency of combination attacks and success rate.

Hands T	**Frequency Success**				**Total**	
	Yes		No			
Kizami tsuki gjaku tsuki Chudan & Judan	1	50%	1	50%	2	8.69%
Mavasi geri & Ura mavasi geri	0	0%	2	100%	2	8.69%
Double Mavasi geri	1	50%	1	50%	2	8.69%
Gjaku tsuki & Mavasi geri	0	0%	1	100%	1	4.34%
Kizami tsuki & Ura mavasi geri	0	50%	1	50%	1	4.34%
Mavasi geri & Gjaku tsuki	1	33.3%	2	66.7%	3	13.04%
Kizami tsuki gjaku tsuki Judan & Mavasi geri	0	0%	1	100%	1	4.34%
Kizami tsuki gjaku tsuki Judan & gjaku tsuki Judan	1	25%	3	75%	4	17.39%
Kizami tsuki & Mavasi geri	0	0%	2	100%	2	8.69%
Throwing& tsuki	3	60%	2	40%	5	21.74%
Total	7	30.4%	16	69.6%	23	100%

Table 7. Success rate of combination technique attacks.

	Value	**df**	**Sig**	**Monte Carlo**		
				Sig	99% Confidence Interval	
					Lower Bound	Upper Bound
Pearson's Chi-Square	5.918	9	0.748	0.906	0.898	0.913
Likelihood Ratio	7.674	9	0.567	0.914	0.906	0.921
Fisher's Exact Test	6.172			0.948	0.942	0.953
Linear-by-Linear Association	0.264	1	0.607	0.618	0.605	0.630

Comparison of hand, kick, and combination attacks

The three different attack models were examined and checked their frequency and their success in scoring points.

As seen in Table 8, of the 216 executed attacks, 49 cases (22.69%) succeeded in scoring and 167 cases (77.31%) failed. Among the three types of executed attacks, hand attacks had the highest frequency (53.70% of the 216 executed attacks).

Table 8. Frequencies of hand, kick, and combination attacks and success rate.

Type of Attack	**Frequency Success**				**Total**	
	Yes		No			
Hands	30	25.86%	86	74.14%	116	53.70%
Kicks	12	15.58%	66	85.72%	77	35.65%
Combination	7	30.43%	16	69.57%	23	10.65%
Total	49	22.69%	167	77.31%	216	100%

Models shown in Table 9, is not statistically significant (p = .16, Fisher's Exact test = 3.827, likelihood ratio = 3.794, Pearson's chi-square = 3.669). Therefore, it can be concluded that among the three implemented models, although combination attack had the highest score with 30.43% successful attacks, the number of attacks leading to scoring using these three models did not have a significant difference.

Table 9. Success rate of hand, kick, and combination technique attacks.

	Value	df	Sig	Monte Carlo		
				Sig	99% Confidence Interval	
					Lower Bound	Upper Bound
Pearson's Chi-Square	3.669	2	0.16	0.163	0.153	0.172
Likelihood Ratio	3.794	2	0.15	0.156	0.146	0.165
Fisher's Exact Test	3.827			0.14	0.131	0.149
Linear-by-Linear Association	0.208	1	0.649	0.721	0.71	0.733

Comparison of the frequency of the attacks at different time points

Out of the 216 executed attacks (Table 10), 49 cases (22.7%) succeeded in scoring and 167 cases (77.3%) failed. Among the three time points, the third minute had the highest frequency of attacks with 98 attacks (45.4% of 216 executed attacks).

Table 10. Frequency of the attacks at different time points.

Time	Frequency Success				Total	
	Yes		No			
First Minute	12	24.00%	38	76.00%	50	23.1%
Second 1 minute	14	20.59%	54	79.41%	68	31.5%
Third 1 minute	23	23.47%	75	76.53%	98	45.4%
Total	49	22.7%	167	77.3%	216	100%

The difference in the frequency of attacks (Table 11) in three times points is not statistically significant (p = .881, Fisher's Exact test = 0.281, likelihood ratio = 0.257, Pearson's chi-square = 0.254). Therefore, it can be concluded that the third minute had the highest number of executed attacks with 98 attacks among the three different time points. However, the number of attacks leading to scoring during these three time points did not have a significant difference.

Table 11. Success rate of attacks at different time points.

	Value	df	Sig	Monte Carlo		
				Sig	99% Confidence Interval	
					Lower Bound	Upper Bound
Pearson's Chi-Square	0.254	2	0.881	0.919	0.912	0.926
Likelihood Ratio	0.257	2	0.879	0.919	0.912	0.926
Fisher's Exact Test	0.281			0.898	0.890	0.906
Linear-by-Linear Association	0.001	1	0.982	0.999	0.995	0.999

Reaction of the six players to the opponent's attacks

The reaction of the six athletes to the opponents' attacks in the Olympic competition showed that dodging (99 times) was the most used defensive reaction to the opponent's attacks, and defence and attack (2 times) was the least used reaction of the finalists to the attacks.

As seen in Table 12, out of 214 reactions, the most frequent reaction was dodging (99 cases). The difference in the type of reaction is statistically significant (*p* = .001, chi-square = 228.64).

Table 12. Frequency of the defensive reactions.

Reaction to opponent attack	Observed N	Expected N	Chi-Square	df	Sig
Dodge	99	6.30	64.228	6	.001
Dodge & attack	50	6.30			
De-ai	23	6.30			
De-asshi	3	6.30			
Defence	20	6.30			
Defence and attack	2	6.30			
No reaction	17	6.30			
Total	214				

Attack target

Out of 261 attacks, 156 cases (72%) were attacks to the face and 60 cases (28%) were attacks to the trunk (Table 13). The difference in the attack target was statistically significant (*p* = .001, x^2= 42.57). Therefore, it can be concluded that between the two targets, the face was the most affected area with 72% of the attacks being targeted to the face.

Table 13. Comparing the two attack target areas.

Attack target	Frequency	Precent	Chi-Square	df	Sig
Face	156	72%	42.57	1	.001
Trunk	60	28%			
Total	216				

Tactics

Out of 104 points earned, in 72 cases (69.2%) the points were obtained through attacking and in 32 cases (30.8%) they were obtained through a counterattack (Table 14). The difference in scoring using both tactics is statistically significant (*p* = .001, chi-square = 15.39). Therefore, it can be concluded that among the two types of scoring tactics, attacking was the most successful tactic for scoring.

Table 14. Comparison of the two tactics in scoring points.

Score tactics	Frequency	Precent	Chi-Square	df	Sig
Attack	72	69.2%	15.39	1	.001
Counterattack	32	30.8%			
Total	104				

DISCUSSION

This study, different attack models were investigated: single attack (hand and kick attacks) and combined attacks (punch and kicks or kick and punches), the frequency and percentage of successful attacks, the most hit area of the body, the highest scoring time point in the match, and the intensity of the time in terms of the frequency of attacks, and the most performed reaction to the opponent's attacks. Several studies on performance analysis in combat sports have found that successful athletes tend to use more strategy while attacking compared to unsuccessful athletes. Previous research on kickboxing athletes found that successful athletes more often using attacking techniques, such as a hook punch and double punch, and blocking techniques attacks compared to unsuccessful athletes (Ouergui et al., 2013). This study showed that 6 finalist athletes were able to score more by attacking compared to that while performing a counterattack. However, that does not necessarily mean that the athlete who attacks more in each game will win the game but means that karate attacks need more accuracy. Moreover, if the 104 points obtained by the six finalists are examined, it can be seen that 72 points (69.2%) were obtained by attacking and only 32 points (30.8%**)** were obtained by counterattacks. This indicates the superiority of the six finalists in being aggressive and in choosing the right technique at the right time. This agrees with (Koropanovski & Jovanovic, 2008) who reported that the achieved score by attack was (52.54%) but counterattack was (23.55%). The findings demonstrated that upper limb techniques (53.70%) were used more than lower limb (35.65%) and combination techniques (10.65%). These results are in accordance with the those of the study conducted by (Helmi Chaabene et al., 2014) who demonstrated that upper-limb techniques (76.19%) are used more frequently that lower-limb techniques (23.80%) in Karate. Koropanovski and Jovanovic (2008) demonstrated that punches have a higher frequency (89.09%) compared to kicks (8.36%). The study conducted in 2020 reported that out of 602 attacks, 422 attacks (70.1%) were made using hands and 180 attacks (29.9%) were made using legs , which is agreement with the results of previous studies (Tabben et al., 2018; Laird & McLeod, 2009). The lower frequency kicking techniques may be explained by the longer lane and time, as well as the time it takes to perform them in relation to punches (Mudric, 2001). In this study, among the four hand techniques the Kisami-tsuki represented 41.4% of the upper-limb attack techniques and was the most frequently used upper limb technique. While Kisami-tsuki & giaku tsuki chudan with 8.6% was the least used technique. These data agree with those of previous studies (Chaabene et al., 2014; Jovanovic & Milosevic, 1992; Alinaghipour & Zareian, 2020) which suggested the predominance of the kizamazuki upper-limb technique. Kizami tsuki was the most predominantly used technique to score, with 32.2% of the points received by the six athletes were gained using this technique, which agrees with the results obtained by a previous study (Alinaghipour & Zareian, 2020) that found that the kizami tsuki technique as the most frequently used scoring technique. The Kizami tsuki punch has the shortest time required to perform compared to the other techniques and requires the shortest line to beat opponents. The shortest time of performing is necessary; the punch gjaku tsuki is 150 ms and kizami tsuki 110 ms (Jovanovic & Milosevic, 1992). However, it is important to emphasize that the data were obtained in a laboratory when the athletes performed the techniques themselves. The mawashi geri kick technique with a frequency of 66.2% was the most used technique among five kick attack models, which agrees with the results obtained by previous studies (Koropanovski & Jovanovic, 2008; Laird & McLeod, 2009; Romanovitch, 2020) that found the mawasi geri technique as the most applicable technique.

The study found that throwing & tsuki had the highest frequency among the 10 combination techniques used by the six fighters with a frequency of 21.74%. Moreover, it was most successful combination technique.

Regarding the target attack areas (the head or trunk), out of the 216 completed attacks by the six fighters, 72% were made to the opponents face and only 28% towards the opponent's trunk. The head and face are parts that are most likely to be affected by attacks compared to the trunk. These results agree with previous study (Reza, S et al., 2021), which showed that 76.7% of the attacks were to the head and 23.3% were to the trunk. However, they disagree with the results of a study by Laird & McLeod (2009) who showed that 54% of the attacks were targeted to the opponent's trunk and only 35% were to the opponent's face and head, while 11% were to the penalty area. The reason for fewer attacks on the opponent's body can be because this area of the body is guarded the opponent's hands (guard), or that the athlete needs to lower his height and rotate their waist and shoulder more when performing an attack on this area of the body, making it more difficult and riskier. Attacks to this area of body compared to those at the head and face, require more skill and more exercise.

Different times had different intensities. The third minute, with 45.4% of attacks, was the highest intensity time in the competition, while the first minute, with 23.1% attacks, was the lowest intensity. These results agree with those of our previous study, in the third one minute with 46.7% attack was the most intense duration in world championships and world karate league competitions in 2018 and 2019, and the first minute with 18.4% attacks was the least intense duration (Reza, S et al., 2021). This indicates that in the first minute, the players are getting to know each other and are finding the right target to attack and are strategizing the exact time to execute it. Additionally, in the last minute, if the player is tied with or losing to their opponent, he will use all his ability to win the game, and thus, tends to attack more.

Among the reactions of the six fighters to the 214 attacks made by the opponent, dodging was most frequent reaction, which was performed 99 times by the six athletes in the Olympic Games, followed by dodge and attack, while defend and attack was the least frequent reaction by the players in the Olympic Games. Our previous study showed that counterattack and dodging were the most used reactions by world karate champions during competitions. Additionally, defence and attack had the least alternation among the different reactions, which necessitates a separate study.

CONCLUSION

The findings of this study are particularly relevant for karate technicians, researchers, coaches, and professional athletes. In summary, karate athletes tend to use upper-limb techniques far more than lower-limb techniques. In particular, the difference in the points scored using the two tactical models of attack and counterattack was significant and 69.2% of the points were scored by attacking.

The main conclusions drawn from the video analysis indicate that there is a significant difference in the frequency of the techniques used to score in competitive karate competitions. Furthermore, the results suggest a clearly predominant scoring technique. The Kisami-tsuki model was used to make the highest number of attacks and is the most successful model for scoring points because it has the fastest execution time. The most frequent reaction was dodging, which was performed 99 times and the difference in the reaction types is statistically significant. Finally, we believe that the results of this observational study will assist karate coaches to further their knowledge on technical and tactical performance in karate competitions. Especially that related to the use and efficiency of various attack techniques and tactics.

Limitations and future research lines

With respect to the limitations of this study, the extent to which outcomes were generalized or externally valid was based only on the six finalists (Olympic athletes). Other studies should consider expanding to and analysing a larger sample-size to identify the extracted models. Further studies that focus on the performance of athletes at various levels of competition, consider the match result, and include more items to provide more data are required to validate the results of this study.

AUTHOR CONTRIBUTIONS

Conceptualization, R.S., and D.Z. Methodology, R.S., and D.Z. Formal analysis, R.X.F. Data curation, R.S., and D. Z. Writing – original draft preparation, R.S. and D.A. Writing – review and editing, D.A., M.T and P.I.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available upon request to the corresponding author.

REFERENCES

Alinaghipour, M.; Zareian, E. 2020. Scoring Techniques in Karate Kumite: The Scoring Techniques in the Final Competitions of the Karate World Championships. Ann Appl Sport Sci, 8(2), e760.

Ashker, S. E. 2011.Technical and tactical aspects that differentiate winning and losing performances in boxing. International Journal of Performance Analysis in Sport, 11(2), 356-364. https://doi.org/10.1080/24748668.2011.11868555

Chaabène, H.; Franchini, E.; Miarka, B.' Selmi, M. A.; Mkaouer, B.; Chamari, K. 2014. Time-motion analysis and physiological responses to karate official combat sessions: Is there a difference between winners and defeated karatekas. International Journal of Sports Physiology and Performance, 9(2), 302-308. https://doi.org/10.1123/ijspp.2012-0353

Costa, I. A. 2013. The planning models of sports training in the 20th century (Spanish language). Revista Electrónica de Ciencias Aplicadas Al Deporte, 6(22), 1-8.

Frigout, J.; Laporte, R.; Lepresle, A. 2017. Modelling and sporting performance in karate. Journal of Sports Science, 5, 332-339. https://doi.org/10.17265/2332-7839/2017.06.005

Hill-Haas, SV.; Dawson, B.; Impellizzeri, FM.; Coutts, AJ. 2011. Physiology of small-sided games training in football: a systematic review. Sports Med, 41(3):199-220. https://doi.org/10.2165/11539740-000000000-00000

Jovanovic, S.; Milosevic, M. 1992. Time structure of interception, defence, and counterattack at karate masters [in Serbian]. Phys Cult Belgrade, 3, 213-217.

Jovanovic, S.; Mudric, R. 2003. Analysis of rule changes in judging in karate from the aspect of frequency of pointing techniques. Collection of works Science and Karate sport, Karate Federation of Vojvodina, Novi Sad. (In Serbian).

Jukić, J.; Čavala, M.; Katić, R.; Zagorac, N.; Blažević, S. 2017. Morphological, motor, and technical determinants of fighting efficiency in Croatian cadet karate athletes. Journal of Combat Sports and Martial Arts, 8(2), 127-134. https://doi.org/10.5604/01.3001.0010.8722

Keith, J.; Dapena, J. 2008. A comparison of the reverse and power punches in oriental martial arts. Journal of Sports Sciences, 26: 189-196. https://doi.org/10.1080/02640410701429816

Koropanovski, N.; Jovanovic, S. 2008. Characteristics of pointing actions of top male competitors in karate at world and European level. Brazilian Journal of Bio motricity, ISSN: 1981-6324.

Koropanovski, N.; Jovanovic, S. 2007. Model characteristics of combat in elite male karate competitors. Serbian J Sport Sci ,1(3), 97-115.

Laird, P.; McLeod, K. 2009. Notational analysis of scoring technique in competitive men's karate. Int J Perform Anal Sport, 9(2), 171-187. https://doi.org/10.1080/24748668.2009.11868475

Lystad, RP; Augustovičová, D; Harris G. 2020. Epidemiology of injuries in Olympic-style karate competitions: systematic review and meta-analysis.British Journal of Sports Medicine ,54:976-983. https://doi.org/10.1136/bjsports-2020-101990

Mudric, R. 2001. Model of time parameter of attack in karate. Security, Belgrade, 1, 91-116 (in Serbian). https://doi.org/10.1016/S1361-3723(01)00701-1

O'Donoghue, P. 2010. Research methods for sports performance analysis. London: Routledge. Routledge. https://doi.org/10.4324/9780203878309

Ouergui, I.; Hssin, N.; Franchini, E.; Gmada, N.; Bouhlel, E. 2013. Technical and tactical analysis of high-level kickboxing matches. International Journal of Performance Analysis in Sport, 13(2), 294-309. https://doi.org/10.1080/24748668.2013.11868649

Reza, S.; Yaping, Z.; Siavash, Kh.; Dominique, S.; Ahad, A.; Qu, Y. 2021. Identifying Keys to Win in the World Karate Championship. Ann Appl Sport Sci, 9(2), e936. e-ISSN: 2322-4479. https://doi.org/10.52547/aassjournal.936

Romanovitch, M. 2020. Tactical and technical performance analysis of the male 65 KG category at the Brazilian. Shotokan karate championship. J Phys Educ, 31, e3106. https://doi.org/10.4025/jphyseduc.v31i1.3106

Silva, J. J.; Del Vecchio, F.; Picanço, L.; Takito, M. Y.; Franchini, E. 2011. Time-Motion analysis in MuayThai and Kick- Boxing amateur matches. Journal of Human Sport & Exercise, 6(3), 490-496. https://doi.org/10.4100/jhse.2011.63.02

Smith, M.S.; Cotterill S.T.; &Brown, H. 2020. An interpretative phenomenological analysis of performance influencing factors within the practice environment. Journal of Physical Education and Sport, 20(4). https://doi.org/10.1123/tsp.2020-0021

Solé, J. 2015. Sports training theory (Spanish WKF) New kata and kumite rules [version 8.0; online].

Tabben, M.; Bianca, M.; Karim, Ch.; Ralph, B. 2018. Decisive Moment: A Metric to Determine Success in Elite Karate Bouts. Int J Sports Physiol Perform, 1, 13(8), 1000-1004. https://doi.org/10.1123/ijspp.2017-0526

World Karate Federation. 2019. Karate competition rules.

ORIGINAL ARTICLE

Examining social support and self-esteem in high-performance sportswomen in Spain

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ABSTRACT

The purpose of this study was to determine whether perceived social support is related to self-esteem and the type of sport performed by elite female athletes. 243 Spanish elite female athletes completed the Multidimensional Scale of Perceived Social Support. The results show that the greatest social support for high-performance sportswomen is family. The social support of the family and the group of friends has an impact on their self-esteem. Athletes who practice team sports versus those who practice individual sports have higher self-esteem and perceive friends as their main social support. In addition, family social support predicts self-esteem.
Keywords: Sport, Woman performance, Self-esteem, Social support.

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INTRODUCTION

The fact that athletes are under constant pressure and stress suggests that they require an important social support network to mitigate the effect of the continuous demands to which they are subjected.

Therefore, the concept of athletes' social support has attracted increasing interest in the last decade, but nevertheless there are few studies, especially in the female collective, and existing studies have usually focused on the benefits of support (Freeman & Rees, 2008; Poucher et al., 2018) or on the analysis of the perspectives of athletes or coaches separately (Thelwell et al., 2017).

The concept of social support is multidimensional (Holt & Hoar, 2006). Social support is generally understood as the emotional, informational, or practical help that an athlete receives from a person who is affectively close to him/her and who is available when needed (Thoits, 2010). Researchers have highlighted the importance of social support for physical and mental health, subjective well-being, coping, and stress management in people of different ages (Cohen et al., 2000; Goodwin et al., 2004; Nurullah, 2012; Schwarzer & Buchwald, 2004). In the field of sport psychology, social support is an external resource that helps athletes cope better with stress (Katagami & Tsuchiya, 2016). And, in some studies it is evident that athletes' perceptions of parental support are related to their sport performance mediated by self-esteem (Rouquette et al., 2021). In Gabana et al. (2017) study conducted with Olympic athletes and their coaches note that the provision of support is personally and professionally rewarding and the athletes appeared highly dependent on their support providers.

Self-esteem is revealed as a protective factor to avoid situations of anger and stress (Muñoz-Villena et al., 2020). In sports, self-esteem does not seem to be improved by having a social support network (Pedrosa et al., 2012) but by the very benefits generated by a continued sports practice (Coatsworth & Conroy, 2006; Levy & Ebbeck, 2005; Warburton, & Bredin, 2017). Parental social support and attachment have a significant positive effect on female athletes' self-esteem (Kang et al., 2015; Mastrogianni et al., 2020). And, Park et al. (2020) note, referring to table tennis athletes, that social support indirectly affects self-esteem. Female athletes are more likely to report high self-esteem than those who do not engage in sport activity (Galante & Ward, 2017).

Therefore, the objective of this study was to determine whether perceived social support is related to self-esteem and the type of sport performed by elite female athletes.

METHOD

Participants

The investigation has been developed by means of a non-probabilistic purposive sampling method with a sample of 243 Spanish elite female athletes in different individual and collective sports with a mean age of 23.89 years (min. 15; max. 52). A cross-sectional observational study was carried out, and the selection of the group was deliberate. The inclusion and exclusion criteria for the group of respondents were verified by survey questions on the presence or absence of the indicators listed below. An elite athlete was considered an elite athlete: if she competes in the first national league or has participated in the national championship. Informed consent was obtained from the participants.

Instrument
The instrument used for the assessment of perceived social support is the Multidimensional Scale of Perceived Social Support –MSPSS (Zimet et al., 1988; Zimet et al., 1990) adapted to Spanish by Trejos-Herrera et al. (2018). It is a 12-item Likert-type scale with 7 response alternatives that measures three factors: family members (items 3, 4, 8 and 11), friends (items 6, 7, 9) and 12), and significant others (items 1, 2, 5 and 10). The results can be calculated in total for the whole test or for each of the scales separately. The higher the scores obtained, the higher the level of social support you have. The scale shows a reliability by Cronbach's α coefficient of 0.84 similar to other studies (Dambi et al., 2018).

To measure self-esteem, the Rosenberg 10-item scale was used, which aims to measure feelings of self-worth and self-esteem (Rosemberg, 1965). Five of the items of the scale are formulated positively and the other five negatively to control for the acquiescence effect; the positive ones are scored from 1 to 4 and the negative ones from 4 to 1 (Martín-Albo et al., 2007). Chronbach's Alpha was also used to measure its reliability, giving a result of α = .871, which implies high reliability (George & Mallery, 2003; Gliem & Gliem, 2003). For the interpretation of the results, the following classification was followed: less than 25: low self-esteem; between 26-29 medium self-esteem and >30-40 high self-esteem.

Procedure
The basic strategy of application in this research consisted of sending the questionnaire to the participants by mail, stating the anonymous and free participation, and the confidentiality of the information. The study was conducted according to the ethical standards established by the Declaration of Helsinki and in agreement with the recommendations of EEC Good Clinical Practice and with the Spanish legislation in force governing research.

Statistical analysis
Statistical analyses were performed with the SPSS v. 23 statistical software (IBM Corp., 2012). Descriptive data analysis was conducted by calculating mean scores and standard deviation. The normality and homogeneity of the variables were calculated. A study of the association between self-esteem and social support was carried out, for which a Spearman correlational test was performed. An ANOVA was performed for the analysis between social support and self-esteem and a T-Student for independent samples for social support and type of sport. The Bonferroni test is used to find out between which categories the differences occur. The significance level for all analyses was $p < .05$ (Sijtsma, 2009).

RESULTS

Most of the female athletes practice futsal (27.16%) and rowing (25.92%). They are followed by rugby (11.52%), handball (9.05%), volleyball (7.41%) and figure skating (5.76%). And to a lesser Football (3.29%), rhythmic gymnastics (3.29%) and basketball (3.29%). Lastly, e-spots (1.65%) and aesthetic gymnastics (1.65%).

The mean age at which women who reach the sports elite start their sports career is 11.84 years. Their self-esteem has a mean of 28.87 and their greatest social support is family (= 24.37). To statistically evaluate the strength of the relationship between self-esteem and perceived social support, a correlation analysis was performed (rho-Spearman correlation coefficient).

Age correlates, although very low, with the level of social support (r = .137) and self-esteem (r = .266) and self-esteem correlates with social support (r = .319), especially with family social support (r = .282) and that of friends (r = .188). As expected, the factors of family and friends' social support correlate with the social support variable, but not with social support from other people. In addition, there is a positive correlation between family support and support from friends (r = .431) and also with respect to support from other people (r = .170). These are, in any case, low values.

Table 1. Descriptive data and correlations between dependent and independent variables.

		M	SD	Age	Career age	Social support	Sources of social support		
							MSPSS F	MSPSS Fr	MSPSS P
Career age	r	11.84	5.41	.423**					
	Sig.			< .001					
Social support	r	20.18	4.01	.137*	-.177**				
	Sig.			.033	.006				
MSPSSF	r	22.37	5.86	.074	-.114	.760**			
	Sig.			.253	.076	< .001			
MSPSSFr	r	24.22	4.14	.122	.037	.464**	.431**		
	Sig.			.058	.570	< .001	< .001		
MSPSSP	r	24.17	6.23	.068	-.094	.120	.170**	.164*	
	Sig.			.293	.144	.061	.008	.010	
Self-Esteem	r	28.87	5.48	.266**	.020	.319**	.282**	.188**	.082
	Sig.			< .001	.753	< .001	< .001	.003	.204

Note. Age: Current age; Career age = Age at the beginning of the sport career; MSPSSF = MSPSS FAMILY¸ MSPSSFr = MSPSS FRIENDS; MSPSSP = MSPSS PEOPLE.

Table 2. Differences between means of social support as a function of grouped self-esteem level.

Variable	Self-Steam	N	Mean	SD	F	sig	Bonferroni
Social support	Low	73	19.28	3.874			
	Medium	77	19.25	4.359			Low-high = .001
	High	93	21.68	3.369	11.21	< .001	Medium-high = .0001
	Total	243	20.19	4.016			
MSPSS Family	Low	73	21.32	6.456			
	Medium	77	21	5.902	9.051	< .001	Low-high = .002
	High	93	24.33	4.773			Medium-high = .001
	Total	243	22.37	5.867			
MSPSS Friends	Low	73	23.78	4.243			
	Medium	77	23.66	4.514	2.938	.045	Low-high = .012
	High	93	25.03	3.63			Medium-high = .001
	Total	243	24.22	4.145			

Table 3. Differences between the means of social support according to the type of individual or collective sport.

Variable	Type of sport	N	Mean	t	sig	ES
Social support	Individual	93	19.1	-3.412	.001	-1.769
	Collective	150	20.87			
Friends	Individual	93	23.46	-2.269	.024	-1.23
	Collective	150	24.69			
Self-Esteem	Individual	93	27.52	-3.085	.002	-2.197
	Collective	150	29.71			

Note. ES: Effect size.

As we can see, social support is greater when self-esteem is also high, especially when the support is derived from the family. However, there are no differences in terms of self-esteem in the case of support from other people. (F = .105; Sig. = .900).

Social support varies according to the source. Social support is greater in group sports, when there is support from the group of friends. Self-esteem is higher in the group of athletes who practice team sports. And there is no difference according to the type of sport, neither in family support (t = -1.567; Sig = .118) nor with respect to the support of other people (t = -1.567; Sig = .118).

DISCUSSION AND CONCLUSIONS

In this study, focused on women who practice high-level sport, it was found that their greatest social support is their family, and they perceive that this support increases with age. The analysis of the results showed that the social support perceived from family and friends correlates (with low values) with the perception of self-esteem in elite athletes.

Studies indicate that there are many benefits to the athlete derived from social support, however, it appears that this support varies depending on the source (Cranmer & Sollitto, 2015; Hatteberg, 2021) and context (Brown et al., 2018). Those athletes who perceive greater family support also perceive this support from the peer group and others. Thus, it appears that athletes who feel supported do so from all sources of support and those who do not feel supported have a tendency to feel no source of support. However, it appears that high levels of support are needed for this social support to influence performance (Poucher et al., 2018).

In relation to self-esteem, we can conclude that when self-esteem is high, there is greater social support from family and friends. Self-esteem is not influenced by the support of other people. Therefore, it seems that self-esteem does improve with the social support network, but it is necessary to determine with what type of sources it improves (Galante & Ward, 2017; Pedrosa et al., 2012; Park et al., 2020). In fact, participating in a competitive sport can improve the self-esteem of adolescent athletes and it is also likely that this engagement strengthens athletes' relationships with their family (Kang et al., 2015; Mastrogianni et al., 2020; Rouquette et al., 2021).

Women who practice team sports feel greater social support from their group of friends and self-esteem is also higher in this group. Curiously, there is no difference depending on the type of sport with respect to family support.

We can conclude that there is a relationship between social support from friends and family with self-esteem, especially in team sports. Therefore, we consider that it is necessary to care for the self-esteem of athletes in demanding sports environments, especially in individual sports, through prevention programs that include psychological resources (such as talking regularly with children about their emotions and needs, helping them to identify the abilities they can modify and those they cannot, considering mistakes as an opportunity for learning, setting plausible goals, avoiding negative phrases or sentences) and social resources so that athletes perceive the necessary social support to avoid situations of stress and anxiety.

The results of this research should be treated with caution. Further research on the association between the level of self-esteem and social support is needed to understand how support providers (primarily family, friends and coaches) can foster their own personal support relationships and whether high levels of interpersonal dependence are needed to achieve athletic success.

AUTHOR CONTRIBUTIONS

Iago Portela-Pino: conceptualization and design of the study; data analysis and writing of results; writing of the manuscript. Millán Brea Castro: data collection and drafting of the manuscript. Myriam Alvariñas-Villaverde: drafting the manuscript, revising and editing.

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REFERENCES

Brown, C. J., Webb, T. L., Robinson, M. A., & Cotgreave, R. (2018). Athletes' experiences of social support during their transition out of elite sport: An interpretive phenomenological analysis. Psychology of Sport and Exercise, 36, 71-80. https://doi.org/10.1016/j.psychsport.2018.01.003

Coatsworth, J.D., Conroy, D.E. (2006). Enhancing the self-esteem of youth swimmers through coach training: Gender and age effects, Psychology of Sport and Exercise, 7, 173-192. https://doi.org/10.1016/j.psychsport.2005.08.005

Cohen, S., Gottlieb, B., & Underwood, L. (2000). Social relationships and health. In S. Cohen, L. Underwood, & B. Gottlieb (Eds.), Measuring and intervening in social support (pp. 3-25). Oxford University Press. https://doi.org/10.1093/med:psych/9780195126709.003.0001

Cranmer, G. A., & Sollitto, M. (2015). Sport support: Received social support as a predictor of athlete satisfaction. Communication Research Reports, 32, 252-264. https://doi.org/10.1080/08824096.2015.1052900

Dambi, J. M., Corten, L., Chiwaridzo, M., Jack, H., Mlambo, T., & Jelsma, J. A. (2018) systematic review of the psychometric properties of the cross-cultural translations and adaptations of the Multidimensional Perceived Social Support Scale (MSPSS). Health Qual Life Outcomes, 16(1), 80. https://doi.org/10.1186/s12955-018-0912-0

Freeman, P., & Rees, T. (2008). The effects of perceived and received support on objective performance outcomes. European Journal of Sport Science, 8, 359-368. https://doi.org/10.1080/17461390802261439

Gabana, N. T., Steinfeldt, J. A., Wong, Y. J., & Chung, Y. B. (2017). Gratitude, burnout, and sport satisfaction among college student-athletes: The mediating role of perceived social support. Journal of Clinical Sport Psychology, 11(1), 14-33. https://doi.org/10.1123/jcsp.2016-0011

Galante, M., Ward, R.M. (2017). Female student leaders: An examination of transformational leadership, athletics, and self-esteem. Personality and Individual Differences, 106, 157-162. https://doi.org/10.1016/j.paid.2016.11.017

George, D., & Mallery, P. (2003). SPSS for Windows step by step: A simple guide and reference, 11.0 update. Allyn & Bacon.

Gliem, J., & Gliem, R. (2003). Calculating, interpreting, and reporting Cronbach's Alpha Reliability Coefficient for Likert-type scales. Midwest Research-to-Practice Conference in Adult, Continuing, and Community Education.

Goodwin, R., Costa, P., & Adonu, J. (2004). Social support and its consequences: "Positive" and "deficiency" values and their implications for support and self-esteem. British Journal of Social Psychology, 43, 465-474. https://doi.org/10.1348/0144666042038006

Hatteberg, S.J. (2021)A Tale of Many Sources: The Perceived Benefits of Significant Other, Similar Other, and Significant and Similar Other Social Support. Sociological Perspectives, 64(1), 37-57. https://doi.org/10.1177/0731121420908885

Holt, N. L., & Hoar, S. D. (2006). The multidimensional construct of social support. In S. Hanton & S. D. Mellalieu (Eds.), Literature reviews in sport psychology (pp. 199-225). Nova.

Kang, S., Jeon, H., Kwon, S., Park, S. (2015)Parental attachment as a mediator between parental social support and self-esteem as perceived by Korean sports middle and high school athletes. Perceptual and Motor Skills, 120(1), 288-303. https://doi.org/10.2466/10.PMS.120v11x6

Katagami, E., & Tsuchiya, H. (2016). Effects of social support on athletes' psychological well-being: The correlations among received support, perceived support, and personality. Psychology, 7(13), 1741. https://doi.org/10.4236/psych.2016.713163

Levy, S. S. and Ebbeck, V. (2005). The exercise and self-esteem model in adult women: The inclusion of physical acceptance. Psychology of Sport and Exercise 6(5): 571-584. https://doi.org/10.1016/j.psychsport.2004.09.003

Martín-Albo, J., Núñez, J. L., Navarro, J. G., and Grijalbo, F. (2007). The Rosenberg self-esteem scale: Translation and validation in university students. The Spanish Journal of Psychology, 10(2), 458-467. https://doi.org/10.1017/S1138741600006727

Mastrogianni, A., Psychountaki, M., Donti, O. (2020). Self-perceptions and self-esteem in adolescent rhythmic gymnasts: Is training level a determinant? Science of Gymnastics Journal, 12(3), 357-366. https://doi.org/10.52165/sgj.12.3.357-366

Muñoz-Villena AJ, Gómez-López M, González-Hernández J. (2020). Perfectionism Profiles and Anger Responses: The Relevant Role of Self-Esteem in Athletes of Professional Quarries. Int J Environ Res Public Health, 17(4), 1416. https://doi.org/10.3390/ijerph17041416

Nurullah, A.S. (2012). Received and Provided Social Support: A Review of Current Evidence and Future Directions. American Journal of Health Studies, 27(3), 173-188.

Park, I. A., Lee, K. S., & Hong, S. B. (2020). The Mediating Effects of Self-esteem on the Relationship between Social Support and Psychological Happiness of Table Tennis Athletes. Journal of Asian Society for Health & Exercise, 2(2), 67-82.

Pedrosa, I., García-Cueto, E., Suárez-Álvarez, J., & Sánchez, B. P. (2012). Adaptación española de una Escala de Apoyo Social percibido para deportistas. Psicothema, 24(3), 470-476.

Poucher, Z. A., Tamminen, K. A., & Kerr, G. (2018). Providing social support to female Olympic athletes. Journal of Sport and Exercise Psychology, 40(4), 217-228. https://doi.org/10.1123/jsep.2018-0008

Rosenberg, M. (1965). Society and the adolescent self-image. Princeton University Press. https://doi.org/10.1515/9781400876136

Rouquette, O. Y., Knight, C. J., Lovett, V. E., Barrell, D., & Heuzé, J. P. (2021). The positive association between perceived parental responsiveness and self-esteem, anxiety, and thriving among youth rugby players: A multigroup analysis. Journal of Sports Sciences, 1-11. https://doi.org/10.1080/02640414.2021.1883311

Schwarzer, C., & Buchwald, P. (2004). Social support. In C. Spielberger (Ed.), Encyclopedia of appliedpyschology. (pp. 435-441). AcademicPress. https://doi.org/10.1016/B0-12-657410-3/00414-1

Sijtsma K. (2009). On the use, the misuse, and the very limited usefulness of Cronbach's alpha. Psychometrika, 74, 107-120. https://doi.org/10.1007/s11336-008-9101-0

Thelwell, R. C., Wagstaff, C. R. D., Chapman, M. T., & Kenttä, G. (2017). Examining coaches' perceptions of how their stress influences the coach-athlete relationship. Journal of Sports Sciences, 35, 1928-1939. https://doi.org/10.1080/02640414.2016.1241422
Thoits, P. A. (2010). Stress and health: Major findings and policy implications. Journal of Health and Social Behavior, 51(Suppl), S41-S53. https://doi.org/10.1177/0022146510383499
Trejos-Herrera, A. M., Bahamón, M. J., Alarcón-Vásquez, Y., Vélez, J. I., & Vinaccia, S. (2018). Validity and reliability of the multidimensional scale of perceived social support in Colombian adolescents. Psychosocial Intervention, 27(1), 56-63. https://doi.org/10.5093/pi2018a1
Warburton, D. E., & Bredin, S. S. (2017). Health benefits of physical activity: a systematic review of current systematic reviews. Current opinion in cardiology, 32(5), 541-556. https://doi.org/10.1097/HCO.0000000000000437
Zimet, G.D., Dahlem, N.W., Zimet, S.G. & Farley, G.K. (1988). The Multidimensional Scale of Perceived Social Support. Journal of Personality Assessment, 52, 30-41. https://doi.org/10.1207/s15327752jpa5201_2
Zimet, G.D., Powell, S.S., Farley, G.K., Werkman, S. & Berkoff, K.A. (1990). Psychometric characteristics of the Multidimensional Scale of Perceived Social Support. Journal of Personality Assessment, 55, 610-17. https://doi.org/10.1207/s15327752jpa5503&4_17

Relationships between throwing distance and physical strength in female hammer throw: Estimating physical strength requirement corresponding to throwing distance

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ABSTRACT

The purpose of this study was to clarify the relationships between female hammer throwers' physical strength and their throwing performance and to create standard values corresponding to throwing distance. Eighty-two female hammer throwers, with the throwing distance ranging from 30.31 to 63.82 meters, participated in this study. The questionnaire was designed to collect data on physical strength. Pearson's product-rate correlation coefficient was used to examine the relationship between each item and the throwing distance. A single regression analysis was performed with each item which was significantly correlated to the throwing distance as the dependent variable and the throwing distance as the independent variable to estimate the standard values corresponding to throwing distance. The results showed that all physical strength variables, except for 30 m sprint, were significantly correlated with the throwing distance, with weight training variables having the higher correlation coefficients. In addition, standard values corresponding to throwing distance were obtained using a single regression analysis.

Keywords: Performance analysis, Athletics, Throwing events, Body weight, Weight training.

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INTRODUCTION

The hammer throw is one of the four throwing events in track and field, alongside the shot put, discus throw, and javelin throw. Athletes throw the hammer in a circle with a diameter of 2.135 meters. Male and female throwers use hammer weighting 7.26 g and 4.0 kg, respectively, with lengths ranging from 1.175 to 1.215 meters. The factors that determine the throwing distance are the initial velocity at release, the release angle, and the release height. Previous studies have reported that the initial velocity at release has the greatest impact on the throwing distance (Gutiérrez et al., 2002; Isele and Nixdorf, 2010). The hammer throw is a complex movement characterized by a spatial structure that involves two or three preparatory winds of the hammer, followed by three, four, or five turns, while simultaneously the thrower-hammer system moves lineally across the throwing circle to achieve maximum final velocity at release (Gutiérrez et al., 2002). Furthermore, the hammer throw is one of strength-related sports, which has characteristics of a high traction force during throwing motion (Brice et al. 2011; Lavellee and Balam, 2010; Murofushi et al., 2005; Okamoto, 2007). Silvester (2002) also stated that muscular power plays a crucial role in generating momentum and energy for achieving longer throwing distance. Consequently, hammer throwers need to possess muscle strength and the ability to generate instantaneous force to withstand this load and accelerate the hammer (Hirose et al., 2013).

Speed, strength, endurance, flexibility and coordination of various physical strengths are essential for achieving higher performance. Especially, high-level performance in track and field heavily relies on strength (Judge, 2014). Several studies have investigated the relationships between physical strength and throwing performance. For example, in the indoor weight throw, which has a significantly correlation with hammer throw performance (Babbitt, 2017), a positive correlation was found between 1 repetition maximum (1RM) squat and performance in both male and female athletes (Judge et al., 2011). Terzis et al. (2007) reported 1RM squat and 1RM bench press were significantly correlated with shot put performance. Similarly, strong correlations were found between 1RM power snatch and the throwing distance achieved in shot put and weight throw (Stone et al., 2003). Regarding the hammer throw, a survey conducted in nine male hammer throwers revealed significant correlations between various factors such as 1RM clean, kettlebell throwing with one and two turns, standing long jump, standing triple jump, overhead shot throw, total score of the TEST QUADRATHLON (Jones et al., 1987), and the throwing distance (Hirose et al., 2013). However, there is a lack of studies investigated the relationships between physical strength and the throwing distance specifically in females, and most previous studies had small sample sizes.

In coaching, to improve athletes' performance, it is effective to follow a training cycle that includes understanding the structure of sports performance and the current situation, setting goals and tasks, developing training plans to solve the problems, training the athletes, and evaluating/diagnosing their progress (Zushi, 2014). Gambetta (2014a) also emphasized the importance of adhering to periodization processes, which encompass a systematic approach, a strategy to distribute training loads in relation to competition goals, a defined structure of progression, a sequential building-block approach, a predetermined time frame for execution of the plan, comprehensive coverage of all training components, the pursuit of specific competition goals, acknowledgement of the undulatory nature of the adaptive process, systematic manipulation of the variables of volume, intensity and density, as well as a method for monitoring training and evaluating competition results. Notably, testing and evaluation of athletes' biomotor abilities, which is an important part of the training plan (Gambetta, 2014a), requires clear standard values as a reference. To evaluate athletes' strength, various tests and scoring tables have been developed. In the case of track and field, "*Scoring for Biomotor Test Battery*" is presented for six different tests, and these indicators are useful for objective assessment of comprehensive fitness levels (Gambetta, 2014b). In recent years, some studies have been conducted to create standard values of physical training (such as the bench press, the standing long jump, 30 m sprint, etc.) in male discus and javelin throw (Maeda et al., 2018, 2019). These standard values provide practical information for setting training goals and evaluating/diagnosing training results. Thus, creating standard values corresponding to throwing distance can be useful in coaching in female hammer throw.

Many sports exhibits sex-related differences in technique, and the hammer throw is no exception. Numerous studies investigated sex-related differences in the hammer throw technique (Bartnietz et al., 1997; Hay, 1993; Konz and Hunter, 2015; Pavlović, 2020). Takanashi et al. (2021) argued that female discus throwers' training regimens were often based on the characteristics of their male counterparts, and the same can be said for the hammer throw. Therefore, the purpose of this study was to clarify the relationships between female hammer throwers' physical strength and their throwing performance and to create standard values corresponding to throwing distance. These insights also could inform training programs, talent identification, and performance enhancement strategies in female hammer throwers.

METHODS

Participants

Eighty-two female hammer throwers, with the throwing distance ranging from 30.31 to 63.82 meters, participated in this study. Regarding the inclusion/exclusion criteria of the participants recruitment procedure, throwers whose official throwing record exceeds 30 meters were chosen. We have directly contacted to coaches/throwers in Japan and ask for research cooperation. The survey was conducted via a paper or online questionnaire (Google form, Google Inc.). The questionnaire was designed to collect data on physical strength. The purpose and contents of the research were explained to all participants through the questionnaire. Each participant provided signed consent for the participation and for the publication of this. This study was approved by the ethics committee of Kyoto University of Advanced Science (No. 21-506).

Measures and procedures

Based on previous research (Hirose et al., 2013; Maeda et al., 2018, 2019) and training practicality, the following variables related to physique and physical strength were investigated: 1) height, 2) weight, 3) arm span, 4) grip strength of both sides, 5) full squat, 6) bench press, 7) snatch, 8) clean, 9) deadlift, 10) 30 m sprint, 11) 50 m sprint, 12) standing long jump, 13) standing triple jump, 14) standing quintuple jump, 15) overhead back toss with a shot (4.0 kg), 16) underhand forward throw with a shot (4.0 kg), 17) overhead back toss with a shot (2.721 kg), 18) underhand forward throw with a shot (2.721 kg), 19) throwing distance in hammer throw. For the variables from full squat to deadlift, we obtained the 1RM, while for the other variables, we investigated the participants' personal best records. We categorized these variables as follows: physique variables (1-3), physical strength variables (4-18), weight training variables (4-18), sprint variables (10-11), jumping variables (12-14), and throwing variables (15-18).

Measurement methods were the same as in previous studies (Maeda et al., 2018, 2019). For 1RMs of snatch and clean, lifting the barbell from either the ground or hang position was allowed, and the use of straps assisting grip was permitted. The times of the 30 m and 50 m sprints were measured manually, and participants could start from either a crouching or standing position. The records for the standing long jump, standing triple jump, and standing quintuple jump were the distance between the take-off and landing points of the participants. The overhead and underhand shot throws were performed by throwing from either on the stop board or ground.

Statistical analysis

Pearson's product-rate correlation coefficient was used to examine the relationship between each item and the throwing distance. A single regression analysis was performed with each item which was significantly correlated to the throwing distance as the dependent variable and the throwing distance as the independent variable to estimate the standard values corresponding to throwing distance. All statical analyses were conducted using SPSS 26.0 for Mac, and the significance level was set at 5%.

RESULTS

Table 1 shows the mean value, standard deviations, maximum and minimum values. The mean value of sample size was 54.4 ± 18.3 (Min.: n = 23, Max.: n = 81). All scattergrams are given in Figure 1. Significant correlations were found between the throwing distance and weight (r = .39, $p < .001$), grip strength (right: r = .44, $p < .001$, left: r = .47, $p < .001$), bench press (r = .56, $p < .001$), full squat (r = .59, $p < .001$), snatch (r = .79, $p < .001$), clean (r = .66, $p < .001$), deadlift (r = .53, $p < .001$), 50 m sprint (r = -.29, p = .04), standing long jump (r = .40, $p < .001$), standing triple jump (r = .61 p = .001), standing quintuple jump (r = 40, $p < .001$), overhead back toss with a shot (4.0 kg) (r = .62, $p < .001$), underhand forward throw with a shot (4.0 kg) (r = .61, $p < .001$), overhead back toss with a shot (2.721 kg) (r = .53, $p = .01$) and underhand forward throw with a shot (2.721 kg) (r = .47, $p = .01$). Table 2 shows the 95% confidence intervals of correlation coefficients with record. All correlation coefficients were within the 95% confidence intervals. Table 3 demonstrates the regression equations used to obtain the standard values corresponding to the throwing distance, coefficients of determination (R^2) and standard errors of each regression equation. Coefficients of determination were ranging from .07 (50 m sprint) to .62 (snatch). Table 4 shows the standard values corresponding the throwing distance (from 30 m to 80 m). In this study, we estimated the standard values for physical strength variables, while the standard values for physique variables were not calculated.

Table 1. Mean value, standard deviations, maximum and minimum values for all variables.

		Mean	SD	Max.	Min.
Record	(m)	46.72	6.90	63.82	30.31
Height	(cm)	161.6	5.9	181	143
Weight	(kg)	65.8	7.0	85	53
Arm span	(cm)	163.6	7.7	191	147
Grip strength: Right	(kg)	39.9	6.9	54	26
Grip strength: Left	(kg)	38.2	6.4	55	27
Full squat	(kg)	94.2	23.4	140	55
Bench press	(kg)	63.0	18.2	115	30
Snatch	(kg)	47.9	12.2	70	12
Clean	(kg)	66.8	16.8	105	35
Deadlift	(kg)	111.8	33.0	200	50
30m sprint	(s)	4.8	0.2	4.26	5.11
50m sprint	(s)	7.4	0.4	6.7	9
Standing long jump	(cm)	216.8	18.8	265	150
Standing triple jump	(m)	6.3	0.6	7.9	5
Standing quintuple jump	(m)	11.0	0.9	13.05	9
Overhead back toss with a shot: 4.0kg	(m)	11.7	1.8	16	9
Underhand forward throw with a shot: 4.0kg	(m)	10.9	1.4	14	8
Overhead back toss with a shot: 2.721kg	(m)	13.3	1.9	17.3	10.04
Underhand forward throw with a shot: 2.721kg	(m)	12.6	1.6	15.5	9.7

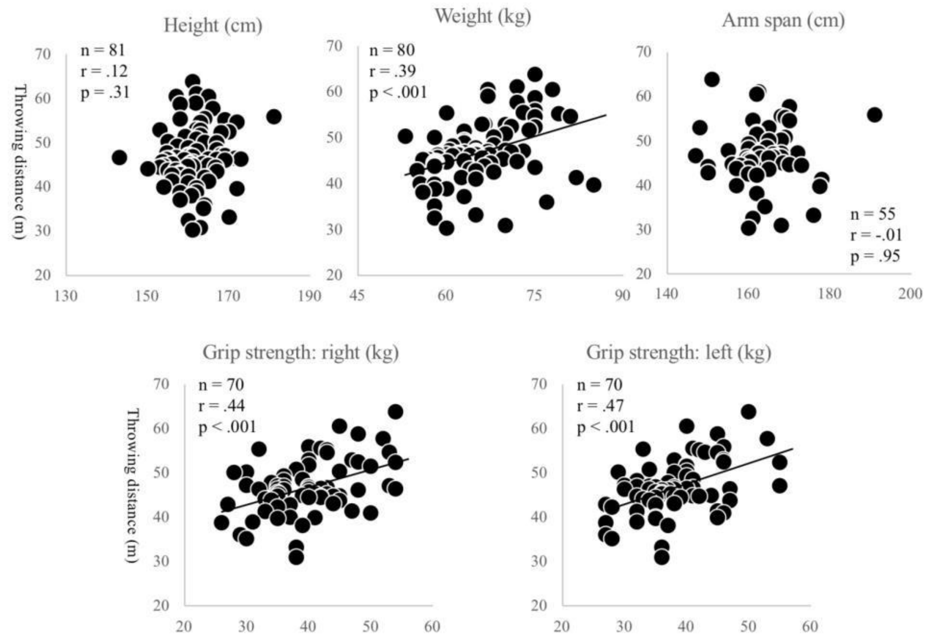

Figure 1a. Relationship between physical strength and throwing distance.

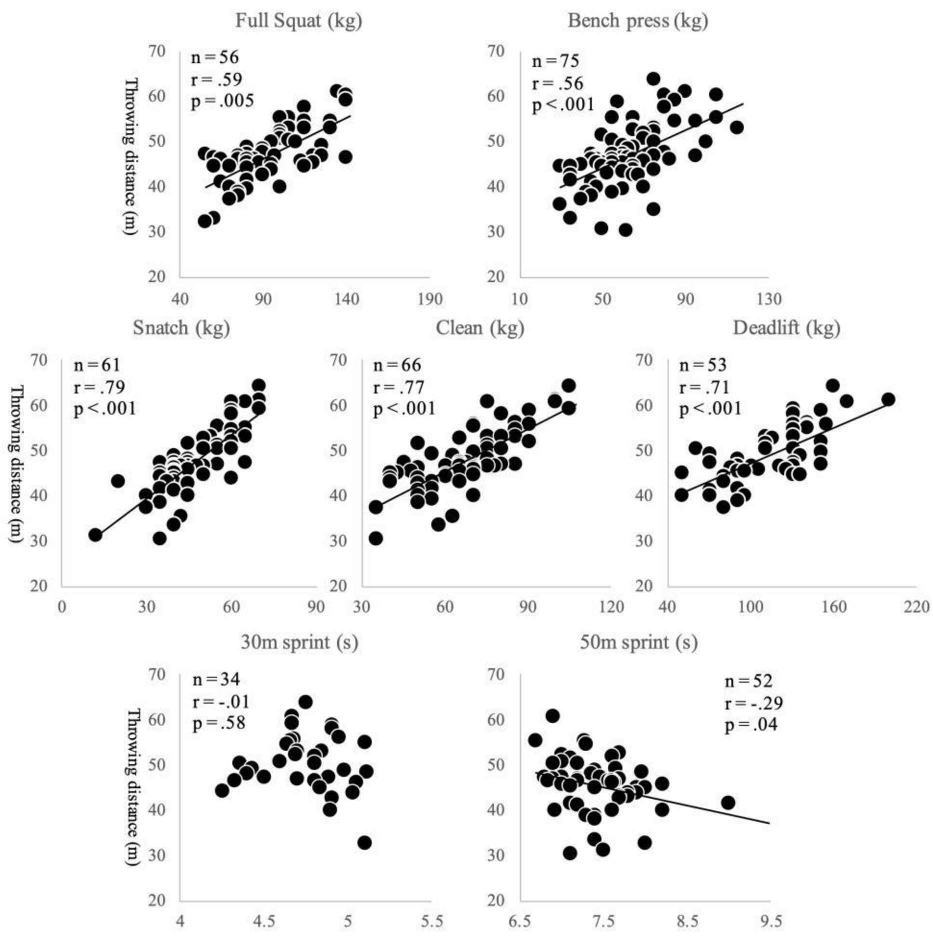

Figure 1b. Relationships between physical strength and throwing distance.

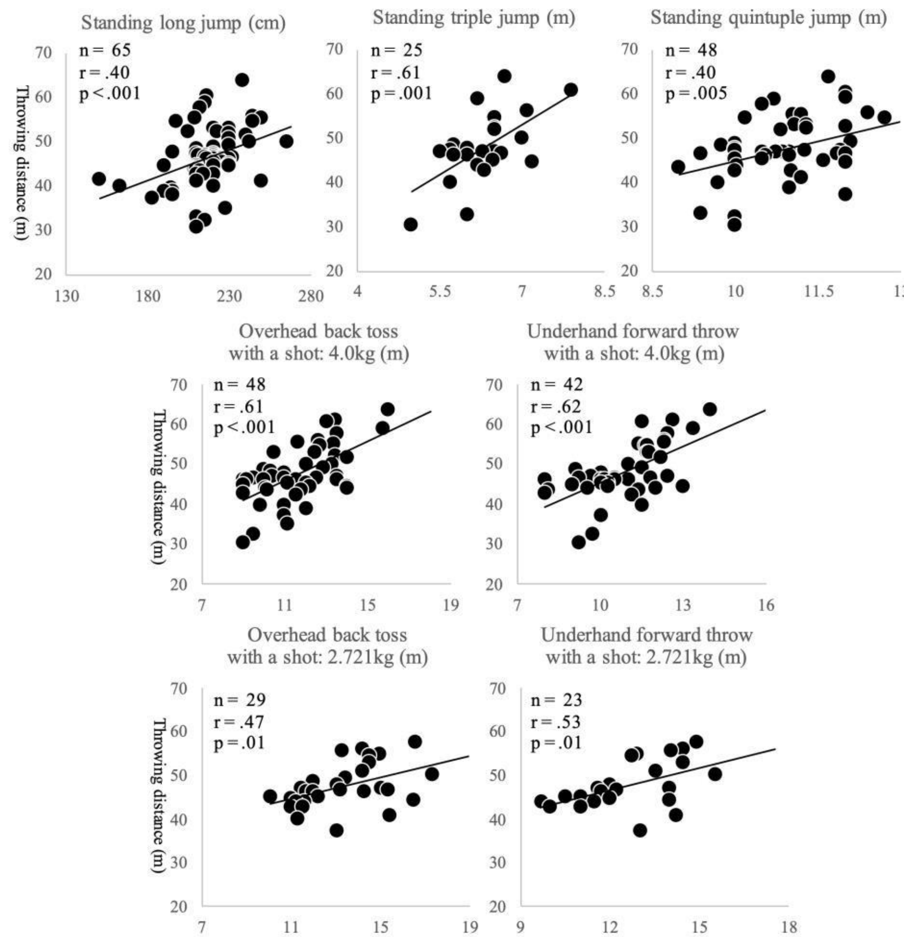

Figure 1c. Relationships between physical strength and throwing distance.

Table 2. 95% confidence intervals of correlation coefficients with record.

	Correlation Coefficient with Record	**95% CIs**
Height	0.12	-0.11 to 0.33
Weight	0.39	0.18 to 0.56
Arm span	-0.01	-0.27 to 0.36
Grip strength: Right	0.44	0.22 to 0.61
Grip strength: Left	0.47	0.26 to 0.63
Full squat	0.69	0.52 to 0.80
Bench press	0.56	0.38 to 0.69
Snatch	0.79	0.67 to 0.87
Clean	0.77	0.64 to 0.85
Deadlift	0.71	0.54 to 0.82
30m sprint	-0.10	-0.42 to 0.25
50m sprint	-0.29	-0.52 to -0.01
Standing long jump	0.40	0.17 to 0.58
Standing triple jump	0.61	0.39 to 0.76
Standing quintuple jump	0.40	0.13 to 0.61
Overhead back toss with a shot: 4.0kg	0.61	0.39 to 0.76
Underhand forward throw with a shot: 4.0kg	0.62	0.38 to 0.77
Overhead back toss with a shot: 2.721kg	0.47	0.12 to 0.71
Underhand forward throw with a shot: 2.721kg	0.53	0.13 to 0.77

Table 3. Regression equations used to obtain the standard values.

	Regression equation	R^2	Standard Error
Grip strength: Right	y = 0.493x + 17.047	.18	6.29
Grip strength: Left	y = 0.4918x + 15.448	.21	5.73
Full squat	y = 2.6514x - 30.824	.47	17.09
Bench press	y = 1.4572x - 5.6001	.30	15.22
Snatch	y = 1.3308x - 15.53	.62	10.85
Clean	y = 1.8858x - 22.858	.58	23.37
Deadlift	y = 3.8522x - 75.901	.50	4.89
50m sprint	y = -0.0176x + 8.1934	.07	.42
Standing long jump	y = 1.1481x + 163.46	.15	17.41
Standing triple jump	y = 0.0491x + 3.9714	.34	.50
Standing quintuple jump	y = 0.0532x + 8.4244	.14	.88
Overhead back toss with a shot: 4.0kg	y = 0.1519x + 4.4813	.36	1.41
Underhand forward throw with a shot: 4.0kg	y = 0.1265x + 4.7917	.37	1.15
Overhead back toss with a shot: 2.721kg	y = 0.1794x + 4.7937	.20	1.73
Underhand forward throw with a shot: 2.721kg	y = 0.1595x + 5.0306	.24	1.43

Table 4. Standard values corresponding the throwing distance.

	Grip strength : Right	Grip strength : Left	Full squat	Bench press	Snatch	Clean	Deadlift	50m sprint	Standing long jump
30m	31.8	30.2	48.7	38.1	24.4	33.7	39.7	7.7	197.9
35m	34.3	32.7	62.0	45.4	31.0	43.1	58.9	7.6	203.6
40m	36.8	35.1	75.2	52.7	37.7	52.6	78.2	7.5	209.4
45m	39.2	37.6	88.5	60.0	44.4	62.0	97.4	7.4	215.1
50m	41.7	40.0	101.7	67.3	51.0	71.4	116.7	7.3	220.9
55m	44.2	42.5	115.0	74.5	57.7	80.9	136.0	7.2	226.6
60m	46.6	45.0	128.3	81.8	64.3	90.3	155.2	7.1	232.3
65m	49.1	47.4	141.5	89.1	71.0	99.7	174.5	7.0	238.1
70m	51.6	49.9	154.8	96.4	77.6	109.1	193.8	7.0	243.8
75m	54.0	52.3	168.0	103.7	84.3	118.6	213.0	6.9	249.6
80m	56.5	54.8	181.3	111.0	90.9	128.0	232.3	6.8	255.3

	Standing triple jump	Standing quintuple jump	Overhead back toss with a shot: 4.0kg	Underhand forward throw with a shot: 4.0kg	Overhead back toss with a shot: 2.721kg	Underhand forward throw with a shot: 2.721kg
30m	5.4	10.0	9.0	8.6	10.2	9.8
35m	5.7	10.3	9.8	9.2	11.1	10.6
40m	5.9	10.6	10.6	9.9	12.0	11.4
45m	6.2	10.8	11.3	10.5	12.9	12.2
50m	6.4	11.1	12.1	11.1	13.8	13.0
55m	6.7	11.4	12.8	11.7	14.7	13.8
60m	6.9	11.6	13.6	12.4	15.6	14.6
65m	7.2	11.9	14.4	13.0	16.5	15.4
70m	7.4	12.1	15.1	13.6	17.4	16.2
75m	7.7	12.4	15.9	14.3	18.2	17.0
80m	7.9	12.7	16.6	14.9	19.1	17.8

DISCUSSION

The aim of the study was to investigate the relationships between physical strength of female hammer throwers and their throwing performance and to create standard values corresponding to throwing distance. Our findings indicate that body weight was the only significant physique correlated with the throwing distance. The implement used in the hammer throw involves handle and wire, which may explain why height and arm span have less of an impact on throwing distance compared to other throwing events. In addition, as the high load applied to throwers in the hammer throw (Okamoto, 2007), it is necessary for hammer throwers to have higher power on the basis of greater muscle mass, and therefore body weight is important as the background. Additionally, Castaldi et al. (2022) refer to previous research and point out the importance of a large turning radius and the significant influence of body weight on it. Thus, the results of present study suggest that hammer throwers are required increasing muscle mass and gaining weight to improve their throwing performance.

In this study, the throwing distance in the hammer throw was significantly correlated with all physical strength variables, except for 30 m sprint. These findings emphasize the importance of developing both force and power to enhance hammer throwing performance, as strength and power are crucial for optimal performance in throwing events (Kline, 2003). Similar results have been obtained for other throwing events, such as the discus throw (male and female) and the javelin throw (male) (Hatakeyama et al., 2011; Maeda et al., 2018, 2019; Takanashi et al., 2021).

However, it is worth noting that while the 50 m sprint showed a significant correlation with the throwing distance in this study, the correlation coefficients of the sprinting variables were relatively smaller compared to other variables. Similar findings were observed in male discus throwers (Maeda et al., 2018). In contrast, for male javelin throwers, the correlation coefficient of the 100 m sprint was moderate (Maeda et al., 2019). The differences in the relationship between sprint variables and throwing distance can be attributed to the execution for throwing motion in limited space for hammer throwers and discus throwers, whereas javelin throwers are allowed to utilize an approach run.

In terms of the jumping variables, this study found moderate to large correlation coefficients with the throwing distance. Similar results were reported for the male discus and javelin throwers (Maeda et al., 2018, 2019). These results highlight the importance of jumping ability for throwers across different events. This suggests that coaches and throwers can measure and evaluate the ability to exert power in a short duration by focusing on training or testing the jumping variables.

Furthermore, in the discus and the javelin throws, previous studies have shown higher correlation coefficients of the throwing variables (overhead back toss with a shot and underhand forward throw with a shot) compared to the weight training variables to the throwing distance (Maeda et al., 2018, 2019). However, in the hammer throw, the results of this study revealed that the correlation coefficients of weight training variables were higher than those for the throwing variables. This can be attributed to the specific characteristics of the hammer throw, including longer duration time of motion (Hirose et al., 2016; Kato et al., 2020; Panoutsakopoulos and Kollias, 2012; Saratlija et al., 2013) and higher load applied to the thrower (Hirose et al., 2015; Lanka, 2000; Takamatsu and Sakurai, 2013) compared to other throwing events. In addition, the weight of the implements relative to throwers' body mass is heavier in the hammer throw compared to other throwing events, except for shot put. While the weight of the implement is the same in the shot put and hammer throw, the release velocity of the hammer is greater than that of the shot (elite female hammer throwers: over 26.0 m/s, elite female shot putters: around 13 m/s) (Dinsdale et al., 2018a, 2018b). This difference results in hammer throwers experience a higher load compared to shot putters, emphasizing the need for greater physical strength in the former. These factors likely contributed to the larger correlation coefficients observed for weight training variables in the hammer throw. Singh et al. (2013) revealed that high performance male hammer throwers demonstrated higher maximum strength compared to low performance throwers. Similarly, in this study, for female throwers, improving maximum strength through weight training was identified as a priority for enhancing the hammer throwing performance.

In this study, we estimated standard values corresponding to throwing distance using a single regression analysis. Typically, the throwing distance should serve as the dependent variable, while individual physical strength variables should be the independent variable. However, since one of the purposes of this study was to create standard values corresponding to throwing distance, we used a single regression equation with each variable as the dependent variable and the throwing distance as the independent variable. The coefficients of determination (R^2) ranged from .07 to .62, which is similar to the previous study that reported standard values for the strength of male javelin throwers (Maeda et al., 2019). Nonetheless, caution is warranted when applying estimated values of variables with small coefficients of determination and a limited sample size (e.g., 50 m sprint, standing triple jump, and 2.721 kg shot throw). We calculated the standard errors to evaluate the accuracy of the estimation and represent individual differences in throwers' physical strength. Therefore, when utilizing the standard values proposed in this study, coaches and athletes should consider the standard errors as a mean to evaluate the athletes' physical strength and set their goals. From a practical point of view, as noted by Bompa and Haff (2009), coaches can optimize athletes' performance by implementing a systematic and scientifically grounded training approach. Consequently, the standard values proposed in this study offer potential utility for coaches and athletes in identifying areas that require improvement in physical training, establishing goals, and designing scientifically informed training programs.

While we recruited a larger sample of participants than most previous studies, there still a number of limitations to the study's design. Firstly, the standard values were estimated for throwing distances ranging from 30 to 80 meters, however, the throwing distance of the participants only ranged from 30.31 to 63.82 meters. Therefore, the values from 65 to 80 meters were extrapolated, which could result in larger errors. Secondly, although the study was conducted with specific instructions to ensure consistent measurement, it's important to note that the use of a questionnaire-based approach inherently limits our ability to control the actual measurement environment. Lastly it should be noted that physical strength alone is not sufficient for enhancing the throwing performance in the hammer throw, as throwers also require good technique (Bandou et al., 2006). Physical strength and throwing technique are interrelated (Grosser and Neumaier, 1982). Future research should examine the relationship between physical strength and throwing technique in the hammer throw.

CONCLUSION

The purpose of this study was to clarify the relationships between female hammer throwers' physical strength and their throwing performance and to create standard values corresponding to throwing distance. A total of 82 female hammer throwers with throwing distances ranging from 30.31 to 63.82 meters participated in this study. Physical strength data were collected via a paper or online questionnaire. The results showed that all physical strength variables, except for 30 m sprint, were significantly correlated with the throwing distance, with weight training variables having the higher correlation coefficients. In addition, standard values corresponding to throwing distance were obtained using a single regression analysis, which can be useful for coaches and athletes.

AUTHOR CONTRIBUTIONS

Study concept and design, drafting the article and its critical revision: Kei Maeda. Data collection and analysis, final approval of the version to be published; Tadahiko Kato. Data analysis and interpretation, final approval of the version to be published; Jun Mizushima. Study concept and design, final approval of the version to be published: Mao Kuroda. Conception and design of the study, data collection and analysis, final approval of the version to be published; Keigo Ohyama-Byun.

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DISCLOSURE STATEMENT

No potential conflict of interest were reported by the authors.

REFERENCES

Babbitt, D. G. (2017) A Study in the Correlation between Hammer Throw and Weight Throw Performance and Development for U.S. Collegiate Throwers. Int. J. Coach. Sci., 11(2): 20-30.

Bandou, M., Tanabe, S. and Ito, A. (2006) Relationship between hammer throw performance and hammer head velocity. Japan J. Phys. Educ. Hlth. Sport Sci. 51: 505-514. https://doi.org/10.5432/jjpehss.51.505

Brice, S. M., Ness, K. F and Rosemond, D. (2011) An analysis of the relationship between the linear hammer speed and the thrower applied forces during the hammer throw for male and female throwers. Sports Biomechanics, 10 (3): 174-184. https://doi.org/10.1080/14763141.2011.592210

Bronietz, K., Barclay, L. and Gathercole, D. (1997) Characteristics of top performances in the women's hammer throw: basics and technique of the world's best athletes. New Studies in Athletics, 12(2-3): 101-109.

Bompa, T. O. and Haff, G. G. (2009) Periodization: Theory and Methodology of Training. Human Kinetics: Champaign.

Castaldi, G. M., Borzuola, R., Camomilla, V., Bergamini, E., Vannozzi, G. and Macaluso, A. (2022) Biomechanics of the Hammer Throw: Narrative Review. Front. Sports Act. Living, 4. https://doi.org/10.3389/fspor.2022.853536

Dinsdale, A., Thomas, A., Bissas, A. and Merlino, S. (2018a) Biomechanical report for the IAAF World championships LONDON 2017 Shot Put Women's. Retrieved from [Accessed March 13, 2024]: https://www.worldathletics.org/about-iaaf/documents/research-centre

Dinsdale, A., Thomas, A., Bissas, A. and Merlino, S. (2018b) Biomechanical report for the IAAF World championships LONDON 2017 Hammer Throw Women's. Retrieved from [Accessed March 13, 2024]: https://www.worldathletics.org/about-iaaf/documents/research-centre

Gambetta, V. (2014a) Training Design. In W. Freeman (Ed.), Track & Field Coaching Essentials (p.48-59). Champaign, IL: Human Kinetics.

Gambetta, V. (2014b) Biomotor Training for Speed and Power Events. In W. Freeman (Ed.), Track & Field Coaching Essentials (p.60-82). Champaign, IL: Human Kinetics.

Grosser, M. and Neumaier, A. (1982) Techniktraining: Theorie und Praxis aller Sportarten. BLV-Buchverl: München.

Gutiérrez, M., Soto, V. M. and Rojas, F. J. (2002) A biomechanical analysis of the individual techniques of the hammer throw finalists in the Seville 1999. New Studies in Athletics, 17(2): 15-26.

Hatakeyama, S., Takanashi, Y. and Sasaki, D. (2011) An investigation into characteristics of physical fitness in discus throwers. Research Quarterly of Athletics, 87:17-26.

Hay, J. G. (1993) The Biomechanics of Sports Techniques (4th ed.). Prentice Hall: New Jersey.

Hirose, K., Takanashi, Y., Aoki, K. and Kaneko, K. (2013) Relationship between hammer throw performance and field tests -Focus on the kettlebell throw. Research Quarterly for Athletics, 92: 38-44.

Hirose K., Ohyama-Byun, K., Fujii, H., Aoki, K. and Ogata, M. (2015) Load characteristics of resisted training in the hammer throw: Focusing on throws with heavier hammers. The Japan Journal of Coaching Studies, 29: 31-40.

Hieose, K., Ohyama-Byun, K., Maeda, K. and Ogata, M. (2016) The relationship between the duration time of turn and the throwing record in the men's hammer throw. Proceedings of 34th International Conference on Biomechanics in Sport, 34: 660-662.

Isele, R., and Nixdorf, E. (2010) Biomechanical Analysis of the Hammer Throw at the 2009 IAAF World Championships in Athletics. New Studies in Athletics, 25: 37-59.

Jones, M. (1987) Throwing. The Crowood Press, 91-95.

Judge, L. W., Bellar, D., Turk, M., Judge, M., Gilreath, E., and Smith, J. (2011) Relationship of squat one repetition maximum to weight throw performance among elite and collegiate athletes. International Journal of Performance Analysis in Sport, 11(2): 209-219. https://doi.org/10.1080/24748668.2011.11868542

Judge, L. W. (2014) Coaching throwing Events. In W. Freeman (Ed.), Track & Field Coaching Essentials (p.227-236). Champaign, IL: Human Kinetics.

Kato, T., Maeda, K. and Shariman, I. I. (2020) Classification of the rotational shot-put based onduration time of motion phases. Proceedings of 38th International Conference on Biomechanics in Sport,38: 332-335.

Kline, D. E. (2003) Throwing events. In M. Guthrie (Ed.), Coaching Track & Field Successfully. (p.163-187). Champaign, IL: Human Kinetics.

Konz, S. M. and Hunter, I. (2015) Technique comparison of male and female hammer throwers. Proceedings of 33rd International Conference on Biomechanics in Sport, 33: 1038-1041.

Lanka, J. (2000) Shot Putting. In. V. Zatsiorsky (Ed.), Biomechanics in Sport: Performance Enhancement and Injury Prevention. Wiley-Blackwell: New Jersey. https://doi.org/10.1002/9780470693797.ch21

Lavellee, M. E. and Balam, T. (2010) An overview of strength training injuries: acute and chronic. Curr. Sports Med. Rep., 9 (5): 307-313. https://doi.org/10.1249/JSR.0b013e3181f3ed6d

Maeda, K., Ohyama-Byun, K., Hirose, K. and Ogata, M. (2018) Relationships between throwing distance and parameters about morphology and physical strength in male discus throw: Estimating physical strength requirement corresponding to throwing distance. The Japan Journal of Coaching Studies, 31: 175-184.

Maeda, K., Yamamoto, K., Hirose, K. and Ohyama-Byun, K. (2019) Identifying standard values for the strength of male javelin throwers. Research Journal of Sports Performance, 11: 446-458.

Murofushi, K., Sakurai, S., Umegaki, K. and Kobayashi, K. (2005) Development of a System to Measure Radius of Curvature and Speed of Hammer Head during Turns in Hammer Throw. International Journal of Sport and Health Science, 3: 116-128. https://doi.org/10.5432/ijshs.3.116

Okamoto, A. (2007) Influence of body weight on pulling force in hammer throw. Bulletin of Institute of Environmental Management ,6: 51-53. https://doi.org/10.1016/S0021-9290(07)70609-7

Panoutsakopoulos, V., & Kollias, I. A. (2012). Temporal analysis of elite men's discus throwing technique. Journal of Human Sport and Exercise, 7(4), 826–836. https://doi.org/10.4100/jhse.2012.74.10

Pavlović, R. (2020) Differences in kinematic parameters between male and female hammer throw finalists of the World Championship in Daegu in 2011. Pedagogy of Physical Culture and Sports, 24 (5): 255-63. https://doi.org/10.15561/26649837.2020.0506

Saratlija, P., Zagorac, N. and Babic, V. (2013) Influence of Kinematic Parameters on Result Efficiency in Javelin Throw. Collegium Antropologicum, 37 (2): 31-36.

Silvester, L. J. (2002) Complete Book of Throws. Champaign, IL: Human Kinetics.

Singh, D. S., Dutta, S. and Singh Sidhu, D. A. (2013). Maximum strength parameters of indian male hammer throwers of different performance levels. International Journal of Behavioral Social and Movement Sciences, 2(1), 177-181.

Stone, M. H., Sanborn, K., O'bryant, H. S., Hartman, M., Stone, M. E., Proulx, C., Ward, B., and Hruby, J. (2003) Maximum Strength-Power-Performance Relationships in Collegiate Throwers. Journal of Strength and Conditioning Research, 17(4): 739-745. https://doi.org/10.1519/00124278-200311000-00019

Takamatsu, J. and Sakurai, T. (2013) A biomechanical study of training methods in discus throwing: Effects of over- and underweighted discuses in throwing pattern. The Journal of Ryutsu Keizai University, the Faculty of Health & Sport Science, 6: 43-53.

Takanashi, Y., Fujimori, N. and Koikawa, N. (2021) An investigation into the relationship between throw performance and maximum weight in weight training of female discus throwers. Journal of Human Sport and Exercise, 16(1): 226-234. https://doi.org/10.14198/jhse.2021.161.20

Zushi, K. (2014) A Coaching Model and General Coaching Contents Required in Physical Education. The Japan Journal of Coaching Studies, 27: 149-161.

ORIGINAL ARTICLE

Upper-limb joint kinematics analysis of accuracy dart throwing at different vertical targets between different level dart players

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ABSTRACT

Darts has evolved from a traditional pub room game to a professional sport. More and more people worldwide are participating in the sport of dart throwing. In order to enhance throwing performance, it is important to understand the mechanics of precise dart throwing techniques. Therefore, the purpose of this study was to investigate the fine-tune control of joint kinematics with different vertical targets between different skill levels to understand how to increase the success rate and generate precise fine-tuning of the motor system. Eight advanced players and eight intermediate players participated in this study. A motion capture system measured the kinematic data of the arm during throwing. The results indicated a significant interaction in shoulder internal rotation velocity (p = .031) and elbow supination velocity (p = .047) between advanced and intermediate groups with the different vertical targets. When intermediate players threw darts at different vertical targets, changes in shoulder internal rotation velocity and elbow supination velocity were observed. Conversely, these phenomena were not present in the advanced group. Additionally, we found that dart accuracy or light weight throwing requires an more angle of elbow pronation and generate high angular velocity of wrist palmar flexion during the release process. Based on the findings of this study, these results could provide a reference guide for dart throwing to improve the throwing performance.
Keywords: Biomechanics, Throwing kinematics, Throwing technique, Dart throwing motion.

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INTRODUCTION

Since the 1970s, darts or dart-throwing has rapidly changed from a traditional pub room game into a professional throwing sport. The change was enabled by the creation of the British Darts Organisation (BDO). It was actively promoted by the World Darts Federation (WDF) and the Professional Darts Corporation (PDC) to gain international recognition for darts as a major sport (Davis, 2018). Presently, dart throwing sport is played in over 70 countries in the world owing to advances in sports science and widespread media coverage (World Darts Federation website).

The classic dart game, also known as the "*01 game*," has gained significant popularity in the world of dart throwing (Vasiljev, Rubin, Milosavljevic, & Vasiljev, 2017). In this game, players aim to throw darts at a dartboard with 82 different areas, each offering specific points when hit (Dehghani, Montazeri, Givi, Guerrero, & Dhiman, 2020). The game begins with a set score, usually 301, 501, 701, or 901 points, and the objective was to reduce the score to exactly 0 points by hitting specific marked areas of the dartboard. To achieve this, players must not only target the bull's-eye accurately but also throw darts precisely at various areas on the dartboard. Consequently, studying the kinematics of the upper limb during dart throwing at different targets becomes crucial (Wunderlich, Heuer, Furley, & Memmert, 2020).

Advanced dart players may develop an optimal strategy for fine-tuning the control of joint kinematics to release the dart with an appropriate hand trajectory when aiming at different vertical targets on the dartboard. Previous studies on ball throwing have shown that throwing baseballs to different vertical areas involves changes in hand trajectory controlled by shoulder elevation (Watts, Pessotto, & Hore, 2004). It is important to note that the overarm throwing motion in those studies differs from the dart-throwing action. Dart throwing involves a lighter weight and more intricate finger grip motion (Watts et al., 2004). As of now, no study has investigated how advanced dart players adjust their fine-tune control of their joint kinematics during dart throwing to target different vertical areas on the dartboard.

Additionally, advanced dart players may develop superior biomechanical characteristics in joint kinematics to achieve consistent throwing movement to intermediate players. Previous studies suggest avoiding excessive flexion angular velocity in the wrist during release for accuracy (Hirashima, Kudo, & Ohtsuki, 2003; Hirashima, Ohgane, Kudo, Hase, & Ohtsuki, 2003). However, some research emphasized releasing rigid control over wrist joint kinematics for learning accurate throwing skills (Button, MacLeod, Sanders, & Coleman, 2003; Vereijken, Emmerik, Whiting, & Newell, 1992). The specific wrist joint kinematics in accurate dart throwing and differences between advanced and intermediate players remain unclear. Further research is needed to understand the development of mastery in dart throwing. Such insights could enhance training programs to improve dart players' accuracy and consistency.

Therefore, the purpose of this study was to investigate the fine-tune control of joint kinematics of players of different skill levels throwing at different vertical targets in order to understand how to increase their success rate and generate precise fine-tuning of the motor system. We hypothesized that beyond the elevation of the shoulder joint for the purpose of adjusting the throwing trajectory, the elbow and wrist joints are likely to play integral roles in the fine-tune control mechanics at different vertical targets and advanced groups could have different joint kinematics during dart release than intermediate groups for accuracy dart throwing. A thorough understanding of these biomechanical characteristics of advanced dart player will help to develop new training programs for improving skill of the dart throwing.

MATERIAL AND METHODS

Participants

A total of 16 dart players that come from the Chinese Taipei Darts Federation (CTDF) were recruited in the experiment. All participants were divided into advanced and intermediate groups based on the Phoenix rating (reference). According to Phoenix Rating, ratings range from 1 to 30 and rankings over 19 were generally considered advanced groups. Thus, in our study, eight dart players participated in the experiment as an advanced group. Their characteristics were: height: 175.50 ± 5.83 m; mass: 73.50 ± 16.77 kg; experience: 5.63 ± 4.10 years; rating: 21.75 ± 2.43. The other eight dart players participated as an intermediate group. Although their Phoenix rating did not reach 18, their rating still has the level of over 10. Their characteristics were: height: 175.13 ± 4.58m; mass: 74.75 ± 15.14 kg; experience: 4.86 ± 4.06 years rating:14.13 ± 2.42. All participants signed a written informed consent form prior to the experiment. The study was approved by the institutional review board of Fu Jen Catholic University in Taiwan and all procedures were in accordance with the Declaration of Helsinki.

Experimental setup

Dart throwing motion was captured by eight cameras motion capture system (Eagle, Motion Analysis Corporation., Santa Rosa USA) placed to surround the participant. The motion capture sampling frequency was 200 Hz (Tran, Yano, & Kondo, 2019). Before the experiment began, the research team performed static (L frame) and dynamic (T wand) corrections to calibrate the experimental environment. If the average 3D residual was below 0.5 mm, the calibration was accepted. The three -dimensional coordinate system was identified as the X-axis (anteroposterior) was aligned front to back and toward target direction, while the Z-axis (longitudinal) was aligned vertically upward. The Y-axis (mediolateral) was aligned left to right (Figure 1).

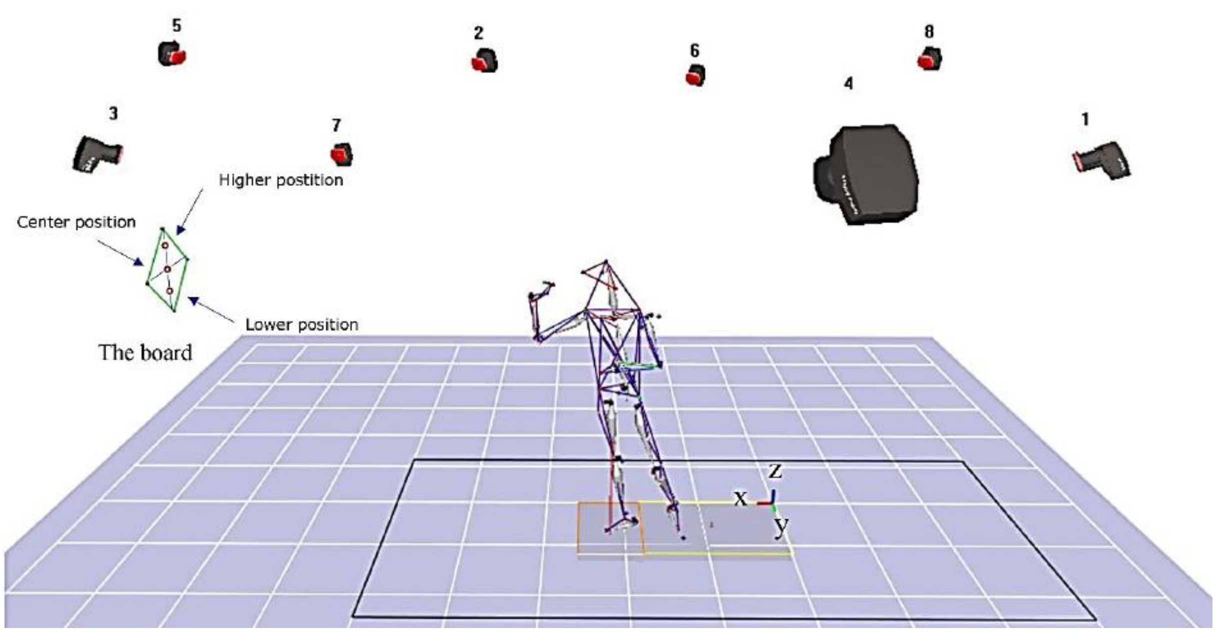

Figure 1. Dart experimental setup: Description of relative position of the cameras and different target position. The three -dimensional coordinate system was identified as the X-axis (anteroposterior) was aligned front to back and toward target direction, while the Z-axis (longitudinal) was aligned vertically upward. The Y-axis (mediolateral) was aligned left to right.

Procedures

The total of 41 reflective markers (diameter, 10–12 mm) were placed on the participant anatomical landmarks bilaterally, dart and target. The markers were attached to the top head, the 7th cervical vertebra (C7), acromioclavicular joint, trigonum scapulae, angulus inferior, later/medial epicondyle, radial/ulnar styloid, third metacarpal, anterior superior iliac spines, posterior superior iliac spines, great trochanters, thighs, knees, medial aspects of knee, shanks, ankles, medial aspects of ankles, toes, heels. Additionally, to identify the actual location by each of the darts on the board, reflective tape was also attached to the dart. The front and back ends of the dart was wound reflective tape (Tran et al., 2019). Although the provided darts were slightly different, the participants said that they had been able to adapt to it through several practice throws. In warm-up stage, participants were required to warm up sufficiently. According to the WDF dart rules, participants were asked to stand in front of the throwing line and the distance from the throwing line to the board was 2.37 m. Then, the height of the centre of the bull's-eye was set 1.73 m above the floor. Following a self-directed 15 min - 30 min warm-up and familiarization period, dart throwing proceeded. In evaluation stage, to confirm the success of the grouping, participants were asked to perform fifteen sets throws (three throws each set) to evaluation of their throw performance. In throwing stage, participants were asked to throw to 3 different heights target positions, which were in the 20-point area (higher position), the bull's-eye (centre position) and the 3-point area (lower position) respectively (Figure 1). Each position performed three throws, average value of three trials were represented the joint kinematics parameters on different position for each participant.

Data processing

The dart throwing movement was processed using a specialized motion capture software (Cortex 7.2, Motion Analysis Corp., Santa Rosa, CA). Cortex software had built-in Virtual Markers (centre of dart, target position and centre of joint) and skeleton (humerus, forearm, and hand segment). The raw marker positions were filtered by a zero-lag second-order Butterworth filter (cutoff frequency 20 Hz). The data were then exported into Microsoft Excel™ to derive the parameters.

Determination of performance assessment

To evaluate dart throwing performance, we analysed the success rate and absolute the vertical error (Nasu, Matsuo, & Kadota, 2014; Tran et al., 2019). The success rate was defined as the ratio of the number of throws hit the bull's-eye to the total number of throws for each subject. The absolute the vertical error was determined by the Euclidean distance between centre position and final dart's position on the dartboard.

Determination of throw movement phase

The dart throwing motion was divided into four phases (aiming, backward move, acceleration, and follow-through) based by previous study (Rezzoug, Hansen, Gorce, & Isableu, 2018). The aiming phase involves directing attention towards the target, succeeded by a backward motion in which the elbow undergoes slight flexion. Concluding this phase, elbow flexion velocity reach a point of equilibrium at zero. The acceleration phase was start from flexion to extension at the elbow joint and it ends with the instant of dart release. The instant of dart release was defined as the moment when the distance exceeded a pre-determined threshold between dart centre position and the thumb marker based by previous studies (Tran et al., 2019). The follow-through signifies the termination of the arm movement, characterized by the gradual deceleration and eventual cessation of articular joint movements. In that study, the analysis was focused on the acceleration phase (Figure 2).

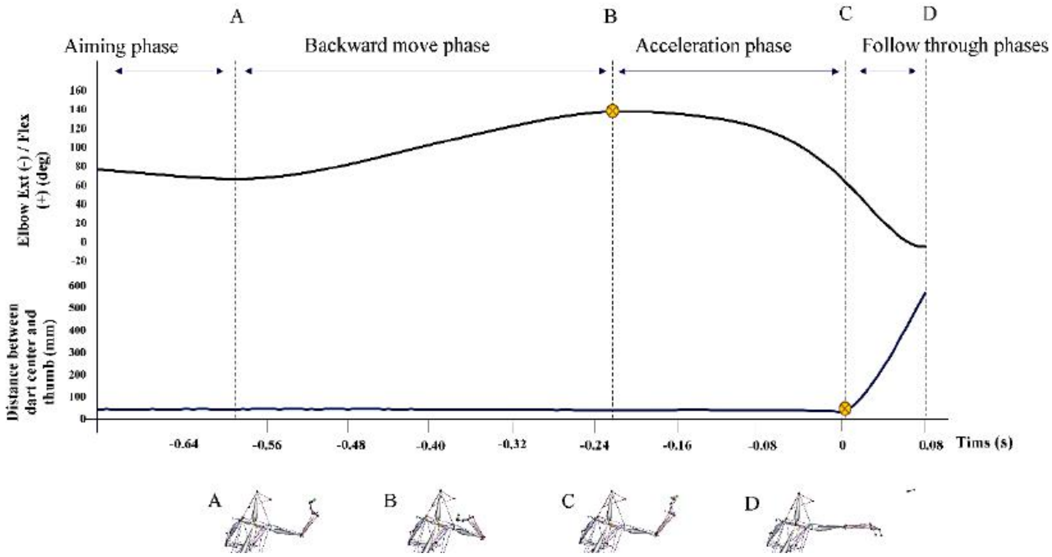

Figure 2. Illustration of dart throw phase definition from a representative participant. Backward move phase is from A to B. Acceleration phase is from B to C. Follow through phases is from C to D. (A) represents the kinematics of the elbow flexion onset (from flexion to extension at elbow joint), and (B) represents the elbow flexion reaches the maximum angle. (C) represents the dart was released (distance of the dart centre relative to the thumb finger exceeded a pre-determined threshold). (C) represents elbow joint full extension.

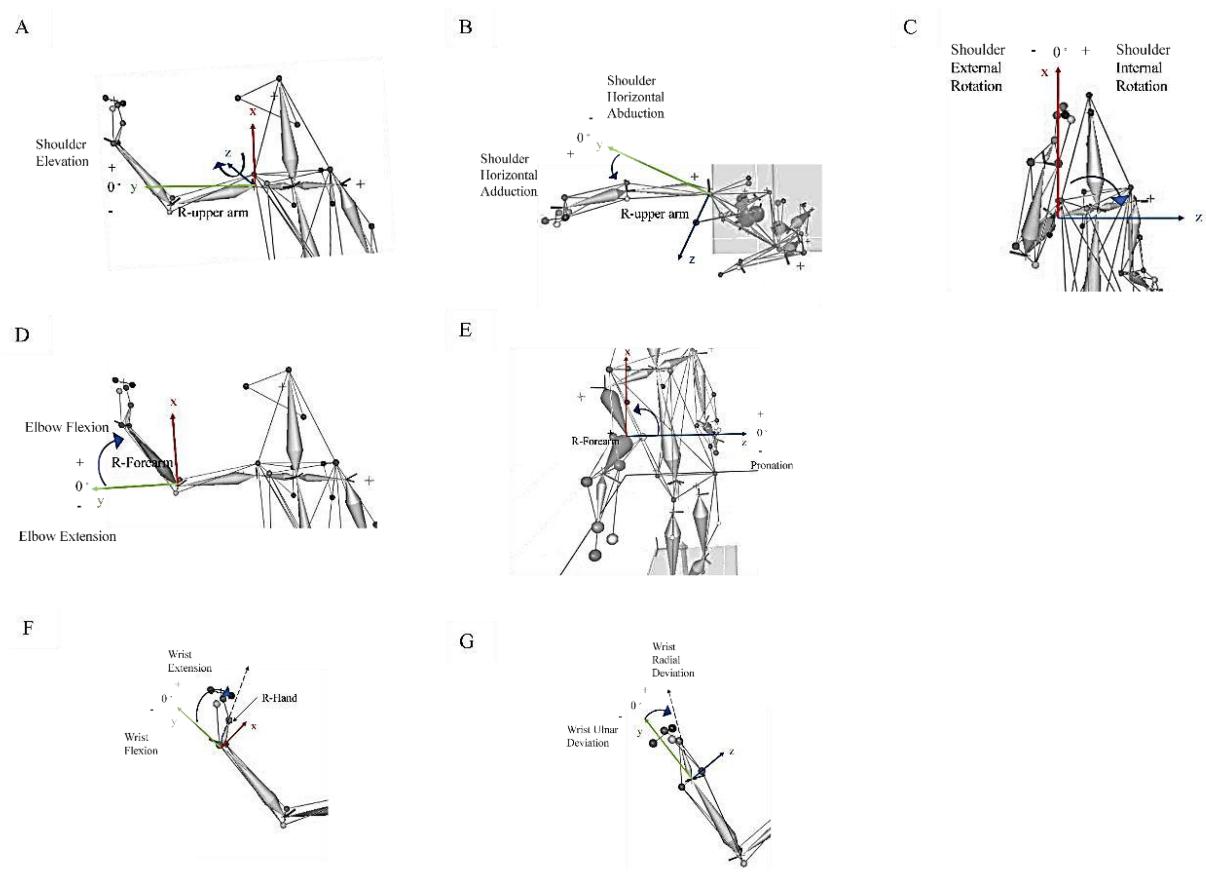

Figure 3. Illustrate the definition of joint angle of the local coordinate system dart throwing. A) Shoulder elevation; B) Shoulder horizontal abduction–adduction; C) Shoulder internal-external rotation; D) Elbow flexion–extension; E) Forearm pronation-supination; F) Wrist flexion–extension; G) Wrist radial-ulnar deviation.

Determination of the kinematics of the upper-limb

The upper extremity kinematic included the shoulder, elbow, and wrist joint. This study examined joint linear displacement and the joint angle amplitudes during acceleration phase of throwing dart. Further, joint rotation angle and angular velocity were evaluated at instant of dart release. Joint coordinate system (JCS) was calculated using the Cortex 7.2 software. According to the recommendations of the International Society of Biomechanics (ISB), the motions of the shoulders, elbows and wrists were described as follows (Wu et al., 2005). The glenohumeral joint motions included flexion–extension (shoulder elevation), horizontal abduction–adduction and internal-external rotation. The elbow joint motions included flexion–extension and forearm pronation-supination. The finally, the wrist motions included radial-ulnar deviation and flexion–extension. The rotation sequence of glenohumeral joint was modified Z-X-Y sequence (Šenk & Cheze, 2006). Local coordinate system was described in figure 5 for each joint motion.

Statistical analyses

All results are expressed as the mean ± standard deviation (SD) and were statistically analysed using SPSS 20.0 (SPSS Inc., Chicago, IL, USA). The Kolmogorov–Smirnov test was used to analyse the normality of the data. When we found that the data were not normally distributed, we used a Mann Whitney test. The results, however, showed that our data were normally distributed by the Kolmogorov–Smirnov test. Thus, the performance outcome was analysed using t-test. A two-way repeated measured ANOVA design was used to examine the interaction of different vertical target and different level player in dart and joint kinematics parameters. When an interaction was found, a one-way ANOVA was applied to determine the effect of targets independent variable on the kinematic variable does depend on the level of the skill independent variable. A Bonferroni's multiple comparison test was used for analysis whenever a significant main effect was found. The significance level was set at $p < .05$.

RESULTS

Performance outcome

The dart throw success rates resulted in significant differences between the advanced and intermediate groups for the different vertical targets (Table 1). The advanced groups achieved significantly higher success rates than the intermediate groups, regardless of the target area.

Table 1. Comparing the throw performance that throw to the different target between the advanced and intermediate groups.

Success rate o (%)	Advanced	Intermediate	*t*	*p*
High target	65.83 ± 10.95	45.00 ± 16.62*	2.961	.010*
Centre target	61.67 ± 18.08	42.50 ± 13.77	2.385	.031*
Low target	78.33 ± 9.25	50.83 ± 7.91	6.385	.000***

*Note. *p < .05, ***p < .001; SD: Standard Deviation.*

Dart kinematics

The dart release position and velocity in three-dimensional space is presented in Table 2. The study showed that throwing at different vertical targets results in adjusting the dart release position and dart release speed in the vertical direction (Z-axis), When a player throws a dart to a target that is higher than the centre of the target, the release dart point will be positioned higher in space and closer to the body. Conversely, when a darts player throws a dart to a target that is lower than the centre of the target, the release dart point will be placed lower in space and further away from the body. The dart release velocity also shows the same phenomenon.

Table 2. The dart release position and velocity at three-dimensional space between different target (t (higher, centre, lower)) and different level (advanced, intermediate).

		Advanced group		
		HT	**CT**	**LT**
Position (mm)	X-axis	1724 ± 70.51	1751 ± 79.48	1761 ± 79.47
	Y-axis	320.9 ± 74.58	322.3 ± 71.47	321.5 ± 65.96
	Z-axis	1734 ± 5978	1698 ± 55.09	1661 ± 51.17
Velocity (mm/s)	Vx -axis	5557 ± 301.5	5676 ± 286.7	5679 ± 320.0
	Vy-axis	4.80 ± 231.1	-24.19 ± 235.3	-6.92 ± 238.6
	Vz-axis	1976 ± 161.1	1587 ± 172.9	1308 ± 162.6
Resultant		5905 ± 292.4	5901 ± 293.6	5835 ± 318.4
		Intermediate group		
		HT	**CT**	**LT**
Position (mm)	X-axis	1690 ± 95.98	1703 ± 102.5	1728 ± 93.54
	Y-axis	331.9 ± 46.45	322.7 ± 42.80	321.8 ± 40.90
	Z-axis	1764 ± 22.98	1729 ± 23.61	1693 ± 21.51
Velocity (mm/s)	Vx -axis	5784 ± 341.0	5804 ± 444.7	5819 ± 347.2
	Vy-axis	-68.17±160.5	-48.65 ± 155.5	-44.98 ± 186.8
	Vz-axis	1872 ± 111.7	1562 ± 121.2	1239 ± 129.7
Resultant		6086 ± 320.3	6017 ± 413.2	5955 ± 327.8
		2-way ANOVA (*p*)		
		Interaction	**ME target**	**ME level**
Position (mm)	X-axis	.094	.000***	.398
	Y-axis	.074	.181	.896
	Z-axis	.817	.000***	.166
Velocity (mm/s)	Vx -axis	.267	.046*	.342
	Vy-axis	.140	.694	.662
	Vz-axis	.102	.000***	.356
Resultant		.469	.006**	.404

*Note. *p < .05, **p < .001; SD: standard deviation; HT: higher target; CT: centre target; LT: lower target; ME: main effect. Data was presented at mean ± SD.*

Joints kinematics

Table 3 and 4 display joint displacement and rotation amplitude during the acceleration phase. Higher targets led to a significant increase in elbow and wrist joint displacement along the vertical axis. Table 4 shows a similar trend for wrist dorsiflexion with increased rotation amplitude for higher targets.

In Table 5, angular velocity at dart release had a significant interaction, particularly for shoulder internal rotation velocity (p = .031) and elbow supination velocity (p = .047), which will be further explored. In terms of shoulder internal rotation angular velocity, the intermediate groups exhibited a significant increase when throwing at higher (133.2 ± 54.21) and centre (120.8 ± 64.51) targets compared to the lower target (94.09 ± 61.47) (F = 8.70; p = .003; η^2 = 0.55). However, the advanced groups showed no significant difference in shoulder internal rotation angular velocity between different targets (F = 0.69; p = .513; η^2 = 0.09). Regarding elbow supination angular velocity, the intermediate groups experienced a significant decrease when throwing at the lower (77.68 ± 92.51) target compared to the higher target (41.10 ± 99.98) (F = 5.43; p = .017; η^2 = 0.43). Similarly, the advanced groups did not show any significant difference in elbow supination angular velocity between different targets (F = 0.15; p = .854; η^2 = 0.02).

Table 3. The joint linear displacement during the acceleration phase between different target (higher, centre, lower) and different level (advanced, intermediate).

Linear displacement (mm)	Advanced group		
	HT	CT	LT
Shoulder on AP axis	9.18 ± 4.40	8.04 ± 3.6	8.17 ± 3.63
Shoulder on ML axis	6.08 ± 2.26	5.66 ± 2.38	5.20 ± 2.27
Shoulder on V axis	6.54 ± 3.19	5.68 ± 3.12	5.77 ± 3.16
Elbow on AP axis	10.59 ± 8.56	11.10 ± 9.3	12.83 ± 10.03
Elbow on ML axis	21.69 ± 19.74	21.18 ± 17.48	20.71 ± 17.26
Elbow on V axis	40.06 ± 14.66	37.82 ± 12.7	37.01 ± 12.76
Wrist on AP axis	236.61 ± 35.72	240.97 ± 36.30	241.33 ± 36.26
Wrist on ML axis	22.02 ± 11.77	21.69 ± 12.41	20.48 ± 9.95
Wrist on V axis	51.83 ± 18.97	36.92 ± 14.84	24.79 ± 13.21
Linear displacement (mm)	Intermediate group		
	HT	CT	LT
Shoulder on AP axis	9.19 ± 5.51	9.96 ± 6.35	9.77 ± 7.29
Shoulder on ML axis	4.87 ± 3.82	5.06 ± 3.75	5.35 ± 3.13
Shoulder on V axis	10.25 ± 8.66	9.51 ± 8.34	8.9 ± 6.11
Elbow on AP axis	12.71 ± 12.75	14.16 ± 16.14	13.69 ± 15.12
Elbow on ML axis	13.55 ± 7.27	13.03 ± 7.80	12.68 ± 7.73
Elbow on V axis	43.64 ± 35.36	41.12 ± 32.25	36.59 ± 25.28
Wrist on AP axis	252.60 ± 35.31	252.55 ± 40.83	252.93 ± 36.61
Wrist on ML axis	12.83 ± 7.00	13.36 ± 8.49	13.44 ± 8.36
Wrist on V axis	67.52 ± 23.12	53.71 ± 21.82	39.30 ± 16.54
Linear displacement (mm)	2-way ANOVA (*p*)		
	HT	CT	LT
Shoulder on AP axis	.149	.900	.656
Shoulder on ML axis	.246	.876	.704
Shoulder on V axis	.800	.154	.240
Elbow on AP axis	.472	.206	.745
Elbow on ML axis	.795	.151	.273
Elbow on V axis	.463	.028*	.858
Wrist on AP axis	.458	.459	.487
Wrist on ML axis	.298	.284	.113
Wrist on V axis	.786	.000***	.104

*Note. *p < .05, ***p < .0001, SD: standard deviation; AP = anteroposterior; ML = mediolateral; V = vertical; HT: higher target; CT: centre target; LT: lower target; ME: main effect.*

Table 4. The amplitudes of joint rotation on upper limb during the acceleration phase between target (higher, centre, lower) and level (advanced, intermediate).

Rotation amplitude (deg.)	Advanced group		
	HT	CT	LT
Shoulder Elevation	6.75 ± 3.02	7.00 ± 2.71	7.10 ± 2.79
Shoulder Int Rot	4.714 ± 2.45	4.47 ± 2.40	4.53 ± 2.66
Shoulder Hor Add	4.40 ± 2.90	3.88 ± 2.69	4.19 ± 2.57
Elbow Flexion	58.34 ± 9.43	60.58 ± 7.89	59.26 ± 9.22
Elbow Supination	9.17 ± 6.18	7.72 ± 6.07	8.57 ± 5.83

Wrist Dorsi flexion	32.84 ± 2.63	32.63 ± 3.45	31.00 ± 2.98
Wrist Rad Deviation	8.12 ± 3.30	9.52 ± 3.87	8.91 ± 3.81
Rotation amplitude (deg.)	**Intermediate group**		
	HT	**CT**	**LT**
Shoulder Elevation	6.54 ± 3.88	6.39 ± 2.68	6.14 ± 2.60
Shoulder Int Rot	5.36 ± 3.58	5.88 ± 3.51	5.34 ± 3.26
Shoulder Hor Add	1.74 ± 1.04	2.11 ± 1.22	1.83 ± 0.85
Elbow Flexion	61.81 ± 10.62	58.97 ± 10.78	58.48 ± 9.35
Elbow Supination	12.60 ± 2.93	11.33 ± 3.07	11.37 ± 2.66
Wrist Dorsi flexion	25.04 ± 2.54	24.09 ± 3.92	23.79 ± 3.14
Wrist Rad Deviation	8.89 ± 2.84	8.23 ± 3.78	8.37 ± 3.71
Rotation amplitude (deg.)	**2-way ANOVA (*p*)**		
	Interaction	**ME target**	**ME level**
Shoulder Elevation	.570	.808	.748
Shoulder Int Rot	.537	.404	.474
Shoulder Hor Add	.323	.775	.103
Elbow Flexion	.406	.177	.588
Elbow Supination	.916	.235	.913
Wrist Dorsi flexion	.494	.029*	.022*
Wrist Rad Deviation	.541	.303	.788

*Note. *p < .05, SD: standard deviation; Int Rot: internal rotation; Hor Add: horizontal adduction; Hor Abd: horizontal abduction; Wrist Rad: wrist radial; HT: higher target; CT: centre target; LT: lower target; ME: main effect.*

Table 5. The joint angle and angular velocity on upper limb at dart release between target (higher, centre, lower) and level (advanced, intermediate). The main effect is not shown if the interaction is significant ($p < .05$).

Joint Angle(deg.)	**Advanced group**		
	HT	**CT**	**LT**
Shoulder Elevation	7.20 ± 11.42	5.75 ± 12.90	4.84 ± 12.28
Shoulder Int Rot	14.84 ± 17.22	14.31 ± 17.91	14.43 ± 18.01
Shoulder Hor Add	38.70 ± 8.98	37.91 ± 9.64	38.79 ± 9.18
Elbow Flexion	69.42 ± 9.76	69.88 ± 8.50	70.77 ± 8.55
Elbow Supination	27.13 ± 9.02	27.10 ± 9.82	26.60 ± 9.41
Wrist Dorsi flexion	50.77 ± 6.40	51.45 ± 7.07	51.98 ± 5.83
Wrist Rad Deviation	15.22 ± 10.47	15.45 ± 10.31	15.86 ± 10.31
Angular velocity (deg./s)	**HT**	**CT**	**LT**
Shoulder Elevation	214.6 ± 56.42	215.5 ± 47.21	209.2 ± 53.13
Shoulder Int Rot	53.27 ± 97.52	43.86 ± 91.16	46.29 ± 88.39
Shoulder Hor Abd	-8.37 ± 47.85	-6.87 ± 47.93	-5.12 ± 48.64
Elbow Extension	478.6 ± 87.81	485.2 ± 87.34	481.2 ± 80.99
Elbow Supination	90.09 ± 137.3	83.72 ± 132.4	85.97 ± 137.2
Wrist Palmar Flexion	-1519 ± 190.8	-1503 ± 164.4	-1504 ± 167.1
Wrist Ulnar Deviation	-510.7 ± 263.9	-507.6 ± 241.6	-498.2 ± 241.7
Joint Angle(deg.)	**Intermediate group**		
	HT	**CT**	**LT**
Shoulder Elevation	3.64 ± 8.56	2.22 ± 8.92	2.71 ± 8.57
Shoulder Int Rot	5.38 ± 21.03	4.85 ± 20.52	4.89 ± 20.38

Shoulder Hor Add	39.52 ± 8.15	40.48 ± 8.41	40.70 ± 8.01
Elbow Flexion	70.03 ± 9.72	71.50 ± 8.57	72.05 ± 7.39
Elbow Supination	38.27 ± 11.15	38.08 ± 11.07	38.23 ± 9.88
Wrist Dorsi flexion	53.23 ± 11.58	53.88 ± 12.21	53.80 ± 12.06
Wrist Rad Deviation	25.45 ± 9.48	25.51 ± 9.54	25.37 ± 9.56
Angular velocity (deg./s)	**HT**	**CT**	**LT**
Shoulder Elevation	219.5 ± 100.6	209.6 ± 102.2	204.2 ± 89.33
Shoulder Int Rot	133.2 ± 54.21	120.8 ± 64.51	94.09 ± 61.47
Shoulder Hor Abd	-4.02 ± 46.17	-1.01 ± 45.86	5.48 ± 48.30
Elbow Extension	503.3 ± 149.5	499.8 ± 155.6	494.7 ± 148.9
Elbow Supination	41.10 ± 99.98	63.02 ± 121.6	77.68 ± 92.51
Wrist Palmar Flexion	-1272 ± 270.7	-1256 ± 255.7	-1255 ± 229.3
Wrist Ulnar Deviation	-661.0 ± 194.8	-673.7 ± 234.8	-690.0 ± 220.0
Joint Angle(deg.)	**2-way ANOVA (*p*)**		
	HT	**CT**	**LT**
Shoulder Elevation	.560	.000**	.569
Shoulder Int Rot	.991	.353	.340
Shoulder Hor Add	.070	.168	.691
Elbow Flexion	.768	.072	.789
Elbow Supination	.652	.767	.042*
Wrist Dorsi flexion	.669	.090	.647
Wrist Rad Deviation	.069	.205	.065
Angular velocity (deg./s)	**HT**	**CT**	**LT**
Shoulder Elevation	.320	.039*	.959
Shoulder Int Rot	.031*		
Shoulder Hor Abd	.288	.013*	.773
Elbow Extension	.363	.560	.778
Elbow Supination	.047*		
Wrist Palmar Flexion	.995	.273	.037*
Wrist Ulnar Deviation	.074	.640	.167

*Note. *p < .05, **p < .001; SD: standard deviation; Int Rot: internal rotation; Hor Add: horizontal adduction; Hor Abd: horizontal abduction; Wrist Rad: wrist radial; HT: higher target; CT: centre target; LT: lower target; ME: main effect.*

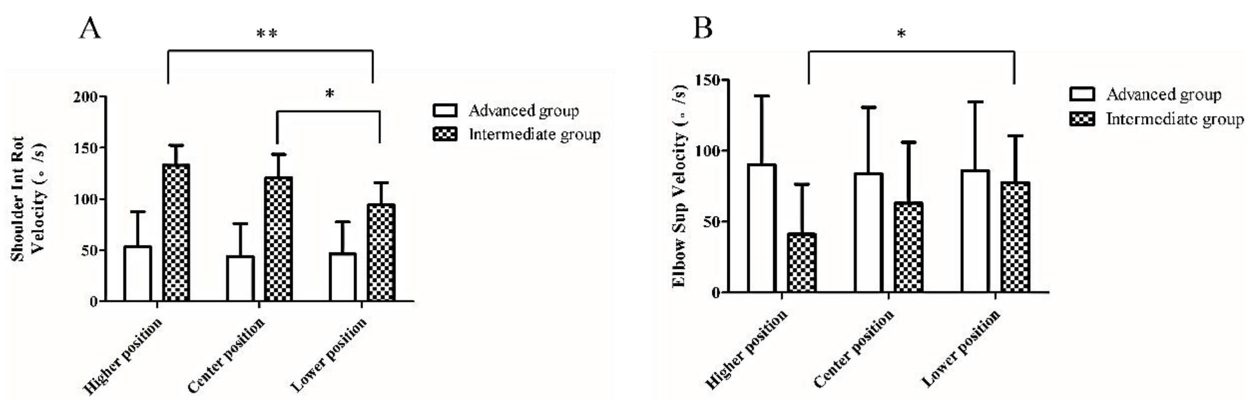

Figure 4. Comparing of the shoulder internal rotation velocity (A) and the elbow supination velocity (B) at dart release among three different target position between advanced and intermediate groups.

On the other hand, the other joint angles and angular velocity did not show significant interactions, and the main effect will be explored. Main effects were explored for different targets. Both groups showed increased shoulder elevation angle and angular velocity when throwing to higher target (Table 6).

Table 6. The main effect of kinematic for different vertical target.

	HT	CT	LT	F	p	η^2	Post Test
Dart Position (mm)							
X-axis	1707 ± 83.18	1728 ± 92.03	1745 ± 85.50	43.47	.000***	0.74	HT > LT HT > CT CT > LT
Z-axis	1749 ± 46.31	1714 ± 43.84	1678 ± 41.42	519.3	.000***	0.97	HT > LT HT > CT CT > LT
Dart Velocity (mm/s)							
Vx -axis	5671 ± 332.4	5740 ± 367.5	5749 ± 330.5	3.359	.048*	0.18	HT > LT
Vz-axis	1925 ± 144.4	1575 ± 144.8	1274 ± 144.6	612.7	.000***	0.97	HT > LT HT > CT CT > LT
Resultant	5996 ± 310.7	5959 ± 351.5	5896 ± 318.3	6.06	.006**	0.28	HT > LT
Joint displacement (deg.)							
Elbow on V axis	41.85 ± 26.22	39.47 ± 23.74	36.80 ± 19.35	4.10	.026*	0.21	HT > LT
Wrist on V axis	59.67 ± 21.98	45.32 ± 20.00	32.04 ± 16.29	148.2	.000***	0.90	HT > LT HT > CT CT > LT
Joint Rotation amplitude (deg.)							
Wrist Dorsi flexion	30.16 ± 6.04	29.32 ± 6.09	28.97 ± 6.18	4.07	.027	0.21	HT > LT
Joint angle at dart release (deg.)							
Shoulder Elevation	5.42 ± 9.92	3.99 ± 10.87	3.78 ± 10.29	8.10	.001**	0.35	HT > CT = LT
Angular velocity at dart release (deg./s)							
Shoulder Elevation	217.1 ± 78.82	212.5 ± 76.95	206.7 ± 71.05	3.59	.039*	0.19	HT > LT
Shoulder Hor Abd	-6.19 ± 45.48	-3.94 ± 45.41	0.17 ± 47.15	4.99	.013*	0.24	LT > HT

*Note. *p < .05, **p < .01, **p < .0001***; SD: standard deviation, Hor Abd: horizontal abduction, Post Test: Bonferroni's Multiple Comparison Test. HT: higher target; CT: centre target; LT: lower target; Data was presented at mean ± SD.*

Table 7. The different of joint kinematic parameter was showed between advanced group and intermediate group (mean ± SD).

	During the acceleration phase			
	Advanced group	Intermediate group	p	E
Joint Rotation amplitude (deg.)				
Wrist Dorsi flexion	32.79 ± 3.62	26.17 ± 6.13	.000 ***	
	At dart release			
	Advanced group	Intermediate group	p	E
Joint Angle (deg.)				
Elbow Supination	26.94 ± 9.01	38.19 ± 10.24	.000 ***	1.16
Angular velocity (deg./s)				
Wrist Palmar Flexion	1509 ± 166.9	1261 ± 241.4	.000 ***	1.19

*Note. ***p < .001; SD: Standard Deviation.*

Analysis of main effects for different skill levels revealed significant differences. Advanced groups had greater wrist flexion amplitudes (32.79 ± 3.26°) than intermediate groups (26.17 ± 2.13°). At dart release, advanced groups had smaller elbow supination angle (26.94 ± 9.01°) and greater wrist palmar flexion angular velocity (1509 ± 166.9°/s) compared to intermediate groups (angle: 38.19 ± 10.24°; velocity: 1261 ± 241.4°/s) (Table 7).

DISCUSSION

The aim of the study was to identify the biomechanical characteristics of upper limb joint kinematics in accurate throws at vertical targets by comparing advanced and intermediate groups. At first, this study compares the difference of the throwing success rate between two groups. The result showed that the advanced group was significantly better than those of the intermediate group. The success rate of advanced group was similar to that of the expert or skilled dart players in previous dart throwing research (Nasu et al., 2014; Tran et al., 2019). This indicates that the participants were successfully divided into two groups of different abilities in this study.

This study investigated the interaction between various vertical targets and groups of different skill levels. The results unveiled a significant interplay between the targets and skill levels concerning the angular velocity of shoulder internal rotation. Specifically, the analysis of simple main effects indicated a notable increase in the angular velocity of shoulder internal rotation among participants with intermediate-level skills when transitioning from a lower target to a higher one during dart throws. Conversely, this significant difference was not observed among participants with advanced-level skills. These findings suggest that the angular velocity of shoulder internal rotation may impact the accuracy of dart throws aimed at different targets. This underscores the importance of maintaining a consistent shoulder rotation as a primary goal for achieving accuracy in dart throws, particularly when targeting varying vertical positions.

Furthermore, this study has also revealed an interaction involving elbow supination velocity and the different abilities of the dart throwers. There was a significant increase observed in elbow supination velocity among the intermediate skill level groups when throwing darts from a higher target to a lower target. Presently, there is no existing research on throwing indicating that altering elbow supination velocity confers an advantage in controlling throws aimed at different vertical targets. Only one study documented substantial changes in forearm supination during reaching tasks. (Vandenberghe, Levin, De Schutter, Swinnen, & Jonkers, 2010). Our study strongly suggests that involving the elbow joint in the regulation of throws aimed at different target positions should be avoided. The participation of the elbow joint may not provide beneficial contributions and could, in fact, lead to an increased likelihood of errors.

When the main effect of the different targets was analysed, our results showed that the shoulder elevation angle and angle velocity play a major role at dart release. This phenomenon is similar to previous studies on overarm throwing (Watts et al., 2004). Interestingly, the angular velocity of shoulder horizontal abduction also significantly increased when the dart was thrown at the lower target to the higher target. These results indicated that when dart is throwed to different targets, shoulder control not only depended on fine-tune control in the sagittal plane, but also needs coordination in the lateral plane, which is different with the regulation of overarm or ball throwing.

This study demonstrated that there was significantly different joint kinematics between the advanced and intermediate groups. Although previous studies have shown that the angle of shoulder elevation was significantly lower in experts than novices during acceleration phase of dart throwing (Rezzoug et al., 2018), joint kinematics of shoulder was not significantly different between the advanced group and the intermediate group in the present study. This result implied that the intermediate group was able to improve the angle of shoulder elevation compared to novices.

In terms of elbow joint movement, our results indicated that the intermediate group exhibited a higher elbow supination angle at dart release than in the advanced group. These results are similar in flying disc throwing research in which elbow pronation during throwing for the skilled participants (Sasakawa & Sakurai, 2008). Moreover, water polo throwing studies have shown that an excessive supination angle could decrease ball release speed (Feltner & Nelson, 1996). The reason is that maintaining the elbow pronation position contributes to flexion velocity at wrist and thus to object release velocity. Therefore, an excessive supination angle may result in a lower wrist flexion velocity at release for the intermediate group. Even though in dart throwing maximal velocity is not the primary objective, elbow pronation can be a marker of advanced levels in dart throwing.

In terms of wrist joint movement, the advanced group exhibited significantly greater wrist flexion amplitude during ACC phase than the intermediate group. Additionally, the advanced group demonstrated higher wrist palmar flexion angular velocity at dart release. Prior research on expert and novice dart players revealed that experts exhibit larger non-muscular interaction torques at the wrist joint that may lead to swifter palmar flexion angular velocity during dart release (Rezzoug et al., 2018). This also means that the wrist joint will have a faster palmar flexion angular velocity for experts during dart release. Moreover, a recent dart study confirmed that an increased angular acceleration of wrist at release was correlated with relative throw performance (Tran et al., 2019). Furthermore, baseball throwing studies have shown that an increase in wrist flexion angular velocity during throwing did not lead to increased performance error while still maintaining a consistent range of wrist flexion during throwing and similar final wrist position at release timing (Debicki, Gribble, Watts, & Hore, 2004; Hirashima, Kudo, Watarai, & Ohtsuki, 2007). Thus, heightened palmar flexion angular velocity signifies a crucial trait for advanced dart throwers. Intermediate dart throwers aiming to improve should gradually relinquish rigid wrist control and increase wrist flexion angular velocity at dart release.

This study successfully found better joint kinematics characteristics of upper limb at release for groups of different ability levels. Moreover, this study is the first focusing on the kinematics of advanced and intermediate groups during a throwing task. Previous studies usually compared the differences in throwing movement between advanced level and novice players (Nasu et al., 2014; Rezzoug et al., 2018; Tran et al., 2019), and these studies have not been able to clearly guide the improvement methods of intermediate players. Therefore, this study explores the differences in throwing movements between advanced and intermediate players to help develop training strategies with players to improve their performance.

The limitation of this study was that the results of this study are aimed at relatively advanced and intermediate players, so the research results cannot be extended to novices. Moreover, the sample size for each group was relatively small, as the recruitment for this study focused exclusively on the top 50 players domestically, leading to insufficient participant numbers. This limitation may hinder the generalizability of the research findings. Additionally, another limitation of this study is the potential impact of the adhesive light markers attached to participants during the experiment on their throwing performance. The presence of these adhesive markers may alter participants' throwing movements, thereby affecting the accuracy of the experimental results.

CONCLUSION

In conclusion, the advanced and intermediate groups appeared to use different strategies of throwing control for throwing darts to different vertical targets. Notably, the angular velocity of shoulder internal rotation displayed a significant interaction between targets and skill levels. Elbow supination velocity also exhibited and interaction with the different target level, emphasizing its role in throwing to different target positions. The analysis revealed a significant increase in the angular velocity of shoulder internal rotation and a decrease in elbow supination velocity among participants with intermediate-level skills while shifting from a lower to a higher target during dart throws. However, this significant difference was not observed among participants with advanced-level skills.

Additionally, this study uniquely focused on differences between advanced and intermediate players, offering insights often absent from prior research. The advanced players can accuracy throw dart to different target keeping the same elbow pronation angle and generate a higher angular velocity of wrist palmar flexion during the release process. Our findings indicate that a release of wrist palmar flexion at release is a key performance indicator for accuracy dart throwing. The results of this study can provide a reference guide for dart or light weight throwing to improve the accuracy performance.

AUTHOR CONTRIBUTIONS

All authors discussed and formulated this study. Conceptualization, Tsung-Yu Huang and Wen-Tzu Tang. Formal analysis, Tsung-Yu Huang, Hsin Yang and Wen-Tzu Tang. Investigation, Tsung-Yu Huang and Wen-Tzu Tang. Data curation, Tsung-Yu Huang and Hsin Yang. Writing original draft preparation, Tsung-Yu Huang and Wen-Tzu Tang. Writing—review and editing, Joseph Hamill and Wen-Tzu Tang. Supervision, Joseph Hamill and Wen-Tzu Tang.

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DISCLOSURE STATEMENT

No potential conflict of interest were reported by the authors.

REFERENCES

Button, Chris, MacLeod, Morven, Sanders, Ross, & Coleman, Simon. (2003). Examining Movement Variability in the Basketball Free-Throw Action at Different Skill Levels. Research quarterly for exercise and sport, 74, 257-269. https://doi.org/10.1080/02701367.2003.10609090

Davis, Leon. (2018). From a pub game to a sporting spectacle: the professionalisation of British Darts, 1970-1997. Sport in History, 38(4), 507-533. https://doi.org/10.1080/17460263.2018.1511462

Debicki, DB, Gribble, PL, Watts, S, & Hore, J. (2004). Kinematics of wrist joint flexion in overarm throws made by skilled subjects. Experimental brain research, 154(3), 382-394. https://doi.org/10.1007/s00221-003-1673-4

Dehghani, Mohammad, Montazeri, Zeinab, Givi, Hadi, Guerrero, Josep M, & Dhiman, Gaurav. (2020). Darts game optimizer: A new optimization technique based on darts game. International Journal of Intelligent Engineering and Systems, 13(5), 286-294. https://doi.org/10.22266/ijies2020.1031.26

Feltner, Michael E, & Nelson, September T. (1996). Three-dimensional kinematics of the throwing arm during the penalty throw in water polo. Journal of Applied Biomechanics, 12, 359-382. https://doi.org/10.1123/jab.12.3.359

Hirashima, Masaya, Kudo, Kazutoshi, & Ohtsuki, Tatsuyuki. (2003). Utilization and Compensation of Interaction Torques During Ball-Throwing Movements. Journal of neurophysiology, 89(4), 1784-1796. https://doi.org/10.1152/jn.00674.2002

Hirashima, Masaya, Kudo, Kazutoshi, Watarai, Koji, & Ohtsuki, Tatsuyuki. (2007). Control of 3D limb dynamics in unconstrained overarm throws of different speeds performed by skilled baseball players. Journal of neurophysiology, 97(1), 680-691. https://doi.org/10.1152/jn.00348.2006

Hirashima, Masaya, Ohgane, Kunishige, Kudo, Kazutoshi, Hase, Kazunori, & Ohtsuki, Tatsuyuki. (2003). Counteractive relationship between the interaction torque and muscle torque at the wrist is predestined in ball-throwing. Journal of neurophysiology, 90(3), 1449-1463. https://doi.org/10.1152/jn.00220.2003

Nasu, D., Matsuo, T., & Kadota, K. (2014). Two types of motor strategy for accurate dart throwing. PLoS One, 9(2), e88536. https://doi.org/10.1371/journal.pone.0088536

Rezzoug, Nasser, Hansen, Clint, Gorce, Philippe, & Isableu, Brice. (2018). Contribution of interaction torques during dart throwing: Differences between novices and experts. Human movement science, 57, 258-266. https://doi.org/10.1016/j.humov.2017.09.004

Sasakawa, Kei, & Sakurai, Shinji. (2008). Biomechanical analysis of the sidearm throwing motion for distance of a flying disc: A comparison of skilled and unskilled Ultimate players. Sports biomechanics, 7(3), 311-321. https://doi.org/10.1080/14763140802270936

Šenk, Miroslav, & Cheze, Laurence. (2006). Rotation sequence as an important factor in shoulder kinematics. Clinical biomechanics, 21, S3-S8. https://doi.org/10.1016/j.clinbiomech.2005.09.007

Tran, Bao Nguyen, Yano, Shiro, & Kondo, Toshiyuki. (2019). Coordination of human movements resulting in motor strategies exploited by skilled players during a throwing task. PLoS One, 14(10), e0223837. https://doi.org/10.1371/journal.pone.0223837

Vandenberghe, Annelies, Levin, Oron, De Schutter, Joris, Swinnen, Stephan, & Jonkers, Ilse. (2010). Three-dimensional reaching tasks: effect of reaching height and width on upper limb kinematics and muscle activity. Gait & posture, 32(4), 500-507. https://doi.org/10.1016/j.gaitpost.2010.07.009

Vasiljev, R, Rubin, P, Milosavljevic, S, & Vasiljev, I. (2017). Transfer of under-foot load and mechanisms of control in dart sports. children, 19(3), 235-242.

Vereijken, Beatrix, Emmerik, Richard EA van, Whiting, HTA, & Newell, Karl M. (1992). Free (z) ing degrees of freedom in skill acquisition. Journal of motor behavior, 24(1), 133-142. https://doi.org/10.1080/00222895.1992.9941608

Watts, Sherry, Pessotto, Ivan, & Hore, Jon. (2004). A simple rule for controlling overarm throws to different targets. Experimental brain research, 159(3), 329-339. https://doi.org/10.1007/s00221-004-1957-3

Wu, Ge, Van der Helm, Frans CT, Veeger, HEJ DirkJan, Makhsous, Mohsen, Van Roy, Peter, Anglin, Carolyn, . . . Wang, Xuguang. (2005). ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion-Part II: shoulder, elbow, wrist and hand. Journal of biomechanics, 38(5), 981-992. https://doi.org/10.1016/j.jbiomech.2004.05.042

Wunderlich, Fabian, Heuer, Herbert, Furley, Philip, & Memmert, Daniel. (2020). A serial-position curve in high-performance darts: The effect of visuomotor calibration on throwing accuracy. Psychological Research, 84(7), 2057-2064. https://doi.org/10.1007/s00426-019-01205-2

ORIGINAL ARTICLE

Comparative analysis of muscular fitness tests and their correlation with anthropometric data in children aged 9-12

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ABSTRACT

Physical fitness, encompassing cardiorespiratory endurance, muscular strength, and body composition, is vital for health and well-being. Muscular fitness, in particular, is associated with decreased risks of depression, cognitive disorders, and metabolic disease. Despite various available tests to measure muscle strength, there is no consensus on the most effective test or combination of tests, and direct comparisons are scarce. This study evaluated the muscular fitness of 484 children aged 9-12 years (225 girls and 259 boys) through multiple tests, including standing broad jump (SBJ), push-ups, bent-arm hang (BAH), sit-ups, handgrip strength, back-leg dynamometry (back-leg), and medicine ball throw (MBT), to assess their correlation with anthropometric data. Our correlation analysis revealed strong relationships (r > 0.6) between handgrip and MBT, handgrip and back-leg, and MBT and back-leg. However, most correlations were weak or very weak, indicating that different aspects of muscle strength, as assessed by these tests, are largely independent and cannot be substituted for one another. This underscores the necessity of employing a variety of tests in the comprehensive assessment of muscular fitness, taking into account the unique predictive value of each.

Keywords: Physical education, Strength, Physical fitness, Dynamometry.

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INTRODUCTION

Physical fitness is a crucial component of overall health and well-being, with monitoring being essential for analysing the condition of both society and individuals. Its components, as defined by the Cooper Institute (2010), include cardiorespiratory fitness, muscular fitness, and body composition. Muscular fitness is the ability of a muscle or a group of muscles to exert force maximally, swiftly, or repetitively (Fraser et al., 2021). Its importance is underscored by its association with improved health outcomes, such as a reduced risk of depression, cognitive dysfunction, and metabolic disorders. Reflecting these findings, the World Health Organization recommends muscle-strengthening and bone-strengthening activities for children aged 5-17 (Chaput et al., 2020).

The relationship between muscular fitness and health outcomes has been scrutinized through various tests, yet the evidence remains limited. For instance, while handgrip strength is positively associated with adiposity, it correlates negatively with body weight tests such as the vertical jump and standing broad jump (SBJ) (Smith et al., 2014). Cardiovascular disease has been linked to handgrip strength and SBJ (Sánchez-Delgado et al., 2023; Steene-Johannessen et al., 2009), and significant relationships with cardiovascular diseases have also been observed in push-ups, SBJ, and handgrip strength tests (Magnussen et al., 2012). However, data for other tests like the bent-arm hang (BAH), medicine ball throw (MBT), pulling strength dynamometers, and sit-ups remain scarce (Morikawa et al., 2018; Sánchez-Delgado et al., 2023; Smith et al., 2014).

Studies on secular trends in muscular fitness have yielded conflicting conclusions. Đurić et al. (2021) reported a decline in SBJ and BAH (21-42%), but a slight increase in the 60s sit-up test (1.1%). In contrast, Fühner et al. (2021) noted a general trend of a slight increase in relative strength and a negative trend in muscle power. While bodyweight tests are highly reliable, they do not match the accuracy of device measurements. A review analysis by Dooley et al. (Dooley et al., 2020) investigated the long-term trend in handgrip strength, revealing a gradual improvement of 3.8% per decade from 1967 to 2017 for children. Although this trend is well-established, results varied significantly between countries, and in some instances, the trend was reversed, as confirmed by Sandercock & Cohen (2019). Therefore, identifying trends is somewhat contingent on the choice of a specific test.

Assessing certain dimensions of physical fitness in children is a routine practice in most physical education curricula (Veldhuizen et al., 2015). Conducting physical fitness assessments serves as a means to evaluate the current fitness status of children, design customized training programs, monitor progress, stimulate participants, and advance physical education. The choice of test for determining muscular fitness levels varies considerably, and it is unclear which test or combination of tests is optimal. For assessing muscular fitness, bodyweight tests (push-ups, pull-ups, BAH, sit-ups) are often utilized to gauge relative strength and muscular endurance (Fühner et al., 2021; Chen et al., 2018). Exercises with external loads (bench press) are used less frequently. The SBJ is commonly employed to determine muscle power levels, and the MBT to a lesser extent. Handgrip strength is one of the most applied tests, with other devices used sporadically (Dooley et al., 2020). There is a broad spectrum of methods to assess muscle strength levels. Test batteries are also employed; however, the selection of tests is not standardized. Fitnessgram includes curl-up, push-ups, and trunk lift; Eurofit comprises SBJ, handgrip strength, and sit-ups (30s), and BAH; the HELENA study utilized SBJ and BAH, handgrip strength; the IDEFICS study included tests of SBJ and handgrip strength (de Miguel-Etayo et al., 2014; Chen et al., 2018; Moliner-Urdiales et al., 2010; Tomkinson et al., 2018).

No sources known to the authors have specifically compared individual tests of muscular fitness to determine their relationship. It is crucial for practice to ascertain which tests are most appropriate or whether a combination of multiple tests is required. This study aims to assess muscular fitness in children aged 9-12 years using a variety of tests, including bodyweight tests, exercises with external loads, and dynamometry. The tests will be analysed to establish their correlation with anthropometric measurements.

METHODS

Participants

The study sample comprised 484 Czech children from public schools, aged 9-12 years (mean age 11.1 ± 0.9 years), including 225 girls and 259 boys. Six schools were randomly selected, and students from grades 3 to 5 were included. All participants were Caucasian. Inclusion criteria were as follows: children within the 9-12 year age range for the duration of the study; absence of significant medical conditions as determined by a standard medical examination; and receipt of parental/legal guardian consent. The study excluded 37 children who did not complete all tests. The sample was stratified by age groups—9-10 (2012), 10-11 (2011), and 11-12 (2010) years—according to birth year. Testing occurred during regular physical education classes over the course of three sessions.

Parents or legal guardians received detailed information about the research process and provided written informed consent. The research was conducted in the latter half of 2022 and received ethical approval from the University of Hradec Kralove Committee for Research Ethics (Approval No. 12/2022), adhering to the Declaration of Helsinki.

Muscular fitness tests

Selected muscular fitness tests were based on established protocols from Fitnessgram, Eurofit, IDEFICS, and HELENA studies. The chosen tests—push-ups, bent-arm hang (BAH), and sit-ups—evaluated relative strength and muscular endurance. Standing broad jump (SBJ) and medicine ball throw (MBT) assessed muscle power. Absolute strength was measured using dynamometers for handgrip strength (MAP 80K1S, KERN. Kern & Sohn GmbH, Germany) and back-leg pulling (SH5007, Saehan Dynamometer. Saehan Corporation, India). These tests were selected to evaluate different muscle groups and aspects of muscular strength. Prior to testing, all children practiced the techniques and were encouraged throughout. Adequate rest periods of 2-5 minutes were provided between each attempt and each test to ensure recovery and maintain motivation. A standard 10-minute dynamic warm-up was completed by all children before testing.

Bent-arm hang (BAH) - the participant is lifted into position with their body raised to a height where their chin is above the bar. Test is stopped when their chin goes below the level of the bar. *Push-ups* – from start position the subject lowers the body until there is a 90-degree angle at the elbows, with the upper arms parallel to the floor. The number of valid repetitions counts. *Sit-ups* – Start lying on the back with the hands on the shoulders and the knees bent, the legs are held by the researcher. The subject must touch the knees with both elbows when lifted. The test is performed for 60 seconds. *Standing broad jump (SBJ)* – the starting position is standing behind the marked line. The participant had to jump and land with both feet at the same time. The distance from the starting line to the point of heel landing is measured. *Medicine ball throw (MBT)* – from a parallel position, the participant throws a medicine ball (3 kg, diameter 30 cm) with both hands from chest level. The distance is measured from the starting line to the point of ball impact. *Handgrip dynamometry (handgrip)* – the subject was standing with his elbow bent. *Pulling back-leg dynamometry (back-leg)* – the participant stands with both feet on the device and holds the handle with both hands at knee level. This motion simulates a partial deadlift.

Table 1. Results of anthropometry and muscular fitness tests.

	Weight (kg)	Height (cm)	BMI	SBJ (cm)	MBT (m)	BAH (s)	Handgrip (kg)	Back-leg (kg)	Push-ups (reps)	Sit-ups (reps)
All										
2012	37.81 (8.76)	144.73 (6.79)	17.96 (3.43)	138.66 (23.16)	3.19 (0.56)	7.05 (7.94)	19.31 (4.16)	53.82 (15.08)	12.14 (10.33)	21.42 (9.54)
2011	42.01 (11.43)	148.85 (8.27)	18.77 (3.88)	147.49 (27.3)	3.48 (0.79)	9.21 (10.49)	21.97 (5.69)	59.57 (17.42)	10.09 (9.28)	22.89 (7.73)
2010	49.06 (12.9)	156.05 (8.66)	19.97 (4.21)	157.17 (25.93)	4.18 (0.85)	8.58 (9.5)	25.87 (5.74)	70.46 (18.23)	10.52 (8.88)	27.45 (9.54)
All	43.49 (12.26)	150.41 (9.28)	18.99 (3.98)	148.7 (26.76)	3.66 (0.86)	8.4 (9.53)	22.7 (5.96)	62.05 (18.44)	10.8 (9.47)	24.18 (9.29)
Girls										
2012	38.41 (8.79)	144.65 (7.21)	18.26 (3.39)	133.2 (23.73)	3.05 (0.56)	7.08 (9.23)	18.74 (3.87)	51.27 (15.39)	10.15 (9.02)	20.94 (10.01)
2011	41.48 (9.32)	149.43 (8.73)	18.42 (3.01)	141.05 (26.96)	3.26 (0.75)	8.16 (9.7)	21.54 (5.59)	56.84 (16.88)	8.91 (9.23)	23.61 (8.01)
2010	50.87 (11.98)	157.15 (7.23)	20.44 (3.94)	151.19 (26.03)	3.94 (0.75)	6.98 (9.42)	25.82 (4.77)	66.58 (14.56)	8.67 (7.84)	27.99 (6.29)
All	43.51 (11.36)	150.39 (9.29)	19.02 (3.58)	141.82 (26.67)	3.41 (0.79)	7.44 (9.48)	22.02 (5.61)	58.2 (16.88)	9.23 (8.76)	24.17 (8.7)
Boys										
2012	37.09 (8.67)	144.82 (6.24)	17.59 (3.45)	145.24 (20.62)	3.35 (0.52)	7 (6.02)	20 (4.38)	56.9 (14.08)	14.53 (11.26)	21.98 (8.92)
2011	42.48 (13)	148.33 (7.81)	19.07 (4.49)	153.16 (26.32)	3.68 (0.77)	10.13 (11.06)	22.35 (5.74)	61.98 (17.52)	11.13 (9.2)	22.25 (7.41)
2010	47.84 (13.34)	155.32 (9.43)	19.65 (4.35)	161.2 (25.07)	4.35 (0.87)	9.66 (9.4)	25.9 (6.3)	73.07 (19.91)	11.77 (9.32)	27.09 (11.2)
All	43.4 (13.04)	150.36 (9.32)	18.95 (4.3)	154.76 (25.34)	5.21 (21.48)	9.26 (9.32)	23.25 (6.18)	65.46 (19.06)	12.27 (9.99)	24.21 (9.76)

Note. SBJ -standing broad jump; MBT – medicine ball throw; BAH – bent-arm hang; Back-leg – Pulling back-leg dynamometry.

Data analysis
Using the IBM SPSS software, version 20, the Spearman rank correlation coefficient was computed for all the obtained variables. The correlation was assessed in compliance with the following relationships (Abbott, 2011): ≤0.8 very strong relationship, 0.6-0.8 – strong relationship, 0.4-0.6 – moderate relationship, 0.2-0.4 weak relationship, <0.2 very weak relationship. The same software generated descriptive statistics and graphical representations of the data.

RESULTS

The anthropometry values are shown in Table 1. The mean values for all tests are described below. The sample was divided between boys and girls and also into three groups according to the date of their birth.

Table 2. Correlation results between muscular fitness tests and anthropometry.

	Weight (kg)	Height (cm)	BMI	SBJ (cm)	MBT (m)	BAH (s)	Handgrip (kg)	Back-leg (kg)	Push-ups (reps)	Sit-ups (reps)
All										
Weight	1.000	0.680	0.903	-0.090	0.515	-0.287	0.577	0.459	-0.264	-0.014
Height	0.680	1.000	0.314	0.180	0.539	-0.121	0.589	0.458	-0.159	0.195
BMI	0.903	0.314	1.000	-0.204	0.368	-0.309	0.416	0.346	-0.253	-0.126
SBJ	-0.090	0.180	-0.204	1.000	0.464	0.401	0.311	0.330	0.325	0.385
MBT	0.515	0.539	0.368	0.464	1.000	0.144	0.637	0.611	0.120	0.314
BAH	-0.287	-0.121	-0.309	0.401	0.144	1.000	0.111	0.120	0.424	0.303
Handgrip	0.577	0.589	0.416	0.311	0.637	0.111	1.000	0.629	0.067	0.258
Back-leg	0.459	0.458	0.346	0.330	0.611	0.120	0.629	1.000	0.237	0.325
Push-ups	-0.264	-0.159	-0.253	0.325	0.120	0.424	0.067	0.237	1.000	0.373
Sit-ups	-0.014	0.195	-0.126	0.385	0.314	0.303	0.258	0.325	0.373	1.000
Girls										
Weight	1.000	0.711	0.894	-0.040	0.560	-0.301	0.571	0.487	-0.228	0.037
Height	0.711	1.000	0.332	0.260	0.576	-0.106	0.618	0.507	-0.047	0.313
BMI	0.894	0.332	1.000	-0.223	0.393	-0.355	0.378	0.349	-0.285	-0.162
SBJ	-0.040	0.260	-0.223	1.000	0.491	0.353	0.308	0.323	0.314	0.426
MBT	0.560	0.576	0.393	0.491	1.000	0.083	0.607	0.592	0.137	0.372
BAH	-0.301	-0.106	-0.355	0.353	0.083	1.000	0.038	0.077	0.375	0.297
Handgrip	0.571	0.618	0.378	0.308	0.607	0.038	1.000	0.618	0.064	0.308
Back-leg	0.487	0.507	0.349	0.323	0.592	0.077	0.618	1.000	0.206	0.344
Push-ups	-0.228	-0.047	-0.285	0.314	0.137	0.375	0.064	0.206	1.000	0.364
Sit-ups	0.037	0.313	-0.162	0.426	0.372	0.297	0.308	0.344	0.364	1.000
Boys										
Weight	1.000	0.662	0.909	-0.138	-0.062	-0.284	0.589	0.450	-0.303	-0.052
Height	0.662	1.000	0.307	0.111	-0.074	-0.139	0.577	0.429	-0.263	0.100
BMI	0.909	0.307	1.000	-0.203	-0.056	-0.283	0.449	0.352	-0.244	-0.104
SBJ	-0.138	0.111	-0.203	1.000	0.067	0.430	0.282	0.280	0.295	0.376
MBT	-0.062	-0.074	-0.056	0.067	1.000	0.070	-0.056	0.074	0.174	0.042
BAH	-0.284	-0.139	-0.283	0.430	0.070	1.000	0.147	0.129	0.453	0.312
Handgrip	0.589	0.577	0.449	0.282	-0.056	0.147	1.000	0.622	0.027	0.222
Back-leg	0.450	0.429	0.352	0.280	0.074	0.129	0.622	1.000	0.223	0.324
Push-ups	-0.303	-0.263	-0.244	0.295	0.174	0.453	0.027	0.223	1.000	0.386
Sit-ups	-0.052	0.100	-0.104	0.376	0.042	0.312	0.222	0.324	0.386	1.000

Note. SBJ -standing broad jump; MBT – medicine ball throw; BAH – bent-arm hang; Back-leg – Pulling back-leg dynamometry.

Table 2 shows the results of the Spearman correlation of the whole sample. A strong correlation was found between the variables handgrip and MBT (0.637), back-leg and handgrip (0.629), back-leg and MBT (0.610). Moderate correlations were found for SBJ and MBT (0.464), push-ups, and BAH (0.424). Otherwise, there was a weak or very weak correlation. When anthropometry and muscle testing were analysed, the strongest correlations were identified between handgrip and height and weight (0.589 and 0.576, respectively), and weight and MBT (0.514). The other relationships were weak or very weak and for the push-ups, and BAH tests a negative trend was reported. In the performance of girls, a strong correlation was found between MBT and handgrip and back-leg, respectively (0.606, 0.617), and comparably for handgrip and back-leg (0.592). In boys, a strong correlation was identified between back-leg and handgrip (0.621). Moderate correlations were found between the following variables: SBJ and BAH (0.430); BAH and push-ups (0.452).

Table 3. Correlation results between muscular fitness tests and anthropometry in age groups.

	Weight (kg)	Height (cm)	BMI	SBJ (cm)	MBT (m)	BAH (s)	Handgrip (kg)	Back-leg (kg)	Push-ups (reps)	Sit-ups (reps)
2012										
Weight	1.000	0.546	0.911	-0.189	0.305	-0.359	0.500	0.355	-0.278	-0.212
Height	0.546	1.000	0.162	0.181	0.355	-0.175	0.414	0.303	-0.148	0.044
BMI	0.911	0.162	1.000	-0.311	0.199	-0.353	0.389	0.279	-0.257	-0.265
SBJ	-0.189	0.181	-0.311	1.000	0.472	0.315	0.285	0.284	0.309	0.360
MBT	0.305	0.355	0.199	0.472	1.000	0.018	0.420	0.425	0.128	0.128
BAH	-0.359	-0.175	-0.353	0.315	0.018	1.000	-0.044	-0.028	0.268	0.320
Handgrip	0.500	0.414	0.389	0.285	0.420	-0.044	1.000	0.637	0.003	0.062
Back-leg	0.355	0.303	0.279	0.284	0.425	-0.028	0.637	1.000	0.216	0.066
Push-ups	-0.278	-0.148	-0.257	0.309	0.128	0.268	0.003	0.216	1.000	0.346
Sit-ups	-0.212	0.044	-0.265	0.360	0.128	0.320	0.062	0.066	0.346	1.000
2011										
Weight	1.000	0.649	0.920	-0.199	0.463	-0.314	0.506	0.453	-0.197	-0.124
Height	0.649	1.000	0.310	0.044	0.465	-0.111	0.523	0.477	-0.041	0.181
BMI	0.920	0.310	1.000	-0.271	0.352	-0.349	0.362	0.330	-0.230	-0.240
SBJ	-0.199	0.044	-0.271	1.000	0.360	0.456	0.100	0.174	0.373	0.330
MBT	0.463	0.465	0.352	0.360	1.000	0.138	0.507	0.523	0.176	0.227
BAH	-0.314	-0.111	-0.349	0.456	0.138	1.000	0.113	0.104	0.534	0.319
Handgrip	0.506	0.523	0.362	0.100	0.507	0.113	1.000	0.480	0.167	0.176
Back-leg	0.453	0.477	0.330	0.174	0.523	0.104	0.480	1.000	0.281	0.333
Push-ups	-0.197	-0.041	-0.230	0.373	0.176	0.534	0.167	0.281	1.000	0.461
Sit-ups	-0.124	0.181	-0.240	0.330	0.227	0.319	0.176	0.333	0.461	1.000
2010										
Weight	1.000	0.615	0.906	-0.244	0.409	-0.336	0.484	0.316	-0.334	-0.100
Height	0.615	1.000	0.241	-0.001	0.353	-0.219	0.456	0.235	-0.276	0.002
BMI	0.906	0.241	1.000	-0.265	0.332	-0.296	0.373	0.279	-0.265	-0.119
SBJ	-0.244	-0.001	-0.265	1.000	0.406	0.393	0.314	0.323	0.381	0.339
MBT	0.409	0.353	0.332	0.406	1.000	0.201	0.616	0.586	0.177	0.259
BAH	-0.336	-0.219	-0.296	0.393	0.201	1.000	0.151	0.193	0.457	0.302
Handgrip	0.484	0.456	0.373	0.314	0.616	0.151	1.000	0.601	0.101	0.205
Back-leg	0.316	0.235	0.279	0.323	0.586	0.193	0.601	1.000	0.318	0.304
Push-ups	-0.334	-0.276	-0.265	0.381	0.177	0.457	0.101	0.318	1.000	0.404
Sit-ups	-0.100	0.002	-0.119	0.339	0.259	0.302	0.205	0.304	0.404	1.000

Note. SBJ -standing broad jump; MBT – medicine ball throw; BAH – bent-arm hang; Back-leg – Pulling back-leg dynamometry.

Relationships between variables were also found between age groups (Table 3). Situations, where at least a moderate relationship was identified, are described further. For the 9-10 years group, strong correlations were found between handgrip and back-leg (0.600), MBT and dynamometry (0.616 and 0.585, respectively); moderate relationships were found between push-ups and BAH (0.457) and sit-ups (0.404). For both boys and girls, the strongest relationships were found between MBT and dynamometry, and SBJ, respectively. Boys also showed a significant relationship between push-ups and BAH.

The entire group of 10-11 years showed r values > 0.4 in the following cases: push-ups and BAH (0.534), MBT and dynamometry (0.506 and 0.522, respectively), handgrip and back-leg (0.479), and push-ups and SBJ (0.455). Girls showed a more significant relationship for MBT and dynamometry (0.587 and 0.485, respectively), and BAH and SBJ (0.564). For boys, the tests (> 0.4) were: MBT and dynamometry, BAH and push-ups.

The 11-12 year group showed a strong correlation between handgrip and back-leg (0.637), moderate for MBT and handgrip, with weak or very weak correlations in all other cases. For both girls and boys, there was a strong correlation between handgrip and back-leg.

DISCUSSION

The primary goal of our study was to evaluate and correlate various muscular fitness tests with anthropometric measurements among Czech children. Out of the seven tests administered, only handgrip with MBT, handgrip with back-leg, and MBT with back-leg demonstrated a strong relationship (r > 0.6). The BAH and push-ups exhibited a moderate correlation. In most instances, correlations were weak or very weak (r > 0.4). This pattern was consistent when examining the relationship between anthropometric variables and muscle tests, with height and weight showing moderate correlations with handgrip and MBT tests. While gender and age group analyses yielded some robust correlations for dynamometry, MBT, and anthropometric measurements, these were not universally observed across all groups.

Previous research has indicated similar trends in the assessment of relative strength, particularly in upper body strength (Beunen & Thomis, 2000; Chen et al., 2018; Milliken et al., 2008). Our findings, however, revealed only moderate correlations, indicating that while there is a common trend, it is not particularly strong. The results suggest that each test of relative strength—including push-ups, BAH, and sit-ups—provides unique insights and does not independently or adequately predict upper body strength. Consequently, reliance on a single test for assessment could lead to misleading conclusions.

The use of the pulling back-leg dynamometer is an innovative approach, offering an alternative to the classical deadlift, which is more technically demanding (Schlegel et al., 2022). This type of pulling strength (isometric midthigh pull) correlates strongly with the 1 RM deadlift (De Witt et al., 2018). Although not as prevalent in children, testing one-repetition maximum (1 RM) has been shown to be effective and safe (Faigenbaum et al., 2003). The absolute strength parameter shows a strong association (r ≥ 0.6) with anthropometric measurements in adult population (Ferland et al., 2020). We can only partially confirm this phenomenon in child population. Before the onset of puberty, there is a marked difference in body composition, amount of muscle mass, and muscle fibre composition (Ervin et al., 2014; Esbjörnsson et al., 2021), which likely influences this relationship.

The study observed a consistent trend where dynamometry measurements strongly correlated with the MBT test, suggesting that the 3 kg medicine ball throw could serve as a predictive marker of absolute strength and a potential substitute for more complex dynamometry in field assessments. However, this hypothesis requires further investigation for validation. The expected strong correlations between handgrip strength, relative strength (push-ups, BAH), and absolute strength did not materialize as anticipated, which contrasts with other studies (Pate et al., 1993; Wind et al., 2010). Although both categories represent a valid tool of testing muscle strength (Baumgartner et al., 2002; Molenaar et al., 2008), no significant association was found here. These discrepancies highlight the necessity for distinct assessments for relative and absolute strength.

When analysed by age, the study did not consistently observe strong correlations between tests or anthropometric measurements. This suggests that a finer stratification by year or even shorter intervals may be more appropriate for analysing physical fitness parameters. Notably, significant changes in physical fitness can occur over quarters, as shown by Veldhuizen et al. (2015). Thus, we recommend yearly evaluations to yield more precise outcomes. This approach is particularly relevant for larger cohorts where biological age significantly influences data interpretation (Gómez-Campos et al., 2018).

Height and weight were not strongly correlated with relative strength (BAH, push-ups, sit-ups) in prepubertal children. While higher weight often corresponds to poorer performance (Castro-Piñero et al., 2009; Ervin et al., 2014; Martínez-López et al., 2018), our study identified only a weak negative correlation, suggesting that this relationship may strengthen during adolescence or adulthood, as supported by other research (Markovic & Jaric, 2004).

The simultaneous assessment of dynamic and relative strength is common in test batteries; however, our results indicate that these dimensions of strength are only weakly related and should be tested independently. Furthermore, SBJ remains an isolated measure of lower body dynamic strength, with no substantial connection to absolute strength. Although SBJ is a reliable predictor of dynamic strength or speed performance, its correlation to overall health or fitness in adults remains ambiguous (Rodriguez et al., 2021; Thomas et al., 2020).

A limitation of our study was the non-standardized age grouping, as no gradual increase in handgrip strength was observed between the 9-10 and 11-12 age groups. Additionally, the presence of zero scores on the push-ups and BAH tests in 12-15% of the children could have skewed the data analysis, suggesting the need for alternative assessments in future research.

CONCLUSION

Assessing muscular fitness is a crucial element of evaluating health and wellness. Our study has established robust correlations specifically between dynamometry and MBT. Furthermore, we found significant but varying degrees of correlation between anthropometric measurements and specific tests such as handgrip and back-leg, with height and weight showing minimal to negative correlations with bodyweight tests like the BAH. The majority of correlations, particularly when accounting for age differences, were weak, suggesting that distinct muscle strength types and their respective tests largely operate independently and cannot be reliably interchanged. Consequently, to gain a comprehensive understanding of muscular fitness, it is essential to utilize a combination of tests, carefully selected for their predictive accuracy and relevance.

AUTHOR CONTRIBUTIONS

Petr Schlegel: conceptualization, methodology, writing – review and editing, supervision. Adam Křehký: formal analysis, data analysis.

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REFERENCES

Abbott, M. L. (2011). Understanding Educational Statistics Using Microsoft Excel and SPSS (1. vyd.). Wiley.

Baumgartner, T. A., Oh, S., Chung, H., & Hales, D. (2002). Objectivity, Reliability, and Validity for a Revised Push-Up Test Protocol. Measurement in Physical Education and Exercise Science, 6(4), 225-242. https://doi.org/10.1207/S15327841MPEE0604_2

Beunen, G., & Thomis, M. (2000). Muscular Strength Development in Children and Adolescents. Pediatric Exercise Science, 12, 174-197. https://doi.org/10.1123/pes.12.2.174

Castro-Piñero, J., González-Montesinos, J. L., Mora, J., Keating, X. D., Girela-Rejón, M. J., Sjöström, M., & Ruiz, J. R. (2009). Percentile values for muscular strength field tests in children aged 6 to 17 years: Influence of weight status. Journal of Strength and Conditioning Research, 23(8), 2295-2310. https://doi.org/10.1519/JSC.0b013e3181b8d5c1

Cooper institute. (2010). Fitnessgram & Activitygram Test Administration Manual-Updated 4th Edition (4 edition). Human Kinetics.

De Witt, J. K., English, K. L., Crowell, J. B., Kalogera, K. L., Guilliams, M. E., Nieschwitz, B. E., Hanson, A. M., & Ploutz-Snyder, L. L. (2018). Isometric Midthigh Pull Reliability and Relationship to Deadlift One Repetition Maximum. The Journal of Strength & Conditioning Research, 32(2), 528. https://doi.org/10.1519/JSC.0000000000001605

de Miguel-Etayo, P., Gracia-Marco, L., Ortega, F. B., Intemann, T., Foraita, R., Lissner, L., Oja, L., Barba, G., Michels, N., Tornaritis, M., Molnár, D., Pitsiladis, Y., Ahrens, W., Moreno, L. A., & IDEFICS consortium. (2014). Physical fitness reference standards in European children: The IDEFICS study. International Journal of Obesity (2005), 38 Suppl 2, S57-66. https://doi.org/10.1038/ijo.2014.136

Dooley, F. L., Kaster, T., Fitzgerald, J. S., Walch, T. J., Annandale, M., Ferrar, K., Lang, J. J., Smith, J. J., & Tomkinson, G. R. (2020). A Systematic Analysis of Temporal Trends in the Handgrip Strength of 2,216,320 Children and Adolescents Between 1967 and 2017. Sports Medicine (Auckland, N.Z.), 50(6), 1129-1144. https://doi.org/10.1007/s40279-020-01265-0

Đurić, S., Sember, V., Starc, G., Sorić, M., Kovač, M., & Jurak, G. (2021). Secular trends in muscular fitness from 1983 to 2014 among Slovenian children and adolescents. Scandinavian Journal of Medicine & Science in Sports, 31(9), 1853-1861. https://doi.org/10.1111/sms.13981

Ervin, R. B., Fryar, C. D., Wang, C.-Y., Miller, I. M., & Ogden, C. L. (2014). Strength and Body Weight in US Children and Adolescents. Pediatrics, 134(3), e782-e789. https://doi.org/10.1542/peds.2014-0794

Esbjörnsson, M. E., Dahlström, M. S., Gierup, J. W., & Jansson, E. C. (2021). Muscle fiber size in healthy children and adults in relation to sex and fiber types. Muscle & Nerve, 63(4), 586-592. https://doi.org/10.1002/mus.27151

Faigenbaum, A. D., Milliken, L. A., & Westcott, W. L. (2003). Maximal Strength Testing in Healthy Children. The Journal of Strength & Conditioning Research, 17(1), 162. https://doi.org/10.1519/1533-4287(2003)017<0162:MSTIHC>2.0.CO;2

Ferland, P.-M., Pollock, A., Swope, R., Ryan, M., Reeder, M., Heumann, K., & Comtois, A. S. (2020). The Relationship Between Physical Characteristics and Maximal Strength in Men Practicing the Back Squat, the Bench Press and the Deadlift. International Journal of Exercise Science, 13(4), 281-297.

Fraser, B. J., Rollo, S., Sampson, M., Magnussen, C. G., Lang, J. J., Tremblay, M. S., & Tomkinson, G. R. (2021). Health-Related Criterion-Referenced Cut-Points for Musculoskeletal Fitness Among Youth: A Systematic Review. Sports Medicine (Auckland, N.Z.), 51(12), 2629-2646. https://doi.org/10.1007/s40279-021-01524-8

Fühner, T., Kliegl, R., Arntz, F., Kriemler, S., & Granacher, U. (2021). An Update on Secular Trends in Physical Fitness of Children and Adolescents from 1972 to 2015: A Systematic Review. Sports Medicine (Auckland, N.Z.), 51(2), 303-320. https://doi.org/10.1007/s40279-020-01373-x

Gómez-Campos, R., Andruske, C. L., Arruda, M. de, Sulla-Torres, J., Pacheco-Carrillo, J., Urra-Albornoz, C., & Cossio-Bolaños, M. (2018). Normative data for handgrip strength in children and adolescents in the Maule Region, Chile: Evaluation based on chronological and biological age. PLOS ONE, 13(8), e0201033. https://doi.org/10.1371/journal.pone.0201033

Chaput, J.-P., Willumsen, J., Bull, F., Chou, R., Ekelund, U., Firth, J., Jago, R., Ortega, F. B., & Katzmarzyk, P. T. (2020). 2020 WHO guidelines on physical activity and sedentary behaviour for children and adolescents aged 5-17 years: Summary of the evidence. International Journal of Behavioral Nutrition and Physical Activity, 17(1), 141. https://doi.org/10.1186/s12966-020-01037-z

Chen, W., Hammond-Bennett, A., Hypnar, A., & Mason, S. (2018). Health-related physical fitness and physical activity in elementary school students. BMC Public Health, 18(1), 195. https://doi.org/10.1186/s12889-018-5107-4

Magnussen, C. G., Schmidt, M. D., Dwyer, T., & Venn, A. (2012). Muscular fitness and clustered cardiovascular disease risk in Australian youth. European Journal of Applied Physiology, 112(8), 3167-3171. https://doi.org/10.1007/s00421-011-2286-4

Markovic, G., & Jaric, S. (2004). Movement performance and body size: The relationship for different groups of tests. European Journal of Applied Physiology, 92(1), 139-149. https://doi.org/10.1007/s00421-004-1076-7

Martínez-López, E. J., De La Torre-Cruz, M. J., Suárez-Manzano, S., & Ruiz-Ariza, A. (2018). Analysis of the Effect Size of Overweight in Muscular Strength Tests Among Adolescents: Reference Values According to Sex, Age, and Body Mass Index. Journal of Strength and Conditioning Research, 32(5), 1404-1414. https://doi.org/10.1519/JSC.0000000000001967

Milliken, L. A., Faigenbaum, A. D., Loud, R. L., & Westcott, W. L. (2008). Correlates of Upper and Lower Body Muscular Strength in Children. The Journal of Strength & Conditioning Research, 22(4), 1339. https://doi.org/10.1519/JSC.0b013e31817393b1

Molenaar, H. M. (Ties), Zuidam, J. M., Selles, R. W., Stam, H. J., & Hovius, S. E. R. (2008). Age-Specific Reliability of Two Grip-Strength Dynamometers When Used by Children. JBJS, 90(5), 1053. https://doi.org/10.2106/JBJS.G.00469

Moliner-Urdiales, D., Ruiz, J. R., Ortega, F. B., Jiménez-Pavón, D., Vicente-Rodriguez, G., Rey-López, J. P., Martínez-Gómez, D., Casajús, J. A., Mesana, M. I., Marcos, A., Noriega-Borge, M. J., Sjöström, M., Castillo, M. J., Moreno, L. A., & AVENA and HELENA Study Groups. (2010). Secular trends in health-related physical fitness in Spanish adolescents: The AVENA and HELENA studies. Journal of Science and Medicine in Sport, 13(6), 584-588. https://doi.org/10.1016/j.jsams.2010.03.004

Morikawa, S. Y., Fujihara, K., Hatta, M., Osawa, T., Ishizawa, M., Yamamoto, M., Furukawa, K., Ishiguro, H., Matsunaga, S., Ogawa, Y., Shimano, H., & Sone, H. (2018). Relationships among cardiorespiratory fitness, muscular fitness, and cardiometabolic risk factors in Japanese adolescents: Niigata screening for and preventing the development of non-communicable disease study-Agano

(NICE EVIDENCE Study-Agano) 2. Pediatric Diabetes, 19(4), 593-602. https://doi.org/10.1111/pedi.12623

Pate, R. R., Burgess, M. L., Woods, J. A., Ross, J. G., & Baumgartner, T. (1993). Validity of field tests of upper body muscular strength. Research Quarterly for Exercise and Sport, 64(1), 17-24. https://doi.org/10.1080/02701367.1993.10608774

Sandercock, G. R. H., & Cohen, D. D. (2019). Temporal trends in muscular fitness of English 10-year-olds 1998-2014: An allometric approach. Journal of Science and Medicine in Sport, 22(2), 201-205. https://doi.org/10.1016/j.jsams.2018.07.020

Sánchez-Delgado, A., Pérez-Bey, A., Izquierdo-Gómez, R., Jimenez-Iglesias, J., Marcos, A., Gómez-Martínez, S., Girela-Rejón, M. J., Veiga, O. L., & Castro-Piñero, J. (2023). Fitness, body composition, and metabolic risk scores in children and adolescents: The UP&DOWN study. European Journal of Pediatrics, 182(2), 669-687. https://doi.org/10.1007/s00431-022-04707-1

Schlegel, P., Křehký, A., & Hiblbauer, J. (2022). Physical Fitness Improvement after 8 Weeks of High-intensity Interval Training with Air Bike. Sport Mont, 20, 75-80. https://doi.org/10.26773/smj.221012

Smith, J. J., Eather, N., Morgan, P. J., Plotnikoff, R. C., Faigenbaum, A. D., & Lubans, D. R. (2014). The health benefits of muscular fitness for children and adolescents: A systematic review and meta-analysis. Sports Medicine (Auckland, N.Z.), 44(9), 1209-1223. https://doi.org/10.1007/s40279-014-0196-4

Steene-Johannessen, J., Anderssen, S. A., Kolle, E., & Andersen, L. B. (2009). Low muscle fitness is associated with metabolic risk in youth. Medicine and Science in Sports and Exercise, 41(7), 1361-1367. https://doi.org/10.1249/MSS.0b013e31819aaae5

Tomkinson, G. R., Carver, K. D., Atkinson, F., Daniell, N. D., Lewis, L. K., Fitzgerald, J. S., Lang, J. J., & Ortega, F. B. (2018). European normative values for physical fitness in children and adolescents aged 9-17 years: Results from 2 779 165 Eurofit performances representing 30 countries. British Journal of Sports Medicine, 52(22), 1445-14563. https://doi.org/10.1136/bjsports-2017-098253

Veldhuizen, S., Cairney, J., Hay, J., & Faught, B. (2015). Relative age effects in fitness testing in a general school sample: How relative are they? Journal of Sports Sciences, 33(2), 109-115. https://doi.org/10.1080/02640414.2014.934708

Wind, A. E., Takken, T., Helders, P. J. M., & Engelbert, R. H. H. (2010). Is grip strength a predictor for total muscle strength in healthy children, adolescents, and young adults? European Journal of Pediatrics, 169(3), 281-287. https://doi.org/10.1007/s00431-009-1010-4

ORIGINAL ARTICLE

Comparing and analyzing elite soft tennis players: Match workload, technique, and action area in high-level competitive games

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ABSTRACT

Analysing data from high-level matches soft tennis from elite players is something that coaches and athletes can use to improve their training and competition. The study aimed to compare the match workload action areas and analyse techniques between male and female soft tennis players in high-level competitions from soft tennis in 10 final matches. Data analysis of match workload, techniques, and action areas occur in matches performed using the Dartfish software. The data is analysed statistically, compared between males and females for match workload, and presented as percentages for each technique and action area. The results of the analysis showed that Rally time shots, Rally total time Work Density, and Percentage rally during the match of male players were significantly higher than those of female players, $p \leq .05$. The Flat technique was used more at the competition (Male; Forehand 38.77% Backhand 39.19% and Female player, Forehand and Backhand are equal at 36.91%) with the correlation between both techniques being r = .0974. Slice and Lob techniques 3.00-10.08%, and Volley and Smash techniques used the least during matches. The playing area of all players will be at the Mid left, up to 31.99-41.10%. Fore right is the area with the least play, 1.97-3.21%. Data from the study shows that male players have a higher match workload than women. However, there are no differences in the use of techniques in the competition, including the playing action area. This result will help coaches and players practice and develop their abilities at a higher level.

Keywords: Performance analysis, Racket sport, Workload analysis, Action area, Technical analysis, Match analysis.

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INTRODUCTION

Soft tennis is a racquet sport that combines technical skills in competition and physical fitness. It involves intermittent high-intensity levels and short rest periods (Martínez, 2014; Mellado-Arbelo & Baiget, 2022). Coordination mainly involves working between the wrists, arms, and torso to create power and accuracy in shots. Therefore, players must have good hand-eye coordination to display their playing skills and techniques (Cui et al., 2017; Paul et al., 2011). Players must have quick feet and agility to move around the field and reach the ball quickly. Footwork involves taking short steps and quick changes in direction to predict the opponent's shot and position for the next shot. Just as one of the critical physiological characteristics of soft tennis is cardiovascular endurance, soft tennis matches can be long and physically demanding, requiring players to have a high level of physical fitness. High levels of aerobic and anaerobic exercise combined (Kilit et al., 2016; Kovacs, 2007; Lees, 2003) and an athlete's stamina can help increase the muscle power needed to create powerful shots in the field. Soft tennis Players must, therefore, focus on improving their cardiovascular fitness, Including strength and muscle power (O'Donoghue et al., 2013). Athletes, therefore, need to develop specific technical and fitness skills simultaneously.

Long and intense competitions cause increased fatigue in the physical (Gomes et al., 2011). Therefore, physical readiness and skills used in competitions must be well-trained. Because the outcome of the competition depends on the decision to hit each point (Kolman et al., 2018), using technology to record data and analyse data from competitions to provide coaches and athletes with a clearer image (Hiroo et al., 2023). Competition data can also be used to plan training, such as intensity, volume, and amount of use. Technique and the speed used in competition can be used to improve and design the players' training programs, leading to training close to real competition (Carvalho et al., 2013; Filipcic et al., 2022). However, the intensity of the competition varies with the players' skill levels (Mellado-Arbelo & Baiget, 2022). At the top level of competition, experienced players at a high level tend to adapt well to training programs and the intensity of competition. As the length of the competition increases, they can better control the situation and pressure of the competition and maintain their physical fitness better than those with less experience (Kovalchik & Ingram, 2018), giving them a greater chance of winning due to their physicality. Technical and tactical skills are superior to the opponent's (Gomes et al., 2011; Kovalchik & Ingram, 2018). Adequate and appropriate training using data is therefore necessary. Allow athletes to develop their physical abilities and skills to the highest level (Kolman et al., 2023; Torres-Luque et al., 2011).

Therefore, it is necessary to use data obtained from the analysis of high-level games for training or competition, considering of the duration of the competition. Rally time ratio of work and rest Intensity of the game Techniques and skills used in competitions (Carboch et al., 2018; Carboch et al., 2019; Martínez-Gallego et al., 2021). Based on video recordings. Today's data analysis programs and technologies provide visibility into critical competitive data (Hiroo et al., 2023), expressed in simple percentages or numbers that are easier for coaches or athletes to understand (Fitzpatrick et al., 2019) and can develop skills, techniques, and physical fitness to be more suitable for soft tennis. This study is therefore interested in analysing and comparing the differences in workload between male and female soft tennis players, as well as the proportion of use of skills, techniques, and playing areas of soft tennis players and leading in order to lead to further development of the trainer's training program.

METHODS

Participants and Measures data

This study is a quantitative data analysis of the competition of top soft tennis athletes from three event finals round (World Championships, Asian Championships, and Asian Games) from 2016-2022 by selecting from match with more than 50 points from competing in the men (5 match) and women (5 match), totalling ten matches. Before the analysis, the researcher checked the scores of each match to ensure that the data to be analysed totalled more than 50 points in each match. The data analysis will divide into three topics these include workload, techniques and skills and action areas. Experts with experience as five coaches and sports scientists of more than 6 ± 2.0 years determined variable analysis. The computer software Dartfish Live S v.10 will analyse the data for all competitions. This research received an exemption from human research ethics from the Human Research Ethics Committee Sirindhorn College of Public Health, Yala.

Procedures

Video analysis was recorded by a Sony Handycam (HDR PJ670) video resolution: AVCHD 1920 x 1080/60p) with a tripod. The video camera will be placed behind the players on either side and 8-10 meters from the field. The camera angle is such that the players and the entire field on both sides can be seen. (Figure 1).

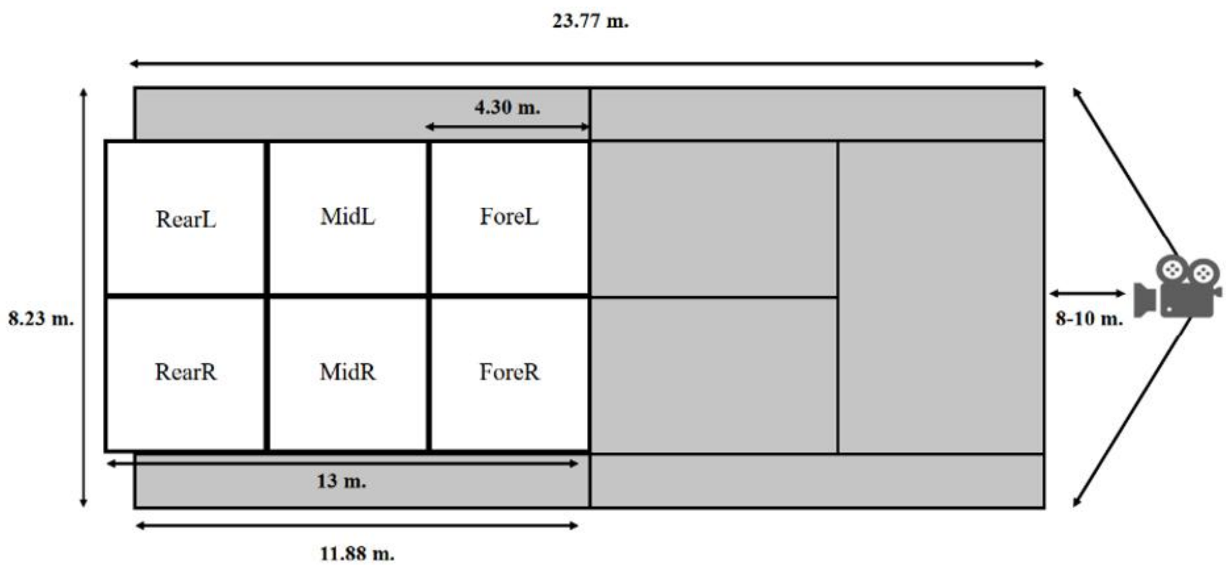

Figure 1. Location of video cameras and analysis of areas within the court.

Data analysis uses the computer program Dartfish Live S v.10 to analyse and compile data from video recordings of selected matches. It records the first data Match workload, including Rally Time (RLT), Time of rally for each score, Rest Time (RT), rest time for each score, Total Time (TT); total time of match, Shots Rally (SRL); number of shot per one score, Work Density (WD); ratio between RLT/RT, Percentage Rally during Match (%RLM); Percentage of total rally time, Percentage Rest during Match (%RM); percentage of total rest time and percentage of time wasting (%TW).

The second data: Technique during match include Forehand Flat (FHFlat), Backhand Flat (BHFlat), Forehand Slice (FHSlice), Backhand Slice (BHSlice), Forehand Lob (FHLob), Backhand Lob (BHLob), Forehand Volley (FHVL), Backhand Volley (BHVL), Forehand Smash (FHSM), and Backhand Smash (BHSM). The third data: Action area includes Fore Left (ForeL), Fore Right (ForeR), Mid Left (MidL), Mid Right (MidR), Rear Left

(RearL), and Rear Right (RearR) (Figure 1). During data analysis, the researcher will have control over the analysis program. All match analysis data will be re-analysed to prevent errors and will not be edited later by researchers to avoid opinions or beliefs about the data.

Statistical analysis

Statistical analysis was performed by SPSS version 26 (IBM, Chicago, Illinois, United States of America) used the independent sample T-Test to compare the match workload between the ten men's and women's matches. The correlation of technique during matches was determined using statistics Pearson correlation. It shows the mean and standard deviation of the data, including presenting the percentage of the item. Statistical significance was set at the $p \leq .05$.

RESULTS

From the results of the independent sample T-Test statistical in the match load analysis found that RLT, SRL, TT, WD, and %RLM of males had a significantly higher average than females, $p < .05$ However, no difference in RT and %RT and %TW (Table 1).

Table 1 Compare the match load data between the men vs women competitions.

Parameter	Workload		
	Female ± SD	Male ± SD	*p*
Rally Time (sec)	7.78 ± 2.66	18.38 ± 6.78	0.012*
Rest Time (sec)	29.7 ± 4.95	32.02 ± 3.02	0.397
Shot Rally (N)	4.87 ± 1.70	12.58 ± 4.64	0.008*
Total Time (min)	22.46 ± 8.40	42.84 ± 13.63	0.022*
Work Density	0.26 ± 0.09	0.58 ± 0.22	0.019*
Percentage Rally during Match (%)	19.70 ± 2.78	32.81 ± 7.84	0.005*
Percentage Rest during Match (%)	73.59 ± 12.95	57.91 ± 9.18	0.058*
Percentage of time wasting (%)	7.27 ± 11.24	9.27 ± 5.09	7.260

*Note. *p ≤ .05.*

The FHFlat and BHFlat techniques were used the most in the competition (Men; FHFlat 38.77%, BHFlat 39.19% and Women; FHFlat 36.91%, BHFlat 36.91%), with the techniques having Pearson correlation high level r = .974 statistically significant $p > .05$, followed by FHSlice and BHSlice (Men; BHSlice 8.32% FHSlice 5.78% and Women; FHSlice 10.08% BHSlice 7.20%) with a Pearson correlation moderate level r = .710, which is statistically significant at the .05. Other techniques, FHLob and BHLob technique women slightly higher than men (Women BHLob 7.33% and FHLob 6.68%, Men; BHLob 3.23% FHLob 3.00%), with FHVL, BHVL FHSM and BHSM being the techniques that Used least (Men; FHVL 0.49% BHVL 0.42% FHSM 0.68% BHSM0.11% and Women; FHVL 0.92% BHVL 0.52% FHSM 0.39% BHSM 0.13%, respectively).

Action area found that MidL is the area used for playing the most (men 41.10%, women 31.99%), followed by RearL (men 23.44%, women 19.63%), MidR (men 17.09%, women 21.94%) RearR (men 11.02% women 17.32%) ForeL (men 5.38% women 6.00%) and the least was ForeR (men 1.97% women 3.12%), respectively.

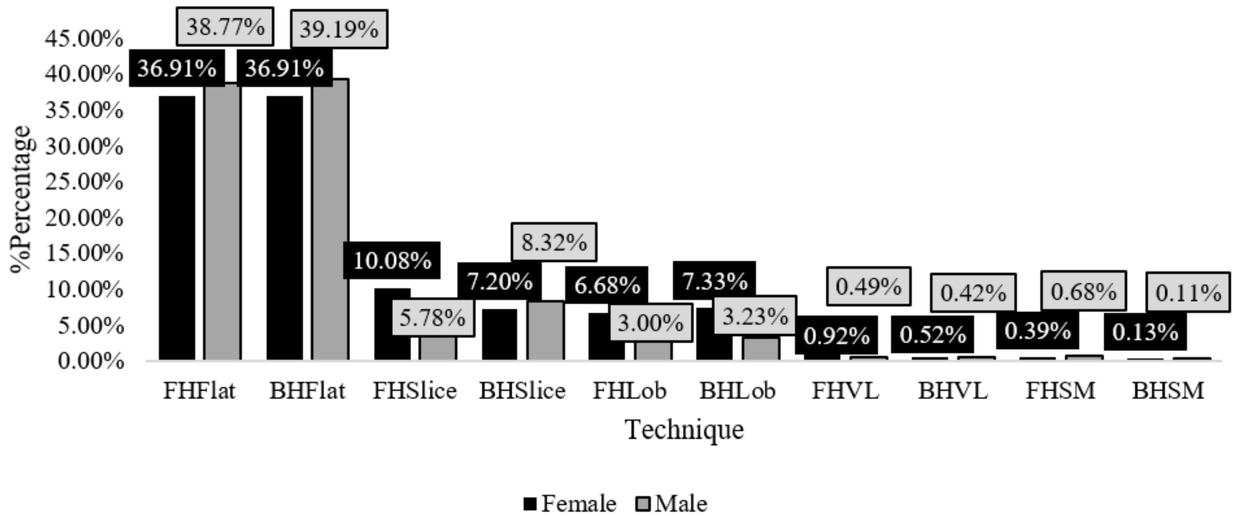

Figure 2. Percentage of techniques used during match by men and women players.

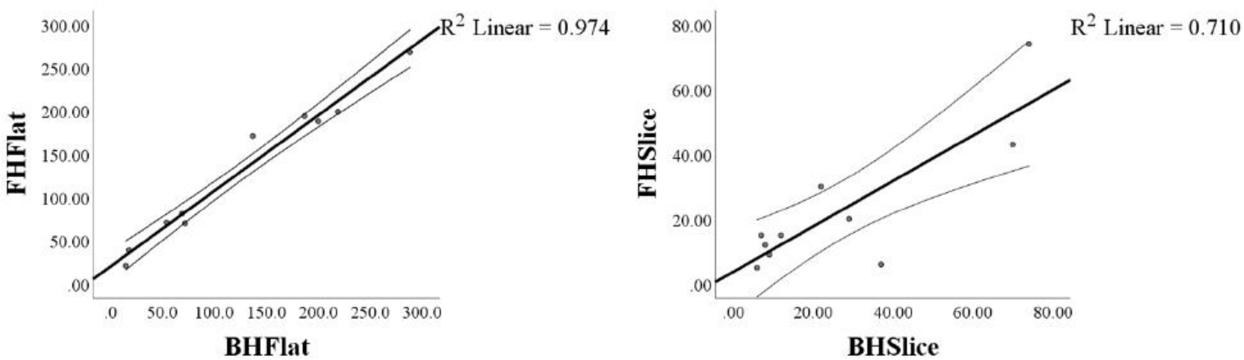

Figure 3. Pearson Correlation techniques used by all players during matches.

DISCUSSION

The match workload of competition between men and women players is different, especially the duration of the rally, which is very different. It shows that during the competition, male players will spend more extended time shooting the ball than female players, resulting in the number of shot rallies being higher and different. The duration of the competition is also different, consistent with the fact that the work density of male players is higher than that of female players. However, there is no difference in the length of time between points, the percentage of time between points in a game, and the dead time between games. These data show that match workload has a relatively high physiological response (Martin & Prioux, 2011).

Specifically, male players have a significantly higher and more intense match workload than female players and a similar proportion of short rest periods (Martínez, 2014). The intensity of such competition affects the performance of athletes during the competition (Martin et al., 2016). Players with more tactical experience have better physical performance, such as muscle power (Aoki et al., 2018); alternatively, an excellent aerobic system helps them physically perform at a lower level (Baiget et al., 2015) and deal with fatigue better (Gomes et al., 2011). These will give players an advantage over their opponents when faced with situations that require high pressure, decision-making, or predictability during matches, which will be better than players with less experience and skill level, which are variables that result in different results (Kolman et al., 2018; Kovalchik & Ingram, 2018). Therefore, coaches must have strategies to help players gain an advantage in intense competition. Different for both male and female players.

Figure 3. The graphic shows the percentage of action area of men and women players.

Most of the techniques used in the competition use the forehand flat and backhand flat as the primary techniques during competitive. Both techniques have a high level of relationship; players will choose techniques to gain an advantage or survive, mainly during returns serve, which is the period that influences the timing of the opponent's counterattack (Gillet et al., 2009), including rally shots. In rally shots that last for a long time, players often use forehand flat and backhand flat techniques to maintain the rhythm of the counterattack continuously. It is also a technique that can control and provide maximum power in hitting (Bollettieri, 2015; Muhamad et al., 2011), making flat-hitting techniques more common in high-level competitive games. Similar to using slice techniques in playing in the service area. The area of the court in which the forehand slice and backhand slice are techniques with a moderate relationship, where the percentage of use of the slice technique is close to the lob technique. However, there is no relationship between the forehand and backhand lob technique. The technique is primarily flat, not complicated, and can create more rhythm than other techniques. Experienced and skilled players will make decisions about their advanced technique (Kolman et al., 2018), the complexity of technique (Kolman et al., 2023), and the speed of serving or hitting the ball with precision is related to the level of the player (Ulbricht et al., 2016).

In the action area in soft tennis in high-level competition, more than 40% of male and female players tend to play in the mid-left area, where the most counterattacking occurs. They are counterattacking in the mid-left area of the player because most players tend to use their right hand to play, resulting in the use of the backhand technique in counterattacking in that area where the backhand is a skill that provides accuracy and a high percentage of hits (Muhamad et al., 2011), making it used by most players for rally shots, as well as the rear left area of the court as an area for counterattacking. Next up, other areas tend to have very little play and may be used for hitting shots to turn into critical points, such as hitting in the fore right area, which has the most minor percentage of play and is where most of the hitting techniques are used forehand, which can provide maximum power for hitting (Bollettieri, 2015).

The importance of using match workload, technical information in high-level competitions, and action area calculations and percentage comparisons can make interpretation more accessible for coaches (Fitzpatrick et al., 2019). The top players in the finals have similar match workloads, but there are differences in the intensity and duration of the rally between the male and female players. The techniques are similar in terms of percentages used during matches, and the percentages of playing space are not significantly different. Whether athletes play the same or different games may have different results. Athletes' competitive abilities or playing methods that differ from current competition may produce different results, which future studies may determine. Trainers should use this information to design physical fitness training programs, techniques, and strategies most appropriate for competition. To increase the players' performance, which will vary with the standard of play. (Mellado-Arbelo & Baiget, 2022). In addition, well-educated data coaches and athletes with proper training can help players have increased positive mental outcomes (Meffert et al., 2021) and can create an impact. Aggressiveness in competition is part of the method that will lead to success in competition (Paserman, 2023).

CONCLUSIONS

The data shows that male players have a significantly higher match load than female players, with no difference in the rest time lost between matches. The intensity of male matches is, therefore, higher. Both had similar percentages of techniques used during the competition, and the main techniques used were also moderately to highly related, indicating that the technical aspects of the competition were very similar. Moreover, the percentage of playing areas during most matches was similar, which may indicate the tactics used by the elite athletes in the finals. This information will help develop physical fitness training methods, techniques, and tactics for high-level competitiveness.

AUTHOR CONTRIBUTIONS

Nathapol Thongthanapat is responsible for conceptualization, research methodology and data collection. Watunyou Khamros is responsible for data analysis, review literature and writing manuscript. Both authors approved the final version for published together.

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DISCLOSURE STATEMENT

No potential conflict of interest were reported by the authors.

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REFERENCES

Aoki, H., Demura, S., Nakada, M., & Kitabayashi, T. (2018). Characteristics of Muscle Power and Agility in Top-Level Junior Soft Tennis Players. World Journal of Education, 8, 211. https://doi.org/10.5430/wje.v8n5p211

Baiget, E., Fernández-Fernández, J., Iglesias, X., & Rodríguez, F. A. (2015). Tennis Play Intensity Distribution and Relation with Aerobic Fitness in Competitive Players. PLOS ONE, 10(6), e0131304. https://doi.org/10.1371/journal.pone.0131304

Bollettieri, N. (2015). Nick Bollettieri's Tennis Handbook-2nd Edition. Human Kinetics. Retrieved from [Accessed April 16, 2024]: https://books.google.co.th/books?id=AT-iCgAAQBAJ

Carboch, J., Placha, K., & Sklenarik, M. (2018). Rally pace and match characteristics of male and female tennis matches at the Australian Open 2017. Journal of Human Sport and Exercise. https://doi.org/10.14198/jhse.2018.134.03

Carboch, J., Sklenarik, M., Šiman, J., & Blau, M. (2019). Match Characteristics and Rally Pace of Male Tennis Matches in Three Grand Slam Tournaments. Physical Activity Review, 7, 49-56. https://doi.org/10.16926/par.2019.07.06

Carvalho, J., Araújo, D., Travassos, B., Esteves, P., Pessanha, L., Pereira, F., & Davids, K. (2013). Dynamics of players' relative positioning during baseline rallies in tennis. J Sports Sci, 31(14), 1596-1605. https://doi.org/10.1080/02640414.2013.792944

Cui, Y., Gómez, M.-Á., Gonçalves, B., Liu, H., & Sampaio, J. (2017). Effects of experience and relative quality in tennis match performance during four Grand Slams. International Journal of Performance Analysis in Sport, 17(5), 783-801. https://doi.org/10.1080/24748668.2017.1399325

Filipcic, A., Crespo, M., & Filipčič, T. (2022). Practice and match workload of a female tennis player in two annual seasons: A single-case study. International Journal of Sports Science & Coaching, 18, 174795412210888. https://doi.org/10.1177/17479541221088836

Fitzpatrick, A., Stone, J. A., Choppin, S., & Kelley, J. (2019). A simple new method for identifying performance characteristics associated with success in elite tennis. International Journal of Sports Science & Coaching, 14(1), 43-50. https://doi.org/10.1177/1747954118809089

Gillet, E., Leroy, D., Thouvarecq, R., & Stein, J.-F. (2009). A Notational Analysis of Elite Tennis Serve and Serve-Return Strategies on Slow Surface. Journal of strength and conditioning research / National Strength & Conditioning Association, 23, 532-539. https://doi.org/10.1519/JSC.0b013e31818efe29

Gomes, R., Coutts, A., Viveiros de Castro, L. E., & Aoki, M. (2011). Physiological demands of match-play in elite tennis: A case study. European Journal of Sport Science, 11, 105-109. https://doi.org/10.1080/17461391.2010.487118

Hiroo, T., Shuhei, O., & Shunsuke, M. (2023). Performance analysis in tennis since 2000: A systematic review focused on the methods of data collection. International Journal of Racket Sports Science, 4(2). https://doi.org/10.30827/Digibug.80900

Kilit, B., Şenel, Ö., Arslan, E., & Can, S. (2016). Physiological Responses and Match Characteristics in Professional Tennis Players During a One-Hour Simulated Tennis Match. Journal of Human Kinetics, 50. https://doi.org/10.1515/hukin-2015-0173

Kolman, N., Huijgen, B., Visscher, C., & Elferink-Gemser, M. (2023). Technical skills in complex tennis situations: Dutch talented players U15 compared to players U17. Frontiers in Sports and Active Living, 5, 1107740. https://doi.org/10.3389/fspor.2023.1107740

Kolman, N., Kramer, T., Elferink-Gemser, M., Huijgen, B., & Visscher, C. (2018). Technical and tactical skills related to performance levels in tennis: A systematic review. Journal of Sports Sciences, 37, 1-14. https://doi.org/10.1080/02640414.2018.1483699

Kovacs, M. S. (2007). Tennis Physiology. Sports Medicine, 37(3), 189-198. https://doi.org/10.2165/00007256-200737030-00001

Kovalchik, S., & Ingram, M. (2018). Estimating the duration of professional tennis matches for varying formats. Journal of Quantitative Analysis in Sports, 14. https://doi.org/10.1515/jqas-2017-0077

Lees, A. (2003). Science and the major racket sports: a review. Journal of Sports Sciences, 21(9), 707-732. https://doi.org/10.1080/0264041031000140275

Martin, C., Bideau, B., Delamarche, P., & Kulpa, R. (2016). Influence of a Prolonged Tennis Match Play on Serve Biomechanics. PLOS ONE, 11(8), e0159979. https://doi.org/10.1371/journal.pone.0159979

Martin, C., & Prioux, J. (2011). Physiological aspects of competitive tennis: a review of the recent literature. Journal of Medicine and Science in Tennis, 16, 6-19.

Martínez-Gallego, R., Vives, F., Guzmán, J. F., Ramón-Llin, J., & Crespo, M. (2021). Time structure in men's professional doubles tennis: does team experience allow finishing the points faster? International Journal of Performance Analysis in Sport, 21(2), 215-225. https://doi.org/10.1080/24748668.2021.1872218

Martínez, B. (2014). A study of the physiological characteristics of tennis. Coach. sport sci. rev, 64, 3-5.

Meffert, D., Ohlendorf, L., Born, P., Grambow, R., & Vogt, T. (2021). Towards an understanding of big points in tennis: Perspectives of coaches, professional players, and junior players. Journal of Physical Education and Sport, 21, 728-735. https://doi.org/10.7752/jpes.2021.02090

Mellado-Arbelo, Ó., & Baiget, E. (2022). Activity profile and physiological demand of padel match play: a systematic review. Kinesiology, 54, 51-61. https://doi.org/10.26582/k.54.1.6

Muhamad, T. A., Rashid, A. A., Razak, M. R. A., & Salamuddin, N. (2011). A comparative study of backhand strokes in tennis among national tennis players in Malaysia. Procedia - Social and Behavioral Sciences, 15, 3495-3499. https://doi.org/10.1016/j.sbspro.2011.04.324

O'Donoghue, P., Reid, M., & Girard, O. (2013). Racket Sports. In (pp. 404-414).

Paserman, M. D. (2023). Gender Differences in Performance in Competitive Environments? Evidence from Professional Tennis Players. Journal of Economic Behavior & Organization, 212, 590-609. https://doi.org/10.1016/j.jebo.2023.05.042

Paul, M., Biswas, S., & Sandhu, J. (2011). Role of sports vision and eye hand coordination training in performance of table tennis players. Brazilian Journal of Biomotricity, 106-116.

Torres-Luque, G., Cabello, D., Raquel, H.-G., & Garatachea, N. (2011). An analysis of competition in young tennis players. European Journal of Sport Science - Eur J Sport Sci, 11, 39-43. https://doi.org/10.1080/17461391003770533

Ulbricht, A., Fernandez-Fernandez, J., Mendez-Villanueva, A., & Ferrauti, A. (2016). Impact of Fitness Characteristics on Tennis Performance in Elite Junior Tennis Players. J Strength Cond Res, 30(4), 989-998. https://doi.org/10.1519/JSC.0000000000001267

ORIGINAL ARTICLE

Effects of different types of warm-ups on performance by young volleyball players

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ABSTRACT

The study aimed to compare the impact of warm-up with dynamic stretching (DS), warm-up with foam roller (FR), and warm-up with a combination of FR and DS (CO) on the performance of movement indicators in tests conducted on young volleyball players (n = 8, age = 15.4 ± 0.5 years, height = 176.3 ± 8.6 cm, weight = 64.5 ± 10.9 kg) during the competition year 2021/2022. To assess the effects of warm-up methods (DS, FR, CO), performance in various movement tests was compared. The tests included the sit and reach test (SR), a 1 kg ball throw in a kneeling position (H1), squat jump (SJ), countermovement jump (CMJ), sit-up test (SU), E-Test (ET), and run to cones (RC). The One-way ANOVA analysis did not reveal significant differences in the effects of DS, FR, and CO warm-ups ($p > .05$) across all investigated indicators. The effect size coefficient (η^2) indicated negligible differences ($\eta^2 < 0.01$), except for the ET indicator, where a small effect size ($\eta^2 = 0.028$, 95%CI: 0.04-0.31) favoured DS. These findings carry social importance as they contribute to enhancing the efficacy of warm-up routines, both in sports performance and health considerations.
Keywords: Performance analysis, Dynamic stretching, Foam rolling, Sports medicine, Sports performance, Sports training.

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INTRODUCTION

Many athletes incorporate stretching into their warm-up routine to enhance athletic performance and prime the body for training or competition (Gerdijan et al., 2021; Pescatello et al., 2014). The choice of stretching methods in warm-ups is a subject of ongoing debate (Shelton and Kumar, 2009).

According to Guissard and Duchateau (2004) and Weppler and Magnusson (2010), the impact of stretching exercises involves both mechanical factors (such as viscoelastic and plastic deformation of connective tissue) and nervous factors (including neuromuscular relaxation and modification of sensation). Dynamic stretching, among various warm-up techniques, has gained global popularity and is widely recommended (Behm et al., 2004).

Studies investigating dynamic stretching have reported positive effects on various aspects, including increased flexibility (Ryan et al., 2014; Haff and Triplett, 2015), enhanced muscle strength (Faigenbau et al., 2006), improved sprint performance (Brahim and Chan, 2022), and improved explosive power performance (Hough et al., 2009; Perrier et al., 2011). Rubini et al. (2007) noted that dynamic stretching with low to moderate intensity movements raises body temperature, enhances motor unit excitability, improves countermovement jump (CMJ) performance (Dalrymple et al., 2010), and fosters kinaesthetic awareness (Mann and Jones, 1999). Another method currently used in warm-up process by athletes is self-massage (self-myofascial release - SMR) (Popelka and Pivovarniček, 2022).

According to Cheatham (2015), SMR is popular in rehabilitation and among athletes to enhance myofascial mobility. This warm-up technique involves using foam rollers of various densities, targeting specific muscle groups, and was developed as an alternative warm-up method (Lee et al., 2018). Higher-density rollers are considered more suitable for SMR, as suggested by Curran et al. (2008), although Cheatham et al. (2018) and Yanaok et al. (2021) found no significant differences when using foam rollers with different densities. SMR helps release muscle and tendon tension, soft tissue adhesions, and scar tissue, potentially increasing the range of motion in the knee joint without compromising muscle performance (Macdonald et al., 2013).

Opinions regarding the use of a foam roller in warm-ups to enhance range of motion (ROM), flexibility, and performance vary. Wiewelhove et al. (2019) suggest that the effects of using a foam roller in warm-ups on jump performance, strength, and recovery are generally small and negligible. However, in specific cases, such as enhancing performance and flexibility in sprinting or reducing the sensation of muscle pain, the effects may be relevant. Gerdijan et al. (2021) highlight that, despite numerous empirical studies on stretching, there are ongoing dilemmas regarding the appropriate type of stretching, with often contradictory study results. As a result, several authors (Kirmizigil et al., 2014; Popelka and Pivovarniček, 2018; Stojanovic et al., 2020) aim to compare different warming-up methods or their combinations to determine the most suitable warm-up approach.

Su et al. (2017) conducted a study comparing static stretching, dynamic stretching, and self-massage during warm-up. They observed a significant improvement in quadriceps and ischiocrural flexibility after self-massage compared to static stretching. Peacecock et al. (2014) examined a warm-up routine that included both dynamic warm-up exercises and a self-myofascial release session using total-body foam rolling. This combined routine led to overall enhancements in athletic performance testing.

On the contrary, Richman et al. (2019) investigated the combined effects of self-massage with a foam roller and dynamic stretching on various parameters, including range of motion, jumping, sprinting, and agility.

Their research has proven that the change in sit-and-reach (SR) after foam rolling session (SMR) was significantly greater than the change seen in SR after light walking (LW), although the total changes seen in each condition were not statistically different after the addition of dynamic stretching (DS). Squat jump (SJ) and countermovement jump (CMJ) improved by 1.72 ± 2.47 cm and 2.63 ± 3.74 cm (p = .070, p = .070), with no significant change to drop jump (DJ), sprint, and the agility T-Test. Self-myofascial release in the form of foam rolling after a general warm-up and preceding a dynamic stretching DS session seems to improve Squat jump and countermovement jump with no detriment to flexibility, drop jump, sprint, and agility performance in comparison with light walking and dynamic stretching.

The study by Konrad et al. (2021) suggests that athletes may not necessarily need to combine stretching with foam rolling, as no additional effect was observed. However, for increased performance, the combination of foam rolling followed by stretching could result in greater improvements. Another study by Seçer and Özer Kaya (2022) found that both DS and DS combined with FR improved flexibility and agility without affecting balance. The combination of DS and FR was not superior to DS alone in terms of improving flexibility and agility. Both methods proved effective as warm-up protocols to enhance factors related to injury risk and performance. Further research on the combined effects of foam rolling and dynamic stretching is needed.

In a preliminary study conducted by Popelka and Pivovarniček (2022), similar effects were observed in warm-ups using foam rolling and dynamic stretching on the performance of motion tests in young volleyball players. However, this study utilized a two-group experimental design. The current study aims to compare the effects of warm-ups involving foam rolling, dynamic stretching, and a combined approach (foam rolling + dynamic stretching) on the performance of movement tests in young volleyball players, utilizing a sequential experiment with a single group where all three warm-up types are implemented. Consistent with the findings of pilot study (Popelka and Pivovarniček, 2022), we also anticipate a comparable (though not statistically significant) impact of all three warm-up methods.

MATERIAL AND METHODS

Participants

The experimental sample comprised young volleyball players participating in the competition year 2021/2022 (n = 8, age = 15.4 ± 0.5 years, body height = 176.3 ± 8.6 cm, body weight = 64.5 ± 10.9 kg). To be included in the research evaluation, participants were required to fully complete the entire study, ensuring 100% participation from each individual. All study participants received clear instructions on the procedures and confirmed their participation by providing informed consent. The research protocol was approved by the Ethical Committee at the respective university. Measurements were conducted in compliance with the ethical standards outlined in the Declaration of Helsinki and the ethical guidelines for research in sport and exercise science (Harriss and Atkinson, 2015).

Organisation of research

The research was conducted during the competition year 2021/2022, spanning from January 24, 2022, to March 29, 2022. On Monday, January 24, 2022, incoming testing was carried out for all players, involving measurements of body weight and height. Performance measurements in motion tests after stretching (DS = dynamic stretching; FR = foam rolling; CO = combination of FR and DS) took place from January 25, 2022, to March 29, 2022.

On January 25, 2022 (Tuesday), the players underwent the DS warm-up. Subsequently, on January 27, 2022 (Thursday), they completed the FR warm-up, and on February 1, 2022 (Tuesday), the CO warm-up.

These three warm-ups then alternated in that order every Tuesday and Thursday. Participants completed a total of 6 warm-ups for each type, each followed by testing of the studied movement indicators. For each warm-up type in the order DS, FR, CO, six measurements were performed. The level in the tests of the investigated indicators was calculated as the average level of six measurements for each type of warm-up (DS, FR, CO). A summary of the basic volume indicators for individual types of warm-ups is presented in Table 1. Prior to each warm-up session, the participants engaged in a uniform 3-minute warm-up routine. The FR and CO warm-up included the use of a Liveup® sports foam roller (Nantong Liveup Sports Co., Ltd, China).

Table 1. The fundamental quantitative measurements of the employed warm-up methods.

Warm-up	Duration (min)	Number of exercises	Length of each exercise (s)	Rest in between Exercises (s)	Number of repetitions
Dynamic Stretching (DS)	11-12	13	35-40	10-12	10-12
Foam Rolling (FR)	11-12	13	40-45	8-10	18-20
Combination (FR + DS)	11-12	FR 13 DS 13	FR 15-20 DS 15-20	6-8	FR 8-10 DS 5-6

Note. (min) = minutes. (s) = seconds. DS = dynamic stretching; FR = foam rolling.

Measurements

The following tests were used in the research:

The sit and reach test (SR) was employed to evaluate flexibility in the lower back and hamstrings. The outcome of a single measurement was the distance reached by the middle fingers during a forward bend, recorded in centimetres on the sit and reach box with a precision of 0.1 cm. Higher number means bigger overhang – better flexibility.

The test – 1 kg ball throw in kneeling position (H1) was used to determine the explosive power of the dominant upper limb. The result of one measurement was the throwing distance measured in meters with accuracy of 1 cm.

To assess the height of a vertical jump, the Squat Jump (SJ) and Countermovement Jump (CMJ) tests were conducted and analysed using Myotest PRO (Myotest SA, Switzerland). The measurement outcome for SJ and CMJ was the average height of the three best jumps out of five, performed in accordance with the Myotest methodology, with a precision of 0.1 cm.

The Sit-Up Test (SU), lasting for 30 seconds, was conducted to assess the explosive and endurance power of abdominal muscles. The measurement outcome for a single trial was the number of repetitions performed in sit-ups within the 30-second time frame.

The E-Test (ET) was employed to measure special speed. The outcome for an individual measurement was the time in seconds (s), with an accuracy of 0.1 s, during which the participant completed the "*E*"-shaped track in the shortest time possible.

The run to cones (RC) was utilized to assess endurance in speed. The result for a single measurement was the time in seconds (s), with an accuracy of 0.1 s, in which the participant completed the "*fan*"-shaped track in the shortest time possible.

Data analysis

We employed One-way analysis of variance (OW-ANOVA) to assess the significance of differences in the effects among the individual types of warm-ups. Due to the small sample size (n = 8), acknowledging the potential for a high error in statistical tests of type II (β), we utilized effect size to evaluate differences between DS, FR, and CO. The effect size was indicated by the coefficient η^2, with minimal values for effect evaluation: $\eta^2 > 0.01$ – small effect, $\eta^2 > 0.06$ – medium effect, $\eta^2 > 0.14$ – large effect (Cohen, 1998). The Levene test verified the Homogeneity of Variance condition for OW-ANOVA. The probability of type I error (alpha, α) was set at .05. Statistical analysis was conducted using SPSS Statistics version 28 software (IBM, Armonk, NY, USA).

RESULTS

The statistical analysis conducted through One-way ANOVA (Table 2) revealed no significant differences in the effects of DS, FR, and CO warm-ups ($p > .05$) across all investigated indicators (SR, H1, SJ, CMJ, SU, and RC). The effect size coefficient also indicated no significant difference ($\eta^2 < 0.01$) for any of the mentioned indicators. The only exception was observed in the case of the ET indicator, where the value of $\eta^2 = 0.028$ indicated a small effect, suggesting differences in warm-up effectiveness in favour of DS.

Table 2. Statistical evaluation of the comparison of the used types of warm-ups for performance in tests of movement indicators in a sample of young volleyball players (n = 8).

Movement indicator	**Warm-up**			**Statistical analysis**		
	DS	FR	CO	One-way ANOVA	Effect size (ES)	
	M SD	M SD	M SD		ES value	ES level
SR	6.8 6.1	6.7 6.3	7.2 6.2	$F_{(2.21)} = 0.012$, $p > .05$	$\eta^2 = 0.001$ (95%CI: 0.04-0.31)	no effect
H1	11.54 2.0	11.61 1.7	11.72 1.8	$F_{(2.21)} = 0.019$, $p > .05$	$\eta^2 = 0.002$ (95%CI: 0.04-0.31)	no effect
SJ	38.2 5.3	38.0 5.3	38.1 5.2	$F_{(2.21)} = 0.001$, $p > .05$	$\eta^2 = 0$ (95%CI: 0.04-0.31)	no effect
CMJ	44.8 5.5	44.7 5.3	44.7 5.4	$F_{(2.21)} = 0.002$, $p > .05$	$\eta^2 = 0$ (95%CI: 0.04-0.31)	no effect
SU	27.4 1.9	27.1 1.7	27.4 1.8	$F_{(2.21)} = 0.052$, $p > .05$	$\eta^2 = 0.005$ (95%CI: 0.04-0.31)	no effect
ET	20.4 1.4	20.8 1.0	20.9 1.8	$F_{(2.21)} = 0.308$, $p > .05$	$\eta^2 = 0.028$ (95%CI: 0.04-0.31)	small effect
RC	63.6 4.9	63.7 5.2	63.5 4.9	$F_{(2.21)} = 0.098$, $p > .05$	$\eta^2 = 0$ (95%CI: 0.04-0.31)	no effect

Note. DS = dynamic stretching; FR = foam rolling; CO = combination of FR and DS; M = Mean; Standard Deviation; SR = The sit and reach test (in centimetres); H1 = The test – 1 kg ball throw in kneeling position (in meters); SJ = Squat jump (in centimetres); CMJ = Countermovement jump (in centimetres); SU = The sit-up test (in the number of repetitions); ET = The E-Test (in seconds); RC = The run to cones = (in seconds).

DISCUSSION

The primary outcome of our study indicates that there were not statistically significant ($p > .05$), or practical ($\eta^2 < 0.01$) differences observed among the employed warm-up methods – dynamic stretching, warm-up with a foam roller, and a combination of dynamic stretching and foam rolling – regarding the assessed movement indicators in young volleyball players. This outcome aligns with our initial hypothesis and the findings from the preliminary study (Popelka and Pivovarniček, 2022). The sole distinction in performance after each type of warm-up was identified in the running E-test. Although the statistical analysis did not reveal a notable difference in this instance (F (2.21) = 0.308, $p > .05$), the effect size coefficient indicated a minimal effect of differences ($\eta^2 = 0.028$; 95%CI: 0.04-0.31) in favour of dynamic stretching compared to the other exercise methods.

Our findings regarding the Sit and Reach test (SR) do not align with the outcomes reported in studies by Su et al. (2017) and Wiewelhove et al. (2019), which suggested that self-massage has a more effective impact compared to dynamic stretching. Similarly, Behara and Jacobson (2017) observed a difference in hip flexion with self-massage (FR) versus dynamic stretching ($p = .0001$). The reason for this disparity may be attributed to the fact that in Behara and Jacobson's research (2017), rolling on one muscle part lasted 60 seconds, whereas in our study, participants spent 45 seconds on one muscle part during self-massage, representing a 15-second difference. This perspective is further supported by the findings of Smith et al. (2018), who observed self-massage ($p = .003$) to be more effective compared to dynamic stretching, with subjects spending 60-65 seconds on one muscle part. However, they noted that this effect diminishes rapidly. In our research, we utilized a softer roller compared to Behara and Jacobson's (2017) study, given the age of our participants (15.38 ± 0.54 years). Based on this, we believe that the duration of self-massage and the hardness of the roller may have influenced the more positive effect of self-massage compared to dynamic stretching on hip flexion. Our results align with studies by Richman et al. (2019), Konrad et al. (2021), and Seçer and Kaya (2022), where no significant changes ($p > .05$) in flexibility were observed compared to dynamic stretching when combined. Similar to our research, the study by Kashara et al. (2023), which aimed to compare the combined effects of FR and SS or DS with various intervention orders, did not find differences in CMJ ($p = .056$, d = 0.31). Additionally, the study by Lin et al. (2020) did not confirm differences in effects ($p > .05$) between dynamic stretching and a combination of dynamic stretching and self-massage with a vibrating foam roller. Although Lin et al. (2020) used a vibrating roller in their research and we used a foam roller without vibration, we believe that this may not have a large impact on the final result. This was confirmed, for example, by the study of Nakamura et al. (2022), who compared the effects of foam rolling with and without vibration on passive and active plantar flexor muscle properties. Their results showed a similar increase in dorsiflexion range of motion ($p < .01$, d = 0.51; $p < .01$, d = 0.65, respectively) and passive torque at dorsiflexion range of motion ($p = .02$, d = 0.51 and $p < .01$, d = 0.65, respectively) after foam rolling and vibration foam rolling. Comparing our results in the SJ test, we found that Richman et al. (2018) did not record a difference in a combined warm-up versus dynamic stretching (1.72 ± 2.47 cm, $p = .07$).

Other studies, such as Behara and Jacobson (2017), who used a harder roller in the warm-up compared to us, also did not find significant differences ($p > .05$) between dynamic stretching and the use of a foam roller in the VJ (vertical jump) peak power test ($p = .45$), VJ average power ($p = .16$), VJ peak velocity ($p = .25$), VJ average velocity ($p = .23$), peak knee extension torque ($p = .63$), average knee extension torque ($p = .11$), peak knee flexion torque ($p = .63$), or average knee flexion torque ($p = .22$). In a similar study, Smith et al. (2018) found that vertical jump height immediately after treatment for DS and FR+DS (combo) was significantly greater than the control and FR counterparts ($p = .002$). Vertical jump height for DS and combo was also significantly greater than FR counterpart at 5 minutes after treatment ($p < .001$). Based on their findings, they state that foam rolling does not seem to enhance VJ height.

It is essential to acknowledge the limitations of our study. The primary limitation is the small sample size, attributed to the high probability of type II error (β). We attempted to partially address this issue by utilizing the coefficient η^2. Our study employed a one-group time-step experimental design without a control group. Although having a control group would be methodologically more accurate, practical considerations prevented us from subjecting some young volleyball players to the used movement tests without warm-up, posing a potential risk of injuries. While it would be methodologically advantageous to create three performance-homogeneous and numerically sufficient experimental samples, with each sample completing all three warm-up methods gradually, logistical, and ethical considerations made this challenging. Future research endeavours might benefit from such an approach to enhance the objectivity of results and mitigate potential biases.

CONCLUSIONS

The objective of the study was to compare the impact of warm-up methods involving dynamic stretching, foam rolling, and a combination of dynamic stretching with foam rolling on the performance of movement tests among young volleyball players. The results of our research indicate that the warm-up techniques employed did not yield statistically significant or practically distinct effects on the performance in the selected movement tests among young volleyball players, aligning with our initial assumptions. These findings offer valuable insights and foundational material for volleyball and fitness coaches, as well as individuals interested in warm-up procedures and fitness training, particularly for young volleyball players. Nonetheless, these results also serve as motivation to pursue further research, exploring the most effective warm-up strategies for diverse age groups of athletes.

AUTHOR CONTRIBUTIONS

JP: Study design, data collection, manuscript preparation. GB: Manuscript preparation. PP: Statistical analysis, manuscript preparation. All authors have read and agreed to the final version of the manuscript.

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No potential conflict of interest were reported by the authors.

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REFERENCES

Behara B, and Jacobson BH. (2017). Acute Effects of Deep Tissue Foam Rolling and Dynamic Stretching on Muscular Strength, Power, and Flexibility in Division I Linemen. J Strength Cond Res. 31(4):888-892. https://doi.org/10.1519/JSC.0000000000001051

Behm DG, Bambury A, Cahill F, and Power K. (2004). Effect of acute static stretching on force, balance, reaction time, and movement time. Med Sci Sports Exerc. 36(8):1397-1402. https://doi.org/10.1249/01.MSS.0000135788.23012.5F

Brahim S, and Mohamad Chan EW. (2020). Acute effect of dynamic stretching versus combined static dynamic stretching on speed performance among male Sukma Sarawak 2016 sprinters. J phys educ sports sci. 9(1):1-8.

Cheatham SW, and Stull KR. (2018). Comparison of three different density type foam rollers on knee range of motion and pressure pain threshold: a randomized controlled trial. Int J Sports Phys Ther. 13(3):474-482. https://doi.org/10.26603/ijspt20180474

Cohen J. (1988). Statistical Power Analysis for the Behavioral Sciences (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates.

Curran PF, Fiore RD, and Crisco JJ. (2008). A comparison of the pressure exerted on soft tissue by 2 myofascial rollers. J Sport Rehabil. 17(4):432-442. https://doi.org/10.1123/jsr.17.4.432

Dalrymple KJ, Davis SE, Dwyer GB, and Moir GL. (2010). Effect of static and dynamic stretching on vertical jump performance in collegiate women volleyball players. J Strength Cond Res. 24(1):149-155. https://doi.org/10.1519/JSC.0b013e3181b29614

Faigenbaum AD, McFarland JE, Schwerdtman JA, Ratamess NA, Kang J, and Hoffman JR. (2006). Dynamic warm-up protocols, with and without a weighted vest, and fitness performance in high school female athletes. J Athl Train. 41(4):357-63.

Fletcher IM. (2010). The effect of different dynamic stretch velocities on jump performance. Eur J Appl Physiol. 109(3):491-498. https://doi.org/10.1007/s00421-010-1386-x

Gerdijan N, Perić D, Ljubojević A, and Vukić Ž. (2021). Effects of static and dynamic stretching exercises on unilateral hamstring to quadriceps strength ratio. Advances in Physical Education, 11(1):89-102. https://doi.org/10.4236/ape.2021.111007

Guissard N, Duchateau J. (2014). Effect of static stretch training on neural and mechanical properties of the human plantar-flexor muscles. Muscle Nerve. 29(2):248-255. https://doi.org/10.1002/mus.10549

Haff GG, and Triplett NT. (2015). Essentials of strength training and conditioning (4th ed.). Champaign, IL: Human Kinetics.

Harriss DJ., and Atkinson G. (2015). Ethical Standards in Sport and Exercise Science Research: 2016 Update. Int J Sports Med. 36(14):1121-1124. https://doi.org/10.1055/s-0035-1565186

Hough PA, Ross EZ, and Howatson G. (2009). Effects of dynamic and static stretching on vertical jump performance and electromyographic activity. J Strength Cond Res. 23(2):507-512. https://doi.org/10.1519/JSC.0b013e31818cc65d

Kasahara K, Konrad A, Yoshida R, Murakami Y, Sato S, Koizumi R, Behm DG, and Nakamura M. (2023). The comparison between foam rolling either combined with static or dynamic stretching on knee extensors' function and structure. Biology of Sport. 40(3):753-760. https://doi.org/10.5114/biolsport.2023.119987

Kirmizigil B, Ozcaldiran B, and Colakoglu M. (2014). Effects of three different stretching techniques on vertical jumping performance. J Strength Cond Res. 28(5):1263-1271. https://doi.org/10.1519/JSC.0000000000000268

Konrad A, Nakamura M, Bernsteiner D, and Tilp M. (2021). The Accumulated Effects of Foam Rolling Combined with Stretching on Range of Motion and Physical Performance: A Systematic Review and Meta-Analysis. J Sports Sci Med. 20(3):535-545. https://doi.org/10.52082/jssm.2021.535

Lee CL, Chu IH, Lyu BJ, Chang WD, and Chang NJ. (2018). Comparison of vibration rolling, nonvibration rolling, and static stretching as a warm-up exercise on flexibility, joint proprioception, muscle strength, and balance in young adults. J Sports Sci. (22):2575-2582. https://doi.org/10.1080/02640414.2018.1469848

Lin WC, Lee CL, and Chang NJ. (2020). Acute Effects of Dynamic Stretching Followed by Vibration Foam Rolling on Sports Performance of Badminton Athletes. J Sports Sci Med. 19(2):420-428.

MacDonald GZ, Penney MD, Mullaley ME, Cuconato AL, Drake CD, Behm DG, and Button DC. (2013). An acute bout of self-myofascial release increases range of motion without a subsequent decrease in muscle activation or force. J Strength Cond Res. 27(3):812-821. https://doi.org/10.1519/JSC.0b013e31825c2bc1

Mann DP, and Jones MT. (1999). Guidelines to the implementation of a dynamic stretching program. Strength Cond J. 21(6):53-55. https://doi.org/10.1519/1533-4295(1999)021<0053:GTTIOA>2.0.CO;2

Nakamura M, Sato S, Ryosuke K, Yoshida R, Yasaka K, Yhata K and Konrad A. (2022). Comparison between foam rolling with and without vibration on passive and active plantar flexor muscle properties. J Strength Cond Res. 36(12): 3339-3344. https://doi.org/10.1519/JSC.0000000000004123

Peacock CA, Krein DD, Silver TA, Sanders GJ, VON Carlowitz KA. (2014). An Acute Bout of Self-Myofascial Release in the Form of Foam Rolling Improves Performance Testing. Int J Exerc Sci. 7(3):202-211.

Perrier ET, Pavol MJ, and Hoffman MA. (2011). The acute effects of a warm-up including static or dynamic stretching on countermovement jump height, reaction time, and flexibility. J Strength Cond Res. 25(7):1925-1931. https://doi.org/10.1519/JSC.0b013e3181e73959

Pescatello LS. (2014). ACSM's guidelines for exercise testing and prescription (9th ed.). Philadelphia, PA: American College of Sports Medicine.

Popelka J, and Pivovarnicek P. (2018). Comparison of the effect of static and dynamic stretching on the force-velocity capabilities of young volleyball players. J Phys Educ Sport. 18(4):2314-2318. https://doi.org/10.7752/jpes.2018.04349

Popelka J, and Pivovarnicek P. (2022). The effect comparison of foam rolling and dynamic stretching on performance in motion tests by young volleyball players: a pilot study. Phys Act Rev. 10(2): 140-149. https://doi.org/10.16926/par.2022.10.28

Richman ED, Tyo BM, and Nicks CR. (2018). Combined Effects of Self-Myofascial Release and Dynamic Stretching on Range of Motion, Jump, Sprint, and Agility Performance. J Strength Cond Res. 33(7):1795-1803. https://doi.org/10.1519/JSC.0000000000002676

Rubini EC, Costa AL, and Gomes PS. (2007). The effects of stretching on strength performance. Sports Med. 37(3):213-224. https://doi.org/10.2165/00007256-200737030-00003

Ryan ED, Everett KL, Smith DB, Pollner C, Thompson BJ, Sobolewski EJ, and Fiddler RE. (2014). Acute effects of different volumes of dynamic stretching on vertical jump performance, flexibility and muscular endurance. Clin Physiol Funct Imaging. 34(6):485-492. https://doi.org/10.1111/cpf.12122

Seçer E, and Özer Kaya D. (2022). Comparison of Immediate Effects of Foam Rolling and Dynamic Stretching to Only Dynamic Stretching on Flexibility, Balance, and Agility in Male Soccer Players. J Sport Rehabil. 31(1):10-16. https://doi.org/10.1123/jsr.2021-0017

Shelton J, and Kumar GP. (2009). Comparison between static and dynamic warm-up exercise regimes on lower limb muscle power. Health, 1(2):117-120. https://doi.org/10.4236/health.2009.12019

Smith JC, Pridgeon B, and Hall MC. (2018). Acute Effect of Foam Rolling and Dynamic Stretching on Flexibility and Jump Height. J Strength Cond Res. 32(8):2209-2215. https://doi.org/10.1519/JSC.0000000000002321

Stojanovic MDM, Mikic M, Vucetic V, Belegisanin B, Karac A, Bianco A, and Drid P. (2020). Acute effects of static and dynamic stretching on vertical jump performance in adolescent basketball players. Gazz Med Ital 181(6):417-424. https://doi.org/10.23736/S0393-3660.20.04575-1

Su H, Chang NJ, Wu WL, Guo LY., and Chu IH. (2017). Acute effects of foam rolling, static stretching, and dynamic stretching during warm-ups on muscular flexibility and strength in young adults. Journal of sport rehabilitation, 26(6):469-477. https://doi.org/10.1123/jsr.2016-0102

Weppler CH., and Magnusson SP. (2010). Increasing muscle extensibility: a matter of increasing length or modifying sensation? Phys Ther, 90(3):438-449. https://doi.org/10.2522/ptj.20090012

Wiewelhove T, Döweling A, Schneider C, Hottenrott L, Meyer T, Kellmann M, Pfeiffer M, and Ferrauti A. (2019). A Meta-Analysis of the Effects of Foam Rolling on Performance and Recovery. Front Physiol. 10:376. https://doi.org/10.3389/fphys.2019.00376

Yanaoka T, Yoshimura A, Iwata R, Fukuchi M, and Hirose N. (2021). The effect of foam rollers of varying densities on range of motion recovery. J Bodyw Mov Ther. 26:64-71. https://doi.org/10.1016/j.jbmt.2020.09.002

ORIGINAL ARTICLE

Modification of the relative age effect on 4-6-year-old schoolchildren's motor competence after an intervention with balance bike

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ABSTRACT

The aims of this study were to explore: 1) the relative age effect (RAE) on aiming and catching (A&C), balance (Bal) and manual dexterity (MD) skills in 4-6-year-old schoolchildren; 2) the effect of the balance bikes program intervention; 3) the effect of this program based on gender. The Movement Assessment Battery for Children-2 (MABC-2) was administered to 50 schoolchildren [26 boys (52%) and 24 girls (48%)], aged between 4 and 5 years (M = 4.46 ; SD = 0.503), from an educational centre in Galicia (Spain), at the beginning and at the end of the intervention program. The results showed that there were statistically significant differences before the application of the intervention program with respect to the quarter of birth in MD (p = .013); A&C (p = .02) and TTS (p < .001) but not in Bal (p = .137). After the intervention, it is observed that the previous differences disappear [MD (p = .755); A&C (p = .806); TTS (p = .507)], in addition, all scores are better than before the application of the intervention program. Regarding gender, no statistically significant effect is observed either before or after applying the intervention program on the variables studied. The results obtained suggest that the application of an intervention using balance bikes could positively influence the improvement of MC in preschool children (boys and girls) and reduce the differences produced by the RAE.
Keywords: Physical education, Quarter of birth, Early childhood, Movement competence, Physical activity programs, Learning to cycle.

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INTRODUCTION

Early childhood is a critical stage in children's motor and cognitive development (Calsamiglia & Loviglio, 2020). In this phase, fundamental motor skills, such as aiming and catching, maintaining balance and developing manual dexterity, are essential for healthy growth and active participation in various physical and sports activities (Leow et al., 2019). Motor competence (MC) in preschool age is an important predictor of motor development during childhood (Clark & Metcalfe, 2002; Stodden et al., 2008). Proof of this is the inclusion of motor coordination as an important content to be developed in educational curricula (López Gallego et al., 2016).

However, relative age, determined by the date of birth in relation to the beginning of the school year (González Aramendi, 2007), can introduce inequalities in the development of these skills, potentially affecting school dropout (Schorer et al., 2011) and future participation in physical activities (Cobley et al., 2008).

Relative age, a phenomenon that describes differences in performance and development between individuals of the same age group due to date of birth, has been the subject of increasing attention in academics and sports (Aune et al., 2018; Roberts & Fairclough, 2012). In the context of physical education in schoolchildren aged 4 to 6 years, the impact of relative age on MC, which encompasses skills such as aiming and catching, balance and manual dexterity, becomes a crucial element to understand and addressed from school (Navarro-Patón, Arufe-Giráldez, et al., 2021; Navarro-Patón, Mecías-Calvo, et al., 2021), since these age groupings imply that in the same class there may be students with up to 12 months of chronological age difference (González Aramendi, 2007), and therefore, possible differences in maturation and experience among its members (Cupeiro et al., 2020). This disparity can generate differences in MC, leading to the perception that some children are more skilled or competent than others, even when the only difference is the date of birth (Brazo-Sayavera et al., 2017), since there is a difference of almost 12 months, the CM could be reinforced for older children, and therefore, for pre-schoolers who are chronologically more mature (Furley & Memmert, 2016). Therefore, the relative age effect (RAE) needs to be addressed in the specific context of physical education and sports programs aimed at preschool children (Navarro-Patón, Arufe-Giráldez, et al., 2021; Navarro-Patón, Mecías-Calvo, et al., 2021).

Preschool sports and physical education programs play a vital role in creating an inclusive and equitable environment for motor development (Gerlach et al., 2018; Herrmann et al., 2015). These programs offer structured opportunities for children to acquire fundamental motor skills, promoting a learning approach based on fun and active participation (Carrillo-López et al., 2018).

Previous studies revealed that children born at the beginning of the school year may have advantages in the development of motor skills compared to their peers born later in the year (Navarro-Patón, Arufe-Giráldez, et al., 2021; Navarro-Patón, Mecías-Calvo, et al., 2021). However, with the application of structured programs (Arufe Giráldez et al., 2021; Mecías-Calvo et al., 2021; Navarro-Patón, Brito-Ballester, et al., 2021; Navarro-Patón, Mecías-Calvo, et al., 2021), this RAE can be reduced. Therefore, it is crucial to evaluate how these programs can mitigate the effects of relative age and ensure that all children have equal opportunities to develop their motor skills.

For all these reasons, the main aim of this research was to systematically explore the RAE on motor competence, specifically in skills such as aiming and catching, balance and manual dexterity, in 4-6-year-old schoolchildren and examine the role of physical education and sports programs in reducing these disparities through an intervention program using balance bikes. As a secondary aim, we seek to explore and analyse the effect of these programs based on the gender of the participants.

MATERIAL AND METHOD

Design and Participants

In this quasi-experimental study without a control group (Ato et al., 2013), a total of 59 pre-schoolers between 4-5 years old were invited to participate, selected in a non-probabilistic way according to the subjects to whom they had access, from a public educational centre in La Coruña (Galicia, Spain).

Of these 59 participants, 9 were excluded (6 dues to incomplete data), 3 for not being present and participating in the complete development of the research (i.e., initial and final data collection and participation in all sessions of the intervention program). Finally, the sample was made up of 50 pre-schoolers.

Participants were classified according to their quarter of birth [quarter 1 (q1; born January to March); quarter 2 (q2; born from April to June); quarter 3 (q3; born from July to September) and quarter 4 (q4; born from October to December)] and gender group (boys and girls).

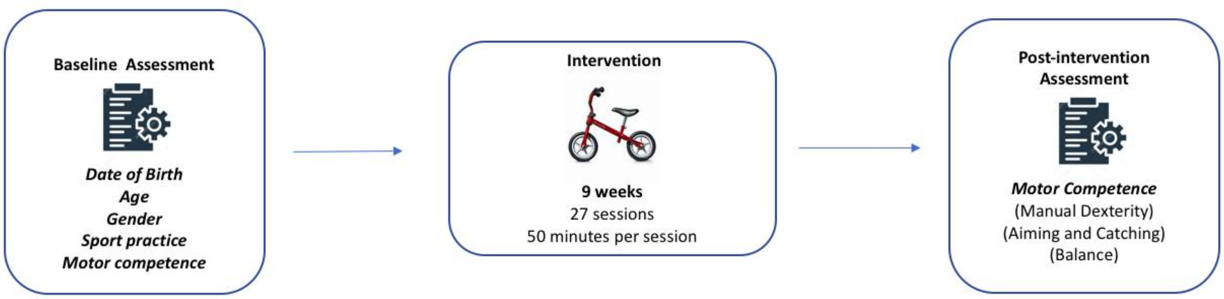

Figure 1. Study design.

The inclusion criteria were: (a) Present signed informed consent from the parents; (b) participate in the entire process (initial assessment, complete intervention program; final assessment); (c) not present an impediment to perform each of the MABC-2 tests.

Instruments

Movement Assessment Battery for Children-2 (MABC-2)

The MABC-2, adapted to the Spanish context (Graupera & Ruiz, 2012), which has been shown to be reliable in identifying changes in motor competence over time in preschool children, was used in this study. The MABC-2 is made up of 8 standardised tests: (1) post coins, (2) threading beads and (3) drawing trail, to calculate manual dexterity (MD); (4) catching bean bag and (5) throwing bean bag onto mat, to calculate aiming and catching skill (A&C); (6) one-leg balance, (7) walking heels raised and (8) jumping on mats, to calculate balance skill (Bal). This tool provides direct and scalar scores for each test, scalar scores for the dimensions with equivalent percentiles, and a total test score (TTS) with its equivalent scalar score and percentile. All direct scores were used for this research.

Intervention program

The duration of the intervention program with balance bikes was 9 weeks (3 sessions/week) and it replaced motor skills classes at school. Each session lasted 50 minutes in which different contents were taught (Table

1). All sessions had the same structure: warm-up or welcome moment (5 min), 6 tasks related to the contents of that session (Table 1; 40 minutes) and a cool-down or farewell moment (5 min). Before the start of each session, the bicycle was adjusted to the anthropometric characteristics of the participants and a helmet was placed and adjusted. All sessions of the program were taught by the main researcher, a graduate in Physical Education, with 15 years of experience as a Physical Education Specialist Teacher in Early Childhood and Primary Education.

Table 1. Contents to work on in the design of the project intervention sessions.

Week	Contents/Sessions
1st	**Information and familiarization** Session 1. Bike mascot, bike parts and basic elements for greater safety Session 2 and 3. Familiarization with the bike. Walking with the bike, getting on and off the bike. Carrying the bike from one side to another (swaying)
2nd	**Control of the exercise bike and first displacements** Session 4, 5 and 6. Get on the bike and move with short steps. Getting on and off the bike
3rd	**Displacements in different directions** Session 7, 8 and 9. Travel by bike from one place to another. Change of direction, turns, dribbling
4th	**Accelerate and brake** Session 10, 11 and 12. Making changes from stopped to started. Acceleration on a straight line. Brake when faced with obstacles
5th	**Displacements with obstacles** Session 13, 14 and 15: Movement avoiding obstacles (cones, cardboard boxes, etc.). Movement through different obstacles, narrow corridors, ramps, descents
6th	**Individual, competitive, cooperative and opposition games** Session 16, 17 and 18: Games of personal improvement, cooperation and opposition
7th	**Games and road education** Session 19, 20 and 21: Games that involve the incorporation of signs and other aspects of road safety education
8th	**Games and road education** Session 22, 23 and 24: Games that involve the incorporation of signs and other aspects of road safety education
9th	**Games and road education** Session 25, 26 and 27: Games that involve the incorporation of signs and other aspects of road safety education

Procedures

The management of the educational institutions and the tutor teachers of the preschool children groups were contacted by the researchers as the first step in explaining the goal of the study. Following clearance from the teachers and administration, the pre-schoolers' parents or legal guardians were notified. This message contained important information such as a confidentiality statement, the ability for parents to voluntarily withdraw their children from the study at any time, and an explanation of the aim, purpose, design, and methods of the study. The necessary sociodemographic data (age and sex) was gathered after the parents' or legal guardians' signed informed consent was accepted. Trained evaluators then used standardised equipment to administer the MABC-2 battery to the pre-schoolers in order to assess them. Wearing casual attire, each pre-schooler underwent an individual assessment in a school room with the evaluators and an administration person in attendance. The students attempted a test where they were rectified by the evaluators before to taking each one. There were no instructions given during the assessment.

After the assessment using the MABC-2 battery, psychomotor experts linked to the educational centre and a team of specialists taught all the program sessions (see intervention program). Once the process was completed, the MABC-2 battery was administered again the day after completing the intervention.

All research was conducted in accordance to Declaration of Helsinki. Research protocol was sent to the Ethics Committee of the national EDUCA platform for review and its approval, being approved with the code number 15/2021.

Statistical analysis

For the statistical treatment of the data, the IBM SPSS Statistics program for Windows, version 25.0, was used. First, descriptive statistics (mean and its standard deviation) were calculated for each dependent variable examined. Secondly, the possible effect of the quarter of birth (Q1; Q2; Q3; Q4) and gender (boy; girl) on the MABC-2 variables (Manual dexterity: MD; Aiming and Catching: A&C; Balance: Bal; and Total test score; TTS) was analysed using a multivariate analysis of variance (MANOVA) and the interaction between both factors using the Bonferroni statistic. Furthermore, the effect size was calculated in terms of eta squared (η^2). The level of significance was set at $p < .05$.

RESULTS

50 preschool children participated in this study [26 boys (52%) and 24 girls (48%)] aged between 4-5 years (M = 4.46; SD = 0.503) who met the inclusion and exclusion criteria. The distribution of the participants was from Q1 [n = 11 (22,0 %)], Q2 [n =12 (24,0%)], Q3 [n = 15 (30,0 %)] and Q4 [n = 12 (24,0 %)], respectively.

Regarding the quarter of birth factor (Table 2), there was a significant main effect in the pre-test on MD ($F_{(3, 42)} = 4.022$, $p = .013$, $\eta^2 = .22$) with lower scores obtained in Q4 compared to Q1 ($p = .030$) and Q2 ($p = .035$). A significant main effect was also found in A&C ($F_{(3, 42)} = 5.730$, $p = .002$, $\eta^2 = .29$), with lower scores in Q4 compared to Q1 ($p = .003$) and Q2 ($p = .015$). Finally, statistically significant differences were found in TTS ($F_{(3, 42)} = 4.022$, $p < .001$, $\eta^2 = .37$), with Q4 scores again lower than those of Q1 ($p < .001$), Q2 ($p = .006$) and Q3 ($p = .034$). The previous differences disappear once the intervention program is applied [MD ($p = .755$); A&C ($p = .806$); TTS ($p = .507$)] in the quarter of birth factor.

Table 2. MABC-2 test total scores based on quarter of birth and gender.

		Q1		Q2	
		***Pre* (M;SD)**	***Post* (M;SD)**	***Pre* (M;SD)**	***Post* (M;SD)**
Manual dexterity	*Boys*	26.17;4,75	26.83;2.22	26.57;7.06	25.42;5.65
	Girls	24,06;4.98	25.20;6.09	23.60;5.41	26.40;6.06
	Total	25.45;4.67	26.09;4.25	25.33;6.34	25.83;5.57
Aiming and catching	*Boys*	20.00;5.95	14.16;6.67	17.71;3.49	19.71;6.94
	Girls	22.00;1.00	18.60;5.36	21.60;3.48	17.00;4.52
	Total	20.90;4.39	16.18;6.25	19.33;4.00	18.58;5.97
Balance	*Boys*	32.83;3.55	34.33;2.87	29.71;5.28	34.85;3.62
	Girls	33.60;3.50	31.00;3.80	29.80;2.16	33.60;3.20
	Total	33.18;3.37	32.81;3.60	29.75;4.11	34.33;3.36
Total test Score	*Boys*	79.00;8.00	75.33;8.86	74.00;8.54	80.00;13.34
	Girls	81.00;3.80	77.40;5.59	75.20;10.40	75.00;9.53
	Total	79.90;6.23	76.27;7.28	74.50;8.92	77.91;11.69

		Q3		Q4	
		Pre **(M;SD)**	***Post*** **(M;SD)**	***Pre*** **(M;SD)**	***Post*** **(M;SD)**
Manual dexterity	*Boys*	23.62;10.18	26.75;8.86	12.80;2.77	17.60;4.15
	Girls	24.42;3.70	24.71;8.07	22.57;4.54	29.71;2.21
	Total	24.00;7.61	25.08;8.26	18.5;6.27	24.66;6.91
Aiming and catching	*Boys*	15.25;5.28	17.00;5.90	14.00;4.18	15.80;6.05
	Girls	18.71;5.18	20.14;6.28	12.28;6.67	19.00;5.91
	Total	16.86;5.35	18.46;6.08	13.00;5.60	17.67;5.92
Balance	*Boys*	28.00;5.50	33.75;1.90	26.00;11.9	27.80;7.01
	Girls	29.28;3.35	32.42;5.12	30.28;4.49	24.85;2.40
	Total	28.60;4.70	33.13;3.68	28.50;8.21	31.91;5.85
Total test Score	*Boys*	66.87;15.69	77.75;11.85	52.80;16.76	61.20;11.00
	Girls	75.28;3.63	77.28;13.18	65.14;9.54	82.14;9,15
	Total	70.80;12.15	75.53;12.03	60.00;13.86	73.41;14.35

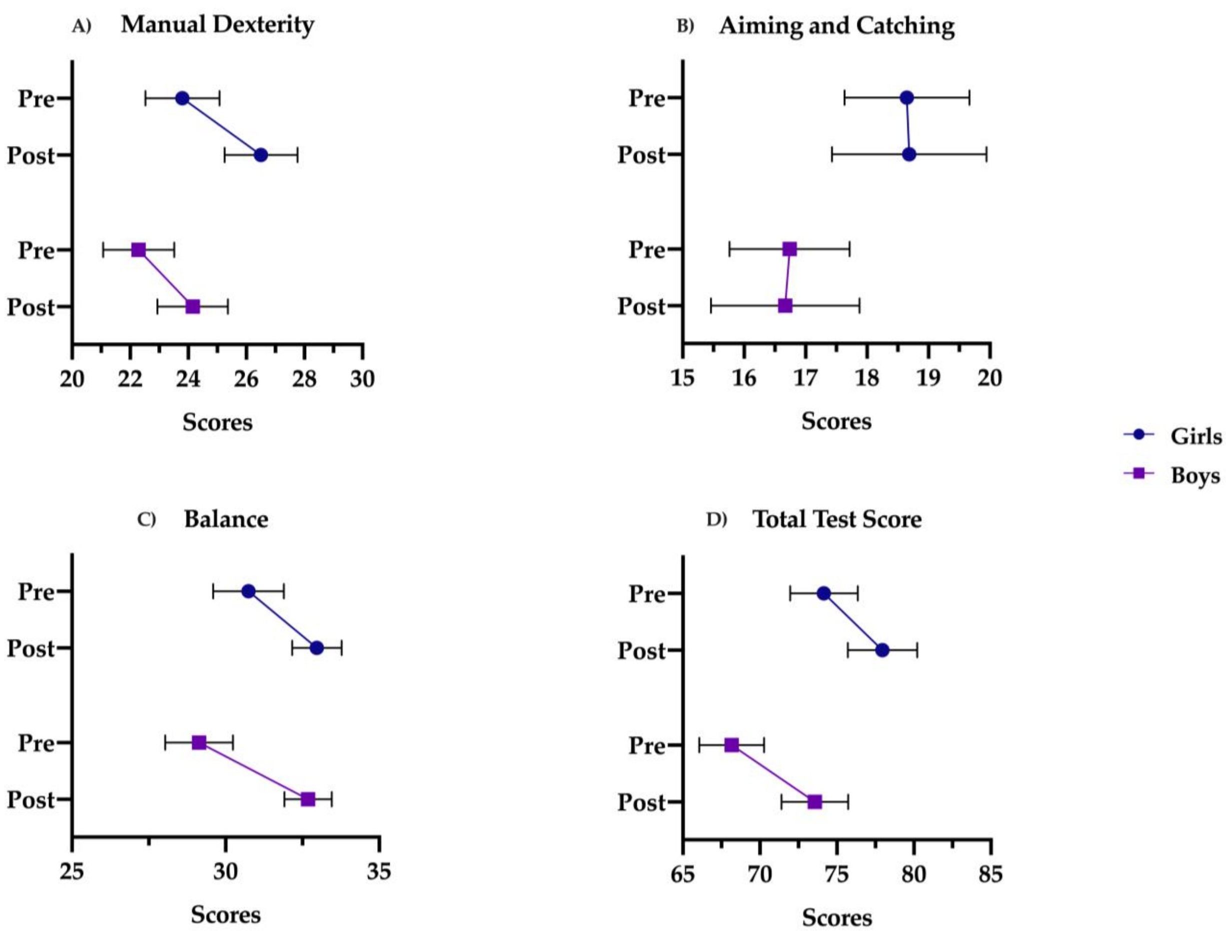

Figure 2. Manual dexterity, aiming and catching, balance and total test scores based on gender.

No statistically significant effect is observed if analysed in terms of the gender factor (Figure 2), both before applying the intervention program [MD (p = .398); A&C (p = .182); Bal (p = .319); TTS (p = .056)], as well as after its application [MD (p = .185); A&C (p = .254); Bal (p = .799); TTS (p = .168)].

Regarding the interaction between the quarter of birth and gender, no significant effect has been found in the interaction of these factors [i.e. (MD (*p* = .072); A&C (*p* = .494); Bal (*p* = .807); TTS (*p* = .535)]. Once the intervention program was applied, statistically significant differences were found in MD ($F_{(3, 42)}$ = 3.59, *p* = .021, η^2 = 0.20), Bal ($F_{(3, 42)}$ = 4.11, *p* = .012, η^2 = 0.23) and TTS ($F_{(3, 42)}$ = 3.26, *p* = .031, η^2 = 0.19). Regarding MD, there is a statistically significant difference between girls and boys of q4 (*p* = .009). The scores achieved in girls are higher. In the Bal analysis, statistically significant differences were found, with lower scores for the girls in q4 than for those in q1 (*p* = .049) and q2 (*p* = .021). Something similar occurs when comparing girls with boys in Q4 (*p* = .003), where girls obtain higher scores. Regarding TTS, significant differences are evident, with lower scores, both in the boys of q4 compared to the boys of q2 (*p* = .031) and between girls and boys of q4 (*p* = .002).

DISCUSSION

The main aim of this research was to explore how relative age impacts MC, specifically in skills such as aiming and catching, balance, and manual dexterity, in schoolchildren aged 4 to 6 years. Additionally, we sought to examine the role of physical and sports education programs in reducing these disparities through an intervention program that uses balance bikes. As a secondary aim, we sought to explore and analyse the effect of these programs based on the gender of the participants. From the results obtained in this study, we can indicate that an intervention using balance bikes improves the MC and consequently, reduces the RAE in pre-schoolers, and can increase the improvements obtained in the tests of manual dexterity, aiming and catching, and balance (Logan et al., 2012; Van Capelle et al., 2017). Therefore, in response to the second main aim, we can say that this type of programs (specific, planned, and appropriate) helps reduce the disparities found before the intervention (Navarro-Patón, Brito-Ballester, et al., 2021; Navarro-Patón, Mecías-Calvo, et al., 2021). Regarding the secondary objective, the results indicate that the participants in this research did not present significant differences before or after the intervention, but a tendency to increase is observed in the assessments obtained in the MABC-2 after the intervention program.

Before the intervention, there was a RAE in the dimensions of MD, A&C, and consequently TTS, since those born in the first quarter of the year obtained higher scores than those born in the second quarter, who in turn obtained higher scores in these three dimensions than those born in the third quarter, but without significant differences. These findings follow the line of previous studies that indicate that older children (in terms of date of birth) have better average scores in terms of MC than younger children (Henderson et al., 2007) because they have better manual dexterity or aiming and catching (Navarro-Patón, Lago-Ballesteros, et al., 2021; Navarro-Patón, Mecías-Calvo, et al., 2021). These scores were especially distant between those born in the last quarter of the year (q4) and those born in q1, q2, and q3, as demonstrated by the statistical significance. Therefore, we can say that RAE exists in these 3 dimensions studied, as previous studies point out (Navarro-Patón, Arufe-Giráldez, et al., 2021; Navarro-Patón, Mecías-Calvo, et al., 2021). These differences may be due to the interaction between physical characteristics, size, and maturation, due to being born earlier (Dalen et al., 2017), the task performed (balance bikes), and the environment (school environment) in which the task is performed (Newell, 1986), which is sometimes confused with greater capacity (Aune et al., 2018).

After the intervention with the balance bikes, the measurement of all the variables studied (i.e. MD; A&C; Bal and TTS) increased with respect to the initial assessment, to the point that the previous differences disappeared, so it can be said that the applied intervention produces improvements in MC (Morgan et al., 2013) and, therefore, reduces the RAE (Navarro-Patón, Brito-Ballester, et al., 2021; Navarro-Patón, Mecías-Calvo, et al., 2021) in MD, A&C and TTS. In this way, we can argue that specific motor interventions developed and implemented for the age of the participants (Logan et al., 2012), have a positive effect on MC components (Jiménez-Díaz et al., 2019; Jiménez Díaz et al., 2015; Van Capelle et al., 2017; Wick et al., 2017).

Regarding gender, before the intervention there were no significant differences between boys and girls in any of the variables studied, as has been shown in previous studies (Kokštejn et al., 2017; Li et al., 2023; Navarro-Patón, Arufe-Giráldez, et al., 2021; Navarro-Patón, Lago-Ballesteros, et al., 2021; Navarro-Patón, Mecías-Calvo, et al., 2021; Valtr et al., 2016). Scores on all tests are higher for girls than for boys, as demonstrated by other studies (Li et al., 2023; Navarro-Patón, Arufe-Giráldez, et al., 2021; Navarro-Patón, Lago-Ballesteros, et al., 2021; Navarro-Patón, Mecías-Calvo, et al., 2021).

Once the intervention was performed, the scores of the different variables increased compared to the previous ones, in both girls and boys, although this brief intervention only lasted 9 weeks as in other similar studies with similar results (Mecías-Calvo et al., 2021; Navarro-Patón, Arufe-Giráldez, et al., 2021; Navarro-Patón, Brito-Ballester, et al., 2021). Again, the scores achieved by girls continue to be higher than those of boys (Goodway et al., 2014; Morley et al., 2015; Valentini et al., 2014; Venter et al., 2015), except in Bal where they are similar and differ from previous studies (Bolger et al., 2018; Kelly et al., 2019).

If we analyse the post-test differences, according to the interaction of gender and quarter of birth, the differences that did not exist before the intervention now appear in favour of girls born in q4 in DM, A&C and TTS; and in Bal between boys of q1 and q2, over those born in q4. This may be because a structured MC program can benefit preschool children (both girls and boys) in these skills (Jiménez-Díaz et al., 2019), because improvements in MC occur after a specific intervention in Physical Education, regardless of the gender of the participants and the duration of the program.

In general, a structured MC program based on balance bikes can benefit both boys and girls (Morgan et al., 2013) in their improvement. Taking into account that improvements have been obtained after this intervention of three weekly sessions, for 9 weeks, not following the parameters of other interventions performed previously (Jiménez-Díaz et al., 2019; Van Capelle et al., 2017; Wick et al., 2017), these improvements could be explained by the ceiling effect (Morgan et al., 2013), achieving better performance in the early stages of the intervention (Mecías-Calvo et al., 2021; Navarro-Patón, Brito-Ballester, et al., 2021; Navarro-Patón, Mecías-Calvo, et al., 2021), so a longer intervention time does not imply better performance (Jiménez-Díaz et al., 2019).

As limitations of this research, we would like to indicate that the sample size is not excessively high and, therefore, the results obtained should be taken with caution. Furthermore, not having used a control group does not ensure that the results are exclusively due to the intervention program, since other factors such as maturation could have influenced the results. On the other hand, the results are assessed as soon as the intervention ends, and no follow-up is performed to check what happens to them in the medium or long term.

CONCLUSION

The results of this research contribute to understanding that a structured and short-term intervention program (three weekly sessions for 9 weeks) reduces the RAEs existing before the intervention. Therefore, we can point out that brief interventions like ours, based on balance bikes, can produce improvements in pre-schoolers' MC. Therefore, one of the contributions made by this study could be the need to inform about the formulation of educational and sports policies focused on equity, as well as the adaptation of pedagogical practices in preschool environments of this type, or the promotion of active transportation in schools.

Likewise, the findings of this research could have direct implications for the design and implementation of educational programs that seek to maximise the motor potential of all children, regardless of their relative age. Additionally, the results could influence the training of physical educators and child development professionals, providing specific strategies to address observed disparities and promote an inclusive and nurturing environment.

AUTHOR CONTRIBUTIONS

Conceptualization, R.N.P. and M.M.C.; methodology, R.N.P. and M.M.C.; validation, R.N.P., F.C.P., M.M.C and V.A.G.; formal analysis, R.N.P.; investigation, F.C.P. and V.A.G.; data curation, F.C.P.; writing—original draft preparation, R.N.P., M.M.C. and V.A.G.; writing—review and editing, R.N.P., F.C.P., M.M.C and V.A.G.; visualization, R.N.P., F.C.P., M.M.C and V.A.G.; supervision, R.N.P., M.M.C and V.A.G.; project administration, F.C.P. and V.A.G. All authors have read and agreed to the published version of the manuscript.

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No potential conflict of interest were reported by the authors.

REFERENCES

Arufe Giráldez, V., Pena García, A., & Navarro Patón, R. (2021). Efectos de los programas de Educación Física en el desarrollo motriz, cognitivo, social, emocional y la salud de niños de 0 a 6 años. Una revisión sistemática. Sportis. Scientific Journal of School Sport, Physical Education and Psychomotricity, 7(3), 448-480. https://doi.org/10.17979/sportis.2021.7.3.8661

Ato, M., López, J. J., & Benavente, A. (2013). Un sistema de clasificación de los diseños de investigación en psicología. Anales de Psicologia, 29(3), 1038-1059. https://doi.org/10.6018/analesps.29.3.178511

Aune, T. K., Ingvaldsen, R. P., Vestheim, O. P., Bjerkeset, O., & Dalen, T. (2018). Relative Age Effects and Gender Differences in the National Test of Numeracy: A Population Study of Norwegian Children. Frontiers in Psychology, 9, 1091. https://doi.org/10.3389/fpsyg.2018.01091

Bolger, L. E., Bolger, L. A., Neill, C. O., Coughlan, E., O'Brien, W., Lacey, S., & Burns, C. (2018). Age and Sex Differences in Fundamental Movement Skills Among a Cohort of Irish School Children. Journal of Motor Learning and Development, 6(1), 81-100. https://doi.org/10.1123/jmld.2017-0003

Brazo-Sayavera, J., Martínez-Valencia, M. A., Müller, L., Andronikos, G., & Martindale, R. J. J. (2017). Identifying talented track and field athletes: The impact of relative age effect on selection to the Spanish National Athletics Federation training camps. Journal of Sports Sciences, 35(22), 2172-2178. https://doi.org/10.1080/02640414.2016.1260151

Calsamiglia, C., & Loviglio, A. (2020). Maturity and school outcomes in an inflexible system: evidence from Catalonia. SERIEs, 11(1), 1-49. https://doi.org/10.1007/s13209-019-0196-6

Carrillo-López, P. J., Rosa-Guillamón, A., & García-Cantó, E. (2018). Analysis of global motor coordination in schoolchildren from 6 to 9 years according to gender and age. TRANCES, 10(3),

281-306. Retrieved from [Accessed 2024, April 20]: https://fb39c223-56a9-4ed3-91f4-073579bde094.filesusr.com/ugd/fa6be1_cb1af81444704cebbb5168afa3b0f29c.pdf
Clark, J. E., & Metcalfe, J. S. (2002). The mountain of motor development: A metaphor. In J. C. Humphrey & J. Humphrey (Eds.), Motor development: Research and reviews (Issue 2, pp. 163-190). NASPE Publications.
Cobley, S., Abraham, C., & Baker, J. (2008). Relative age effects on physical education attainment and school sport representation. Physical Education and Sport Pedagogy, 13(3), 267-276. https://doi.org/10.1080/17408980701711983
Cupeiro, R., Rojo-Tirado, M. A., Cadenas-Sanchez, C., Artero, E. G., Peinado, A. B., Labayen, I., Dorado, C., Arias-Palencia, N. M., Moliner-Urdiales, D., Vidal-Conti, J., Conde-Caveda, J., Mora-Gonzalez, J., Vicente-Rodríguez, G., & Benito, P. J. (2020). The relative age effect on physical fitness in preschool children. Journal of Sports Sciences, 38(13), 1506-1515. https://doi.org/10.1080/02640414.2020.1746559
Dalen, T., Ingvaldsen, R. P., Roaas, T. V., Pedersen, A. V., Steen, I., & Aune, T. K. (2017). The impact of physical growth and relative age effect on assessment in physical education. European Journal of Sport Science, 17(4), 482-487. https://doi.org/10.1080/17461391.2016.1268651
Furley, P., & Memmert, D. (2016). Coaches' implicit associations between size and giftedness: implications for the relative age effect. Journal of Sports Sciences, 34(5), 459-466. https://doi.org/10.1080/02640414.2015.1061198
Gerlach, E., Herrmann, C., Dania, A., Heim, C., Jidovtseff, B., Quitério, A., Vrbas, J., Kossyva, I., Adamakis, M., Zounhia, K., Seelig, H., Ennigkeit, F., Vandeloise, V., Morgado, L., Mornard, M., Cloes, M., Costa, J., Martins, J., Onofre, M., & Scheuer, C. (2018). Basic motor competencies. In Changes in Childhood and adolescence: Current Challenges for Physical Education (pp. 81-90).
González Aramendi, J. M. (2007). El efecto relativo de la edad en el fútbol. Archivos de Medicina Del Deporte, XXIV(117), 5-13. Retrieved from [Accessed 2024, April 20]: http://femede.es/documentos/Original_edad_futbol_5_117.pdf
Goodway, J. D., Famelia, R., & Bakhtiar, S. (2014). Future directions in physical education & sport: Developing fundamental motor competence in the early years is paramount to lifelong physical activity. Asian Social Science, 10(5), 44-54. https://doi.org/10.5539/ass.v10n5p44
Graupera, J. L., & Ruiz, L. M. (2012). Batería de evaluación del movimiento para niños-2. In Batería de evaluación del movimiento para niños (Vol. 2). Pearson.
Henderson, S. E., Sudgen, D. A., & Barnett, A. (2007). Movement Assessment Battery for Children-2 (2nd ed). The Psychological Corporation. https://doi.org/10.1037/t55281-000
Herrmann, C., Bund, A., Gerlach, E., Kurz, D., Lindemann, U., Rethorst, S., & Pühse, U. (2015). A review of the assessment of basic motor qualifications and competencies in school. International Journal of Physical Education, 52(3), 2-13. https://doi.org/10.5771/2747-6073-2015-3-2
Jiménez-Díaz, J., Chaves-Castro, K., & Salazar, W. (2019). Effects of Different Movement Programs on Motor Competence: A Systematic Review With Meta-Analysis. Journal of Physical Activity and Health, 16(8), 657-666. https://doi.org/10.1123/jpah.2018-0179
Jiménez Díaz, J., Salazar Rojas, W., & Morera Castro, M. (2015). Age and gender differences in fundamental motor skills. Pensar En Movimiento: Revista de Ciencias Del Ejercicio y La Salud, 13(2), 4. https://doi.org/10.15517/pensarmov.v13i2.18327
Kelly, L., O'Connor, S., Harrison, A. J., & Ní Chéilleachair, N. J. (2019). Does fundamental movement skill proficiency vary by sex, class group or weight status? Evidence from an Irish primary school setting. Journal of Sports Sciences, 37(9), 1055-1063. https://doi.org/10.1080/02640414.2018.1543833

Kokštejn, J., Musálek, M., & Tufano, J. J. (2017). Are sex differences in fundamental motor skills uniform throughout the entire preschool period? PLOS ONE, 12(4), e0176556. https://doi.org/10.1371/journal.pone.0176556

Leow, L.-A., Marinovic, W., Rugy, A. de, & Carroll, T. J. (2019). Task errors drive memories that improve sensorimotor adaptation. BioRxiv, 538348. https://doi.org/10.1101/538348

Li, K., Chen, S., Ma, J., Martins, C., Duncan, M., Sheng, X., Liu, S., & Cai, Y. (2023). The relative age effect on fundamental movement skills in Chinese children aged 3-5 years. BMC Pediatrics, 23(1), 150. https://doi.org/10.1186/s12887-023-03967-6

Logan, S. W., Robinson, L. E., Wilson, A. E., & Lucas, W. A. (2012). Getting the fundamentals of movement: a meta-analysis of the effectiveness of motor skill interventions in children. Child: Care, Health and Development, 38(3), 305-315. https://doi.org/10.1111/j.1365-2214.2011.01307.x

López Gallego, F., Lara Sánchez, A., Espejo Vacas, N., & Cachón Zagalaz, J. (2016). Influence of gender, age and level of physical activity over Physical Condition of Students in Primary Education. Retos, 29, 129-133. https://doi.org/10.47197/retos.v0i29.34846

Mecías-Calvo, M., Arufe-Giráldez, V., Cons-Ferreiro, M., & Navarro-Patón, R. (2021). Is It Possible to Reduce the Relative Age Effect through an Intervention on Motor Competence in Preschool Children? Children, 8(5), 386. https://doi.org/10.3390/children8050386

Morgan, P. J., Barnett, L. M., Cliff, D. P., Okely, A. D., Scott, H. A., Cohen, K. E., & Lubans, D. R. (2013). Fundamental Movement Skill Interventions in Youth: A Systematic Review and Meta-analysis. Pediatrics, 132(5), e1361 LP-e1383. https://doi.org/10.1542/peds.2013-1167

Morley, D., Till, K., Ogilvie, P., & Turner, G. (2015). Influences of gender and socioeconomic status on the motor proficiency of children in the UK. Human Movement Science, 44, 150-156. https://doi.org/10.1016/j.humov.2015.08.022

Navarro-Patón, R., Arufe-Giráldez, V., Sanmiguel-Rodríguez, A., & Mecías-Calvo, M. (2021). Differences on Motor Competence in 4-Year-Old Boys and Girls Regarding the Quarter of Birth: Is There a Relative Age Effect? Children, 8(2), 141. https://doi.org/10.3390/children8020141

Navarro-Patón, R., Brito-Ballester, J., Villa, S. P., Anaya, V., & Mecías-Calvo, M. (2021). Changes in Motor Competence after a Brief Physical Education Intervention Program in 4 and 5-Year-Old Preschool Children. International Journal of Environmental Research and Public Health, 18(9), 4988. https://doi.org/10.3390/ijerph18094988

Navarro-Patón, R., Lago-Ballesteros, J., Arufe-Giráldez, V., Sanmiguel-Rodríguez, A., Lago-Fuentes, C., & Mecías-Calvo, M. (2021). Gender Differences on Motor Competence in 5-Year-Old Preschool Children Regarding Relative Age. International Journal of Environmental Research and Public Health, 18(6), 3143. https://doi.org/10.3390/ijerph18063143

Navarro-Patón, R., Mecías-Calvo, M., Rodríguez Fernández, J. E., & Arufe-Giráldez, V. (2021). Relative Age Effect on Motor Competence in Children Aged 4-5 Years. Children, 8(2), 115. https://doi.org/10.3390/children8020115

Newell, K. M. (1986). Constraints on the development of coordination. In M. G. Wade & H. T. . Whiting (Eds.), Motor development in children: Aspects of coordination and control (pp. 341-361). Springer Netherlands. https://doi.org/10.1007/978-94-009-4460-2_19

Roberts, S. J., & Fairclough, S. J. (2012). The Influence of Relative Age Effect in the Assessment of High School Students in Physical Education in the United Kingdom. Journal of Teaching in Physical Education, 31(1), 56-70. https://doi.org/10.1123/jtpe.31.1.56

Schorer, J., Neumann, J., Cobley, S. P., Tietjens, M., & Baker, J. (2011). Lingering Effects of Relative Age in Basketball Players' Post Athletic Career. International Journal of Sports Science & Coaching, 6(1), 143-147. https://doi.org/10.1260/1747-9541.6.1.143

Stodden, D. F., Goodway, J. D., Langendorfer, S. J., Roberton, M. A., Rudisill, M. E., Garcia, C., & Garcia, L. E. (2008). A Developmental Perspective on the Role of Motor Skill Competence in Physical Activity: An Emergent Relationship. Quest, 60(2), 290-306. https://doi.org/10.1080/00336297.2008.10483582

Valentini, N. C., Ramalho, M. H., & Oliveira, M. A. (2014). Movement assessment battery for children-2: translation, reliability, and validity for Brazilian children. Research in Developmental Disabilities, 35(3), 733-740. https://doi.org/10.1016/j.ridd.2013.10.028

Valtr, L., Psotta, R., & Abdollahipour, R. (2016). Gender differences in performance of the Movement Assessment Battery for Children - 2nd edition test in adolescents. Acta Gymnica, 46(4), 155-161. https://doi.org/10.5507/ag.2016.017

Van Capelle, A., Broderick, C. R., van Doorn, N., E.Ward, R., & Parmenter, B. J. (2017). Interventions to improve fundamental motor skills in pre-school aged children: A systematic review and meta-analysis. Journal of Science and Medicine in Sport, 20(7), 658-666. https://doi.org/10.1016/j.jsams.2016.11.008

Venter, A., Pienaar, A. E., & Coetzee, D. (2015). Extent and nature of motor difficulties based on age, ethnicity, gender and socio-economic status in a selected group of three-to five-year-old children. South African Journal for Research in Sport, Physical Education and Recreation, 37(3), 169-183. Retrieved from [Accessed 2024, April 20]: https://www.ajol.info/index.php/sajrs/article/view/126551

Wick, K., Leeger-Aschmann, C. S., Monn, N. D., Radtke, T., Ott, L. V, Rebholz, C. E., Cruz, S., Gerber, N., Schmutz, E. A., Puder, J. J., Munsch, S., Kakebeeke, T. H., Jenni, O. G., Granacher, U., & Kriemler, S. (2017). Interventions to Promote Fundamental Movement Skills in Childcare and Kindergarten: A Systematic Review and Meta-Analysis. Sports Medicine, 47(10), 2045-2068. https://doi.org/10.1007/s40279-017-0723-1

ORIGINAL ARTICLE

Association between heart rate variability and cardiorespiratory fitness in individuals with type 2 diabetes mellitus: A cross-sectional study

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ABSTRACT

Background: Type 2 Diabetes Mellitus (T2DM) is associated with cardiovascular risk, which is partly due to autonomic dysfunction and decreased cardiorespiratory fitness. This study examines the relationship between heart rate variability (HRV) and maximal oxygen uptake (VO_{2max}) in T2DM patients to understand their interconnected impacts on autonomic and aerobic functions. Methods: In a cross-sectional study, 77 T2DM patients underwent HRV and VO_{2max} assessments using standard protocols. HRV metrics were analysed in conjunction with VO_{2max}, measured through direct breath-by-breath analysis. Pearson's correlation coefficient was used to investigate the relationships between HRV indices and VO_{2max}. Results: VO_{2max} showed strong positive correlations with RMSSD (r = 0.89, p < .001), HF (r = 0.54, p < .001), and pNN50% (r = 0.52, p < .001), indicating higher parasympathetic activity with improved cardiorespiratory fitness. Negative correlations with LF (r = -0.60, p < .001) and the LF/HF ratio (r = -0.39, p < .001) suggested that better fitness levels lead to sympathetic withdrawal and a more favourable autonomic balance. Moderate positive correlations with SDNN (r = 0.46, p < .001) and TP (r = 0.58, p < .001) further suggested that overall autonomic modulation is enhanced with increased cardiorespiratory fitness. Conclusion: This study substantiates a significant correlation between HRV and VO_{2max} in individuals with T2DM, highlighting the intricate relationship between autonomic function and aerobic capacity. These findings suggest that enhancing cardiorespiratory fitness may improve autonomic balance, offering potential avenues for mitigating cardiovascular risk in the T2DM population.
Keywords: Sport medicine, Cardiac autonomic modulation, Exercise testing, Parasympathetic, Sympathetic.

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INTRODUCTION

Type 2 Diabetes Mellitus (T2DM) represents a significant global health concern, marked by its complex pathophysiology and an elevated risk of cardiovascular complications (Galicia-Garcia et al., 2020). This metabolic disorder affects millions worldwide, underscoring the importance of understanding and managing its multifaceted impact on health (Zheng et al., 2018). Among the various factors influencing the cardiovascular sequelae of T2DM, the autonomic control of the heart, as reflected by heart rate variability (HRV), stands out for its predictive value regarding cardiovascular health and outcomes (Benichou et al., 2018). HRV, a non-invasive marker of autonomic nervous system functionality, reveals the heart's ability to respond to varying physiological conditions, highlighting its relevance in the context of diabetes management (Shaffer & Ginsberg, 2017).

Concurrently, cardiorespiratory fitness (CRF), often quantified by maximal oxygen uptake (VO_{2max}), is a robust predictor of cardiovascular and all-cause mortality, underlining its crucial role in assessing overall health and the risk of chronic diseases (Gonzales et al., 2021). The significance of VO_{2max} extends beyond its representation of physical fitness; it encapsulates the efficiency of the cardiovascular, respiratory, and muscular systems to supply and utilize oxygen during sustained physical activity (Gim & Choi, 2016). This efficiency is paramount, especially in the context of T2DM, where decreased CRF is a common finding (Regensteiner et al., 1995; Tadic et al., 2021). Individuals with T2DM typically exhibit lower VO_{2max} values compared to their nondiabetic counterparts, a disparity that not only marks impaired physical fitness but also signifies an elevated risk of cardiovascular complications and reduced quality of life (Cai et al., 2023).

Given that T2DM is characterized by insulin resistance and metabolic dysregulation (Galicia-Garcia et al., 2020), which have been associated with reduced HRV and impaired CRF. For instance, a study by Larsen et al. (2012) demonstrated that CRF is highly correlated with insulin sensitivity and secretion in a healthy population, suggesting the potential for similar associations in T2DM (Larsen et al., 2012). Further, investigations such as the 23-year cohort study by Zaccardi et al. (2015) have underscored the inverse relationship between CRF and T2DM risk, independent of other factors (Zaccardi et al., 2015). The relationship between HRV and cardiovascular health indicators, such as endothelial function and physical fitness, especially in T2DM, further elucidates the intertwined nature of these metrics (Picard et al., 2021; Tuttolomondo et al., 2021). Additionally, Kadoglou et al. (2009) found that cardiorespiratory capacity is associated with a favourable cardiovascular risk profile in T2DM patients, offering a further insight into the potential benefits of improving HRV and VO_{2max} in this demographic (Kadoglou et al., 2009).

While both HRV and VO_{2max} have independently demonstrated associations with cardiovascular disease risk and mortality in various populations, their interrelationship, particularly in the context of T2DM, remains relatively unexplored. Existing literature predominantly examines these parameters in isolation or in non-diabetic population (Benichou et al., 2018; Granero-Gallegos et al., 2020; Grant et al., 2013; Leite et al., 2009). This study uniquely focuses on individuals with T2DM, a group in which these relationships are less understood and potentially more complex due to the interplay of metabolic, cardiovascular, and autonomic factors. Therefore, the aim of this study is to determine the correlation of HRV metrics align with VO_{2max}, in a T2DM population. We hypothesize that there exists a significant correlation between HRV metrics and VO_{2max} in individuals with T2DM, suggesting an intertwined relationship between autonomic function and aerobic capacity in this population.

METHODS

Sample size calculation

The sample size of this study was determined using G*Power 3.1.9.4, implementing a bivariate normal model for correlation analysis. The power analysis was conducted a priori to compute the necessary sample size, given alpha, power, and the anticipated effect size. We selected a one-tailed hypothesis test with an alpha error probability of 0.05, and we aimed for a power of 0.85, indicating a 15% probability of a Type II error. The effect size for the expected correlation (ρ H1) was set at 0.3, reflecting a medium effect size following Cohen's conventions (Cohen, 2013). Based on these parameters, the analysis yielded a sample size of 77 participants.

Sampling

A cross-sectional study was conducted on 77 patients with T2DM at Centre for Physiotherapy and Rehabilitation Sciences, Jamia Millia Islamia, New Delhi, India. The participant recruitment was performed from outpatient clinics of MA Ansari Health Centre and the Physiotherapy clinic of Centre for Physiotherapy and Rehabilitation Sciences, Jamia Millia Islamia, New Delhi, India by convenience sampling. Participants included in the study were required to have been diagnosed with T2DM for a minimum of one year and be between the ages of 30 and 70 years. Exclusion criteria included severe arrhythmias, pregnancy, breastfeeding, other metabolic disorders, significant comorbidities, contraindications for exercise testing, and acute complications related to T2DM (Ferguson, 2014; Tang et al., 2013).

Procedure

The cross-sectional study was conducted from August 2023 to January 2024, adhering to the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines for reporting cross-sectional research (Cuschieri, 2019). All participants have provided their informed consent prior participation in this study. The research followed the ethical guidelines set forth in the Declaration of Helsinki (Ashcroft, 2008). The eligibility criteria were evaluated by medical professionals at Dr. M. A Ansari Health Centre, Jamia Millia Islamia, New Delhi, India. On the first day, eligible participants underwent an assessment of general demographic details, including age, height, weight, gender, and body mass index (BMI), along with clinical parameters such as the duration of diabetes, resting heart rate, systolic blood pressure (SBP), and diastolic blood pressure (DBP). Instructions for the procedures on subsequent days were provided at this time. On the second day of the study, participants underwent assessments for HRV and VO_{2max}. Resting HRV measurements were taken initially, followed by the evaluation of VO_{2max}.

Blood pressure and body mass index assessment

The SBP and DBP measurements were taken using a conventional sphygmomanometer. Participants were instructed to avoid caffeine, exercise, and smoking for 30 minutes before their assessment. They were asked to sit calmly for 5 minutes. After a 10-minute rest period in the seated position, blood pressure readings were obtained with the sphygmomanometer. The cuff was applied to either the right or left arm, and the initial blood pressure reading was recorded. A follow-up reading was conducted 2 minutes later on the same arm to ensure accuracy. The final blood pressure reading was determined by taking the average of two consecutive stable measurements (Muntner et al., 2019). Subsequently, after a brief rest interval of 1-2 minutes, a recording was taken from the opposite arm as well. In cases where discrepancies were observed between the measurements from both arms, the arm with the higher reading was selected for the purpose of analysis (Muntner et al., 2019).

For the assessment of BMI, height and weight measurements were accurately obtained using standard medical scales and a stadiometer. Participants were requested to remove heavy clothing and shoes for precise measurement. BMI was then calculated by dividing the participant's weight in kilograms by the square of their height in meters (kg/m^2) (Weir & Jan, 2019).

Assessment of resting heart rate variability

The evaluation of HRV for all participants was scheduled between 9:00 AM and 12:00 PM, after ensuring a fasting period of at least 2 hours post-meal. This specific timing was selected to reduce the impact of circadian rhythms on autonomic function and to prevent any potential disturbances in test outcomes caused by recent food consumption (Bhati & Hussain, 2021). Participants were advised to avoid medications that could alter autonomic nervous system activity for at least 24 hours before undergoing tests for autonomic function and blood pressure. This guideline follows the recommendations issued by the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology in 1996 ("*Heart rate variability. Standards of measurement, physiological interpretation, and clinical use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology,*" 1996).

After resting for at least 15 minutes in a supine position within an environment maintained at 24°C, an electrocardiogram (ECG) was captured for a duration of 10 minutes using a standard lead II setup. Analysis focused on the final 5 minutes of the ECG recording to examine both time and frequency domain aspects of HRV. This analysis was performed utilizing LabChart software version 7.3.7 (Power Lab 8 SP, AD Instruments, Australia) to process the data. Careful examination was undertaken to identify and interpolate ectopic beats, ensuring they did not exceed 10% of all beats for a consistent dataset. The analysis employed Fast Fourier Transform for power spectral analysis to delineate signal power into its frequency components, applying a lowpass filter with a 40 Hz cut-off to the data. Evaluated metrics included Total Power (TP), Low Frequency (LF) in millisecond square (ms^2), High Frequency (HF) in ms^2, and the LF/HF ratio. Time domain measures such as the standard deviation of all normal-to-normal intervals (SDNN), the root mean square of successive differences between normal heartbeats (RMSSD), and the percentage of successive R-R intervals varying by more than 50 ms (pNN50%) were also assessed ("*Heart rate variability. Standards of measurement, physiological interpretation, and clinical use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology,*" 1996).

Assessment of cardiorespiratory fitness

In this study, VO_{2max} measurements were obtained through a direct breath-by-breath analysis technique, which is critical for evaluating CRF. This process involved the use of an open circuit spirometry system. Participants inhaled and exhaled through a mouthpiece connected to a gas analysis unit (Model: ML206), allowing for the precise capture of respiratory data. This data was then analysed with the Metabolic Module within LabChart Software by AD Instruments, ensuring the integrity and accuracy of VO_{2max} calculations. This technique aligns with established protocols for accurately determining VO_{2max}, underscoring the efficacy of breath-by-breath analysis in measuring aerobic fitness levels (Beltz et al., 2016).

The study exclusively implemented the modified Bruce protocol during the graded exercise test on a treadmill. Unlike the traditional Bruce protocol, this modified approach starts at a lower intensity, progressively escalating through stages that last 3 minutes each. This gradual increase from a gentle walk to more intense levels of speed and incline is specifically designed to accommodate a wide range of participant fitness levels (Trabulo et al., 1994). Such customization ensures that all participants can safely achieve their maximal exertion. Continuous monitoring of heart rate, oxygen uptake, and expired gases was conducted throughout the test. This provided real-time feedback necessary for the accurate calculation of VO_{2max}, facilitating a thorough assessment of each participant's cardiopulmonary fitness.

Statistical analysis

The statistical analysis in this study was conducted with the aid of SPSS version 21 (SPSS Inc., Chicago, Illinois) and MedCalc Statistical Software version 19.2.6 (MedCalc Software bv, Ostend, Belgium). Data are presented as mean and standard deviation unless otherwise specified. The normality of data distribution was assessed using the Shapiro-Wilk test. For variables not normally distributed, log transformation was applied to achieve normality. The correlation between HRV indices and VO_{2max} was analysed using Pearson's correlation coefficient to determine the strength and direction of the association, which provided insights into both the strength and direction of the association. Interpretation of Pearson's correlation coefficient values was based on the established ranges: values from -0.19 to 0.19 indicate a very weak correlation, 0.20 to 0.39 (or -0.20 to -0.39) a weak correlation, 0.40 to 0.59 (or -0.40 to -0.59) a moderate correlation, 0.60 to 0.79 (or -0.60 to -0.79) a strong correlation, and 0.80 to 1.0 (or -0.80 to -1.0) a very strong correlation. These value ranges are used to quantify the linear relationship between two variables, where the closer the value is to ±1, the stronger the relationship (Akoglu, 2018).

RESULTS

The demographic and clinical characteristics of the 77 participants with T2DM are illustrated in Table 1, revealed an average age of 46.8 ± 7.7 years, with a male predominance (46 males and 31 females). The HRV indices demonstrated significant correlations with VO_{2max} levels among participants (Table 2). Specifically, RMSSD, indicative of parasympathetic activity, showed the strongest positive correlation with VO_{2max} ($r = 0.89$, $p < .001$), indicating a strong relationship (Figure 1). On the other hand, LF, a marker of sympathetic activity, was negatively correlated with VO_{2max} ($r = -0.60$, $p < .001$), suggesting that improvements in cardiorespiratory fitness are associated with reduced sympathetic dominance (Figure 2). The LF/HF ratio, which assesses the balance between sympathetic and parasympathetic activity, also negatively correlated with VO_{2max} ($r = -0.39$, $p < .001$), indicating that higher fitness levels are associated with a more favourable autonomic balance (Figure 3).

Table 1. Demographic characteristics of participants.

Variables	Mean ± SD (n = 77)
Age (years)	46.8 ± 7.7
Sex (M/F)	46/31
BMI (kg/m^2)	33.5 ± 4.7
T2DM duration (years)	6.9 ± 0.5
SBP (mmHg)	131.5 ± 13.3
DBP (mmHg)	83.3 ± 4.8
HR_{rest} (beats/min)	81.2 ± 11
FBG (mg/dl)	110 ± 5
PPBG (mg/dl)	159.7 ± 6.8
HbA1c (%)	6.2 ± 0.3
VO_{2max} (ml/kg/min)	26.6 ± 6.4

Abbreviations: M: male; F: female; BMI: body mass index; HR_{rest}: resting heart rate; SBP: systolic blood pressure; DBP: diastolic blood pressure; FBG: fasting blood glucose; PPBG: post-prandial blood glucose; HbA1c: glycosylated haemoglobin; VO_{2max}: volume of maximum oxygen consumption.

Table 2. Descriptives, and correlation statistics of HRV indices with VO_{2max}.

Variables	Mean ± SD	Correlation coefficient (r)	*p*-value
SDNN (ms)	50.1 ± 1.3	0.46	<.001
pNN50 (%)	32.4 ± 13.7	0.52	<.001
RMSSD (ms)	59.6 ± 9	0.89	<.001
LF (ms^2)	293 ± 123.2	-0.60	<.001
HF (ms^2)	406.6 ± 159.5	0.54	<.001
TP (ms^2)	952.5 ± 129	0.58	<.001
LF/HF	1.1 ± 1	-0.39	<.001

Abbreviations: SDNN: standard deviation of the normal-to-normal sinus node-initiated R-R intervals; pNN50% : Proportion of differences in consecutive N-N intervals that are longer than 50 ms; RMSSD: root mean square of successive R-R interval differences; LF: Low frequency; HF: High frequency; TP: Total power; LF/HF: Low frequency by high frequency ratio; SD: standard deviation.

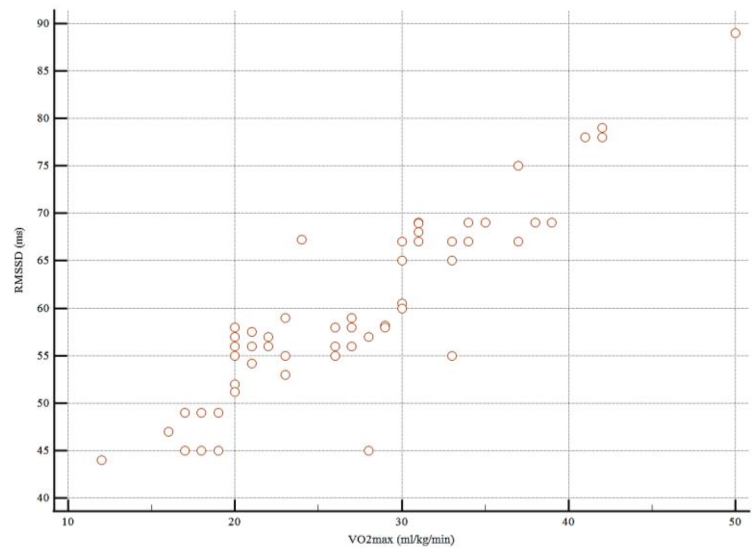

Figure 1. Scatter plot illustrating the correlation between root mean square of successive differences between normal heartbeats (RMSSD) and VO_{2max} in individuals with Type 2 Diabetes.

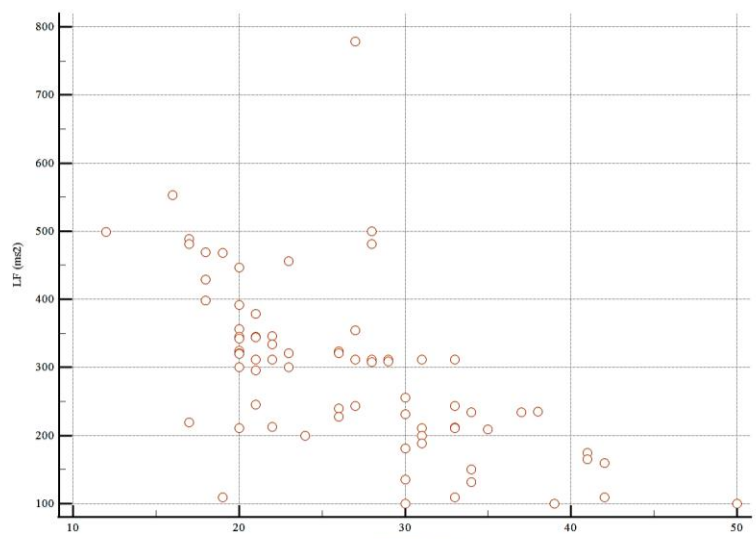

Figure 2. Scatter plot illustrating the correlation between Low Frequency (LF) and VO_{2max} in individuals with Type 2 Diabetes.

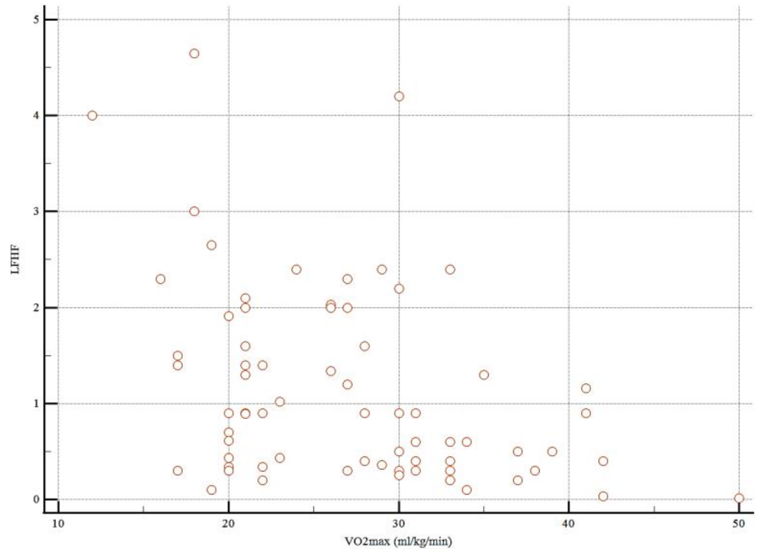

Figure 3. Scatter plot illustrating the correlation between Low Frequency to High Frequency ratio (LF/HF) and VO_{2max} in individuals with Type 2 Diabetes.

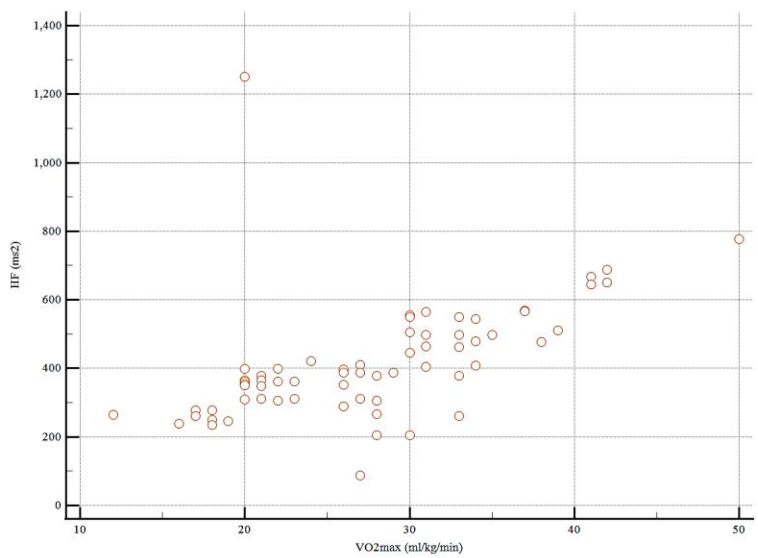

Figure 4. Scatter plot illustrating the correlation between High Frequency (HF) and VO_{2max} in individuals with Type 2 Diabetes.

The indicators of parasympathetic control including HF (r = 0.54, $p < .001$) and pNN50% (r = 0.52, $p < .001$) have demonstrated moderate significant correlation (Figure 4 and Figure 5). Additionally, SDNN (r = 0.46, $p < .001$) and TP (r = 0.58, $p < .001$) were moderately correlated, indicating increase in overall autonomic modulation is associated with better VO_{2max} level (Figure 6 and Figure 7). These findings highlight the intricate relationship between autonomic function and cardiorespiratory fitness, with significant influence by both sympathetic and parasympathetic influences, alongside overall sympathovagal balance.

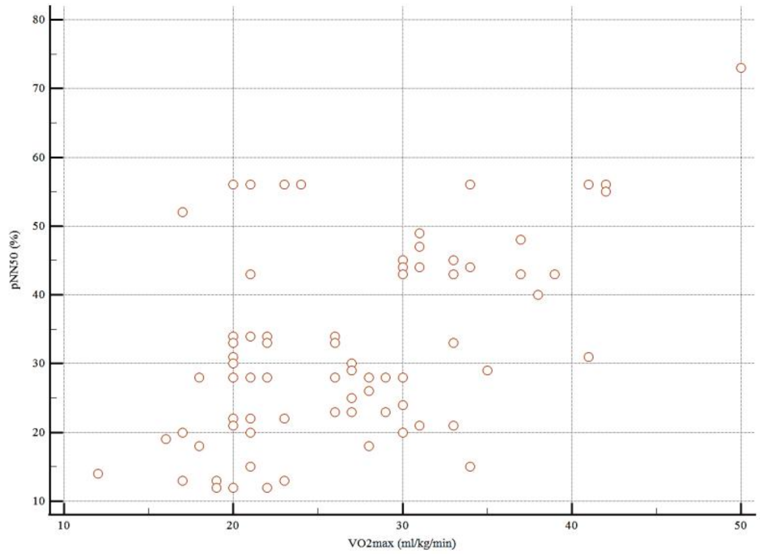

Figure 5. Scatter plot illustrating the correlation between the percentage of successive R-R intervals varying by more than 50 ms (pNN50%) and VO_{2max} in individuals with Type 2 Diabetes.

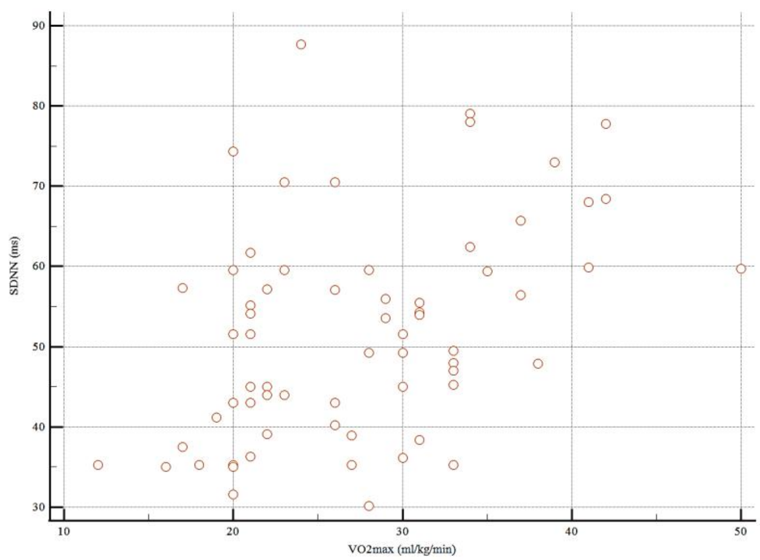

Figure 6. Scatter plot illustrating the correlation between standard deviation of all normal-to-normal intervals (SDNN) and VO_{2max} in individuals with Type 2 Diabetes.

DISCUSSION

The present study aimed to elucidate the correlation between cardiac autonomic control, as measured by HRV, and CRF, quantified through VO_{2max}, in individuals with T2DM. Our findings reveal a linear relationship between HRV and VO_{2max}, significantly influenced by both sympathetic and parasympathetic branches of the autonomic nervous system, as well as the overall sympathovagal balance. This relationship underscores the potential for HRV and VO_{2max} as critical markers in assessing cardiovascular risk and fitness levels in a population inherently at higher risk for cardiovascular diseases. Such insights contribute to a deeper understanding of the autonomic and cardiovascular interplay in T2DM, highlighting the importance of integrated approaches in managing and mitigating cardiovascular risk among these patients.

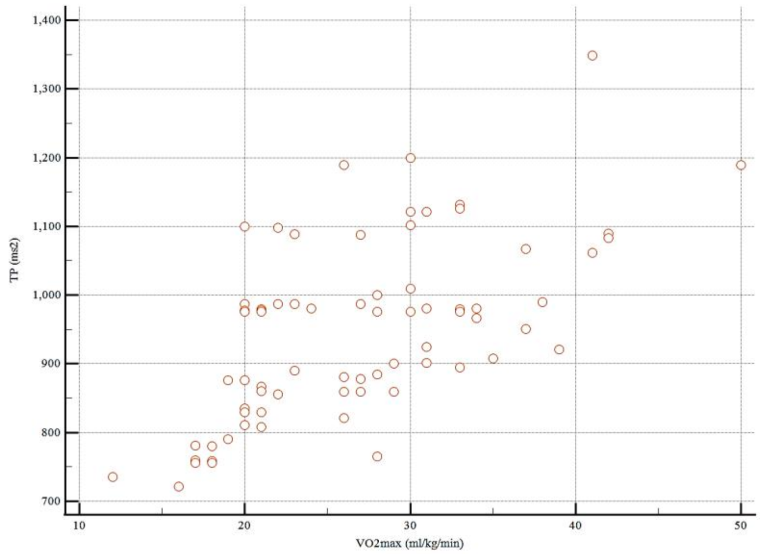

Figure 7. Scatter plot illustrating the correlation between Total Power (TP) and VO_{2max} in individuals with Type 2 Diabetes.

The strong positive correlation between RMSSD and VO_{2max}, suggests that higher cardiorespiratory fitness levels are associated with enhanced parasympathetic modulation (Cabral et al., 2019). This is significant because enhanced parasympathetic activity is known to be cardioprotective, reducing the risk of arrhythmias and cardiac events (Shaffer & Ginsberg, 2017). Conversely, the negative correlation between LF and VO_{2max} underscores the concept that improved fitness levels might lead to a reduction in sympathetic dominance, which is beneficial since excessive sympathetic activity is associated with adverse cardiovascular outcomes (Tuttolomondo et al., 2021). The inverse relationship between the LF/HF ratio and VO_{2max} further supports the notion that higher levels of fitness are associated with a more favourable autonomic balance, possibly reflecting better cardiovascular health (Daniela et al., 2022). This balance is critical in T2DM patients, where autonomic dysfunction can exacerbate the risk of cardiovascular complications (Tuttolomondo et al., 2021).

Further, the observed moderate positive correlation between SDNN and VO_{2max} indicates that individuals with higher CRF exhibit greater overall variability in heart rate, suggesting a healthier autonomic nervous system and a lower risk of cardiac complications (Shaffer & Ginsberg, 2017). Similarly, the significant association between pNN50% and VO_{2max} highlights the role of acute changes in HRV in response to stressors, further emphasizing the benefits of enhanced parasympathetic activity (Picard et al., 2021). Additionally, the relationship between TP and VO_{2max} underscores the holistic influence of physical fitness on the spectrum of autonomic heart rate modulation. Higher TP values, indicative of overall HRV, suggest that increased fitness levels are associated with an autonomic system capable of a wider range of responses to physiological stimuli, a characteristic deemed protective against cardiovascular morbidity (Granero-Gallegos et al., 2020; Picard et al., 2021).

Previous research has shown similar associations, indicating that individuals with T2DM often exhibit reduced HRV and VO_{2max}, reflecting impaired autonomic regulation and diminished CRF. For instance, Larsen et al.

(2012) found that CRF is highly correlated with insulin sensitivity (Larsen et al., 2012), indicating that improved VO_{2max} could have beneficial effects on metabolic control in T2DM. Further, Loimaala et al. (2003) demonstrated that exercise training enhances baroreflex sensitivity and HRV, alongside improvements in VO_{2max}, suggesting that physical activity can ameliorate autonomic balance and cardiovascular risk in T2DM patients (Loimaala et al., 2003). Moreover, the metabolic improvements associated with higher VO_{2max}, such as better glucose control and reduced insulin resistance, are particularly beneficial in T2DM, potentially contributing to the observed relationships (Zaki et al., 2023). These metabolic benefits, alongside improved autonomic balance, could explain the strong correlations observed in the study.

Clinical implications

From a clinical perspective, these findings emphasize the importance of promoting physical activity and improving CRF as non-pharmacological strategies to mitigate cardiovascular risk in T2DM. Given the modifiable nature of HRV and VO_{2max} through lifestyle interventions, these markers could serve as valuable tools in monitoring the effectiveness of interventions aimed at reducing cardiovascular risk in the T2DM population.

Limitations and future research

While the study's findings are robust, it is essential to acknowledge its cross-sectional design, which limits the ability to infer causality. Longitudinal studies are needed to ascertain the causal relationships between HRV, VO_{2max}, and cardiovascular outcomes in T2DM. Additionally, exploring the impact of specific types of physical activity and their intensity on HRV and VO_{2max} could provide more nuanced guidelines for managing T2DM.

CONCLUSION

This study demonstrated the significant correlation between HRV metrics and VO_{2max}, underscoring the complex interplay between autonomic function and CRF in T2DM. These findings not only advance our understanding of the physiological mechanisms at play but also highlight the potential of incorporating HRV and VO_{2max} assessments in the clinical management of T2DM to improve cardiovascular health outcomes.

AUTHOR CONTRIBUTIONS

The full manuscript has been read and approved by all authors. Each listed author fulfils the requirements for authorship, and each author attests that the manuscript represents honest work.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

No potential conflict of interest were reported by the authors.

RESEARCH QUALITY AND ETHICS STATEMENT

Ethical clearance for this study was granted by the Institutional Ethics Committee, Jamia Millia Islamia (Approval number: 24/5/323/JMI/IEC/2021, on July 7, 2021). The research was carried out as part of a larger project, which has been registered with the Clinical Trial Registry India (CTRI/2021/09/036711, registration date September 21, 2021). In conducting this study, the authors adhered to relevant guidelines from the EQUATOR Network, specifically following the STROBE guideline.

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REFERENCES

Akoglu, H. (2018). User's guide to correlation coefficients. Turk J Emerg Med, 18(3), 91-93. https://doi.org/10.1016/j.tjem.2018.08.001

Ashcroft, R. E. (2008). The declaration of Helsinki. The Oxford textbook of clinical research ethics, 141-148. https://doi.org/10.1093/oso/9780195168655.003.0014

Beltz, N. M., Gibson, A. L., Janot, J. M., Kravitz, L., Mermier, C. M., & Dalleck, L. C. (2016). Graded Exercise Testing Protocols for the Determination of VO(2)max: Historical Perspectives, Progress, and Future Considerations. J Sports Med (Hindawi Publ Corp), 2016, 3968393. https://doi.org/10.1155/2016/3968393

Benichou, T., Pereira, B., Mermillod, M., Tauveron, I., Pfabigan, D., Maqdasy, S., & Dutheil, F. (2018). Heart rate variability in type 2 diabetes mellitus: A systematic review and meta-analysis. PloS one, 13(4), e0195166. https://doi.org/10.1371/journal.pone.0195166

Bhati, P., & Hussain, M. E. (2021). Leisure-Time Physical Activity and Glycemic Control Independently Predicts Cardiac Autonomic Neuropathy in Type 2 Diabetes Mellitus. J Phys Act Health, 18(11), 1393-1403. https://doi.org/10.1123/jpah.2020-0194

Cabral, D. A. R., da Costa, K. G., Tavares, V. D. d. O., Rêgo, M. L. d. M., Faro, H. K. C., & Fontes, E. B. (2019). Cardiorespiratory fitness predicts greater vagal autonomic activity in drug users under stress. Substance Abuse: Research and Treatment, 13. https://doi.org/10.1177/1178221819862283

Cai, L., Gonzales, T., Wheeler, E., Kerrison, N. D., Day, F. R., Langenberg, C., Perry, J. R. B., Brage, S., & Wareham, N. J. (2023). Causal associations between cardiorespiratory fitness and type 2 diabetes. Nature Communications, 14(1), 3904. https://doi.org/10.1038/s41467-023-38234-w

Cohen, J. (2013). Statistical power analysis for the behavioral sciences. Academic press. https://doi.org/10.4324/9780203771587

Cuschieri, S. (2019). The STROBE guidelines. Saudi J Anaesth, 13(Suppl 1), S31-s34. https://doi.org/10.4103/sja.SJA_543_18

Daniela, M., Catalina, L., Ilie, O., Paula, M., Daniel-Andrei, I., & Ioana, B. (2022). Effects of Exercise Training on the Autonomic Nervous System with a Focus on Anti-Inflammatory and Antioxidants Effects. Antioxidants (Basel), 11(2). https://doi.org/10.3390/antiox11020350

Ferguson, B. (2014). ACSM's Guidelines for Exercise Testing and Prescription 9th Ed. 2014. In J Can Chiropr Assoc (Vol. 58, pp. 328). © jcca 2014.

Galicia-Garcia, U., Benito-Vicente, A., Jebari, S., Larrea-Sebal, A., Siddiqi, H., Uribe, K. B., Ostolaza, H., & Martín, C. (2020). Pathophysiology of Type 2 Diabetes Mellitus. Int J Mol Sci, 21(17). https://doi.org/10.3390/ijms21176275

Gim, M. N., & Choi, J. H. (2016). The effects of weekly exercise time on VO2max and resting metabolic rate in normal adults. J Phys Ther Sci, 28(4), 1359-1363. https://doi.org/10.1589/jpts.28.1359

Gonzales, T. I., Westgate, K., Strain, T., Hollidge, S., Jeon, J., Christensen, D. L., Jensen, J., Wareham, N. J., & Brage, S. (2021). Cardiorespiratory fitness assessment using risk-stratified exercise testing and dose-response relationships with disease outcomes. Sci Rep, 11(1), 15315. https://doi.org/10.1038/s41598-021-94768-3

Granero-Gallegos, A., González-Quílez, A., Plews, D., & Carrasco-Poyatos, M. (2020). HRV-Based Training for Improving VO(2max) in Endurance Athletes. A Systematic Review with Meta-Analysis. Int J Environ Res Public Health, 17(21). https://doi.org/10.3390/ijerph17217999

Grant, C. C., Murray, C., Janse van Rensburg, D. C., & Fletcher, L. (2013). A comparison between heart rate and heart rate variability as indicators of cardiac health and fitness. Front Physiol, 4, 337. https://doi.org/10.3389/fphys.2013.00337

Heart rate variability. Standards of measurement, physiological interpretation, and clinical use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. (1996). Eur Heart J, 17(3), 354-381.

Kadoglou, N. P., Iliadis, F., Angelopoulou, N., Sailer, N., Fotiadis, G., Voliotis, K., Vitta, I., Liapis, C. D., & Alevizos, M. (2009). Cardiorespiratory capacity is associated with favourable cardiovascular risk profile in patients with Type 2 diabetes. J Diabetes Complications, 23(3), 160-166. https://doi.org/10.1016/j.jdiacomp.2007.12.008

Larsen, F. J., Anderson, M., Ekblom, B., & Nyström, T. (2012). Cardiorespiratory fitness predicts insulin action and secretion in healthy individuals. Metabolism, 61(1), 12-16. https://doi.org/10.1016/j.metabol.2011.05.010

Leite, S. A., Monk, A. M., Upham, P. A., & Bergenstal, R. M. (2009). Low cardiorespiratory fitness in people at risk for type 2 diabetes: early marker for insulin resistance. Diabetol Metab Syndr, 1(1), 8. https://doi.org/10.1186/1758-5996-1-8

Loimaala, A., Huikuri, H. V., Kööbi, T., Rinne, M., Nenonen, A., & Vuori, I. (2003). Exercise training improves baroreflex sensitivity in type 2 diabetes. Diabetes, 52(7), 1837-1842. https://doi.org/10.2337/diabetes.52.7.1837

Muntner, P., Shimbo, D., Carey, R. M., Charleston, J. B., Gaillard, T., Misra, S., Myers, M. G., Ogedegbe, G., Schwartz, J. E., & Townsend, R. R. (2019). Measurement of blood pressure in humans: a scientific statement from the American Heart Association. Hypertension, 73(5), e35-e66. https://doi.org/10.1161/HYP.0000000000000087

Picard, M., Tauveron, I., Magdasy, S., Benichou, T., Bagheri, R., Ugbolue, U. C., Navel, V., & Dutheil, F. (2021). Effect of exercise training on heart rate variability in type 2 diabetes mellitus patients: A systematic review and meta-analysis. PloS one, 16(5), e0251863. https://doi.org/10.1371/journal.pone.0251863

Regensteiner, J. G., Sippel, J., McFARLING, E. T., Wolfel, E. E., & Hiatt, W. R. (1995). Effects of non-insulin-dependent diabetes on oxygen consumption during treadmill exercise. Medicine and science in sports and exercise, 27(6), 875-881. https://doi.org/10.1249/00005768-199506000-00012

Shaffer, F., & Ginsberg, J. P. (2017). An Overview of Heart Rate Variability Metrics and Norms. Front Public Health, 5, 258. https://doi.org/10.3389/fpubh.2017.00258

Tadic, M., Grassi, G., & Cuspidi, C. (2021). Cardiorespiratory fitness in patients with type 2 diabetes: A missing piece of the puzzle. Heart Fail Rev, 26(2), 301-308. https://doi.org/10.1007/s10741-020-10015-3

Tang, Z.-H., Liu, J., Zeng, F., Li, Z., Yu, X., & Zhou, L. (2013). Comparison of prediction model for cardiovascular autonomic dysfunction using artificial neural network and logistic regression analysis. PloS one, 8(8), e70571. https://doi.org/10.1371/journal.pone.0070571

Trabulo, M., Mendes, M., Mesquita, A., & Seabra-Gomes, R. (1994). [Does the modified Bruce protocol induce physiological stress equal to that of the Bruce protocol?]. Rev Port Cardiol, 13(10), 753-760; 735-756.

Tuttolomondo, A., Del Cuore, A., La Malfa, A., Casuccio, A., Daidone, M., Maida, C. D., Di Raimondo, D., Di Chiara, T., Puleo, M. G., Norrito, R., Guercio, G., & Pinto, A. (2021). Assessment of heart rate variability (HRV) in subjects with type 2 diabetes mellitus with and without diabetic foot: correlations with endothelial dysfunction indices and markers of adipo-inflammatory dysfunction. Cardiovasc Diabetol, 20(1), 142. https://doi.org/10.1186/s12933-021-01337-z

Weir, C. B., & Jan, A. (2019). BMI classification percentile and cut off points.

Zaccardi, F., O'Donovan, G., Webb, D. R., Yates, T., Kurl, S., Khunti, K., Davies, M. J., & Laukkanen, J. A. (2015). Cardiorespiratory fitness and risk of type 2 diabetes mellitus: A 23-year cohort study and a meta-analysis of prospective studies. Atherosclerosis, 243(1), 131-137. https://doi.org/10.1016/j.atherosclerosis.2015.09.016

Zaki, S., Sharma, S., & Vats, H. (2023). Effectiveness of concurrent exercise training in people with type 2 diabetes: A systematic review and meta-analysis. Physiother Theory Pract, 1-22. https://doi.org/10.1080/09593985.2023.2225717

Zheng, Y., Ley, S. H., & Hu, F. B. (2018). Global aetiology and epidemiology of type 2 diabetes mellitus and its complications. Nature Reviews Endocrinology, 14(2), 88-98. https://doi.org/10.1038/nrendo.2017.151

Ecological dynamics approach in physical education to promote cognitive skills development: A review

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ABSTRACT

The aim of this paper is to carry out a theoretical transposition of the principles of the ecological dynamic approach in the field of physical and sports education, aimed at defining educational approaches capable of promoting an effective acquisition of cognitive skills, through the practice of physical activity and sport. Physical education, according to an ecological dynamics perspective, considers the performer a complex adaptive system, which interacts with the environments in a functionally integrated way, underlining the interrelationship between motor processes, cognitive and perceptive functions. The cognitive area of Life Skills (Cognitive Life Skills, CLS), divided by the WHO, into decision making, problem solving, creative thinking and critical thinking processes, can be framed as an intrinsic part of goal-directed behaviour influenced by functional constraints determined by individual-environment interaction. Therefore, physical and sport activity practiced according to the principles of the ecological dynamic approach can be configured as an elective tool to promote the development of cognitive skills. In this article, the relevant theories of ecological dynamics are discussed and recent empirical data on the perceptual-cognitive processes which are activated through the practice of physical education and sport are described to underline the potential of such practices for the development of cognitive skills. The development of this specific theoretical transposition represents a starting point for the definition and experimentation of ecological dynamic interventions designed with the aim of investigating the effects of physical and sporting activity on the development of cognitive skills for life.

Keywords: Physical education, Non-linear pedagogy, Cognitive skills, Ecological approach, Inclusion.

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INTRODUCTION

The World Health Organization (WHO) to contrast health risk behaviours and to promote a life-style wellbeing oriented also within the educational field, has developed different documents, starting from the first "*Life Skills Education for Children and Adolescents in Schools*" (1993), up to the last "*Life skills education school handbook*" of 2020. In these documents, life skills, which transversally involve all domains of a person's life, from the cognitive to the personal to the interpersonal/social domains, are described as indispensable tools for the promotion of well-being, personality development and social inclusion, for the younger generation (WHO, 1993). In particular, the cognitive dimension refers to problem solving, decision making, critical thinking and creative thinking skills. The scientific literature has long described cognitive functions as rooted in the sensorimotor system and, therefore, strongly linked to the processes of perception/action that the subject experiences in interaction with others and the environment (Wilson, 2002; Barsalou, 2008; Glenberg et al., 2013; Caruana & Borghi, 2016). Thus, motor/sports activities, i.e. activities that quintessentially involve the individual in all dimensions of being, represent an elective learning context able to promote the personal, emotional, and cognitive development of the individual (Minghelli et al., 2023).

In the scientific literature there are several studies that have investigated the effectiveness of educational interventions in the motor and sports fields for the development of Life Skills (WHO, 1993); the results show that physical and sport activity are configured as elements capable of promoting the development of these skills (Coppola et al., 2014; Bean et al., 2018; Coppola & Vastola, 2019; Kendellen & Camire, 2019; Matsankos et al., 2020; Holt et al., 2020), due to some specific characteristics and consonant elements between motor skills and life skills, including which the essential presence of the experiential activity for the development of both and the peculiarity related to the transferability of the skills acquired through physical activity in other domains of life (Goudas et al., 2006; Goudas, 2010; Ballester et al., 2019). In continuity with the principles of non-linear pedagogy (Chow, 2013) and in continuing reflections on the concept of the transfer of learning, from the motor domain to life contexts, it is essential to emphasize the importance of the choice of the level of representativeness of the teaching or training proposal. In both the educational and sporting domains, this principle refers to the concept of the transfer of skills learned in terms of performance (problem solving, decision making, initiative, communicating, collaborating, etc.) and in everyday life contexts (life skills) (Minghelli et al., 2023). Thus, interaction with an effectively representative environment would seem to expand the possibilities for interaction and meaningful experiences, offering the subject the opportunity to directly experience problem solving, decision making, creative and critical thinking skills. Physical education in the ecological dynamics perspective, considers the performer as a complex adaptive system (Kugler et al., 1982; Newel, 1986; Thelen & Smith, 1994), interacting with environments in a functionally integrated way, emphasizing the inter-relation between motor processes, cognitive and perceptual functions (Davids et al., 2012; Rudd et al., 2020; Romano et al., 2022; 2023; Renshaw et al., 2022).

According to these considerations, the dynamic ecological approach is configured as a potential educational model to favour the development of transversal skills, in particular skills of a cognitive nature (Araújo et al., 2020).

In the context of the ecological dynamics approach, the activity is not made explicit through the repetition of a solution to a given task, but through the processing of stimuli and affordances present in the environment which guide self-regulated motor investment and performance (Chow et al., 2020), activating the cognitive and perceptive functions in order to experiment, through the principle of variability, the different motor solutions (Davids et al., 2003; Silva et al., 2013; Pesce et al., 2019; Chow et al., 2019; Coppola et al., 2021).

In the ecological perspective, a crucial role is played by affordances, which are essential tools of individualization and personalization that, unlike a traditional approach, are effective in order to favour all subjects a flexible active participation consistent with the prerequisites of each one and consequently in promoting the development of new competences, transferable to life contexts. In this perspective, didactic action implies the mobilization of resources and cognitive functions aimed at the emergence of spontaneous (heuristic) solutions to contingent motor problems (Hepler et al., 2012; Furley et al., 2013), stimulating and enhancing executive variability, through a complex and non-linear processes of searching for motor solutions which is expressed through the constant presence of variability (Preatoni et al., 2010; 2013; Seifert & Davids, 2012; Silva et al., 2016). "*This type of planning can include the prediction of which affordances learners may select and their potential movement solutions and elaborating on how these may be developed to potentiate further performance behaviours*" (Correia et al, 2019, p. 119).

There are several studies in the scientific literature that have investigated the potential in the use of the ecological dynamic approach in sports for the development of different cognitive abilities; most have focused attention on aspects related to the development of decision-making skills (Araújo et al., 2019; Renshaw et al., 2019).

The Ecological Dynamic Approach, in line with the theories of enactivism (Varela et al., 1991) contributes to the thesis that the cognitive structures of the mind emerge from the recurrent sensory-motor dynamics between the incarnate agent (embodied) and inserted in a natural environment (embedded), which allow the action to be guided perceptively (Adolph & Hock, 2019). According to the theses of enactivism, conscious experiences are constitutively connected to sensory-motor interactions between subject and external environment (Shapiro, 2010; Mahon, 2015; Varela et al., 2017; Shapiro & Stolz 2019; Meloni & Reynolds, 2021). In the field of motor and sports activities, in the constant interaction with the environment (physical and social) and in function of the morpho-functional characteristics of the body, motor behaviour assumes characteristics of adaptability and flexibility in the choice and execution of functional movements in significant environments. Behavioural flexibility will consist of "*the ability to select and modify actions to meet changes in body, environment and task*" (Bernstein, 1996, in Adolph & Hock, 2019, p. 143).

Consistent with what has been described so far, Physical Education in the school environment allows for immersive teaching that engages students in realistic or authentic tasks, motivating them to use their acquired knowledge and skills in an organized manner in problem-solving, decision-making, constructing and creating of ideas.

In this theoretical framework, sport, and more generally physical activities, offer the possibility of stimulating and promoting in an extremely effective manner the acquisition of personal, cognitive, and social skills, which can be generalized and transferred to other social and life contexts, favouring the pursuit of bio-psycho-social well-being. The ecological dynamics approach can fully fit into the educational model of Life Skills (WHO, 2020) as a potential approach to build, through the experience of physical activity, transversal cognitive skills for life.

The aim of this contribution is to carry out an overview of the scientific literature, in order to frame the topic of physical and sport activities within the perspective promoted by the ecological dynamics approach, to better understand what has been argued and experimented on this specific topic, both in sporting contexts and in the educational/scholastic field, in order to be able to orient future research perspectives and plan possible implementations of practices.

METHODS AND MATERIALS

To achieve this aim, relevant theoretical principles from ecological psychology are discussed, focusing on ecological dynamics, as a potential elective area for the development of Cognitive Life Skills. To support the argumentation, recent empirical data on perceptual-cognitive process training inherent in the practice of physical education and sport are described. These studies delineate and emphasize the potential of this educational paradigm to build, through the experience of physical activity, transversal cognitive skills.

Selection of the literature

During January 2024, a comprehensive search of databases of literature (PubMed, EBSCO, Web of Science, Scopus and SpringerLink) from 2013 through February 2024 was undertaken.

The principal terms were as follows: (1) "*Ecological Dynamics Approach*"; (2) "*Physical activities*" (3) "*Sport*" (4) "*Cognitive skills*".

Inclusion criteria

A predetermined set of inclusion criteria was used to select papers. Each study had to meet the following criteria: (1) been published between 2013 and February 2024; (2) the focus had to be the Ecological Dynamics Approach, Physical Activities, Sport, and Cognitive Skills.

Data extraction and reliability

A standard data extraction template was developed to extract the main details for every eligible study in terms of author, title, year of publication, objective, methodology and skills investigated.

RESULTS

Research findings in the scientific literature have led to several studies that have investigated the potential in the use of the dynamic ecological approach in the motor and sports fields for the cognitive skills. Most of the studies conducted have focused attention on aspects related to the development of cognitive skills of decision-making, attention, memory, thinking, brain plasticity, spatial ability, through the dynamic ecological approach in sports.

Table 1. Part of the literature review within Sport, Physical Education and Ecological Dynamics approach to promote cognitive skills development.

Year	Title	Authors	Objective	Study design	Skills investigated
2023	Team decision-making behaviour: An ecological dynamics approach.	Araújo, D., Brito, H., & Carrilho, D. (2023).	Summarizing the key principles of ecological dynamics, the contribution describes decision-making and, more generally, behaviour as arising from processes of self-organization from which functional synergies develop. The article suggests that the dynamic ecological approach represents a theoretical framework that is particularly well adapted to explore the topic of individual and group cognition, with possible important applications to practice.	Argumentative paper	Cognitive skill (Decision-making)

2023	An applied model for using variability in practice.	Czyż, S. H., & Coker, C. A. (2023).	The contribution frames the problem of the variability of practice within the processes of motor learning from an applied perspective. In particular, within the implications of the application of variability in practice, are described the positive effects on decision making processes, within a dynamic ecological perspective.	Argumentative paper	Cognitive skill (Decision-making)
2020	Cognition, emotion and action in sport: an ecological dynamics perspective	Araújo, D., Davids, K., & Renshaw, I. (2020).	This study summarizes advances in ecological dynamics and discusses their implications for cognition, perception, and action in sport performance.	Argumentative paper	Cognitive and emotional skills
2019	Evaluating weaknesses of "*perceptual-cognitive training*" and "*brain training*" methods in sport: An ecological dynamics critique.	Renshaw, I., Davids, K., Araújo, D., Lucas, A., Roberts, W. M., Newcombe, D. J., & Franks, B. (2019).	This study proposes how an ecological dynamics approach, aligned with an embodied framework of cognition, can be considered together as part of a process training approach proposing enhanced cognitive and perceptual skills and brain capacity to support performance in everyday life activities.	Argumentative paper	Cognitive processes (attention, memory, thinking)
2017	Ecological cognition: expert decision-making behaviour in sport.	Araújo, D., Hristovski, R., Seifert, L., Carvalho, J., & Davids, K. (2017).	Through a critical review of the literature, this study supported the thesis according to which expert decision-making can be directly assessed, if sport action is understood as an expression of embedded and embodied cognition.	Argumentative paper	Cognitive skill (decision-making)
2016	Variability of practice as an interface between motor and cognitive development	Pesce, C., Croce, R., Ben-Soussan, T. D., Vazou, S., McCullick, B., Tomporowski, P. D., & Horvat, M. (2016).	This study adopts a joint sport science and neuroscience approach to identify the characteristics of the construct of variability, as it is conceived in the ecological approaches to motor skill learning, that can impact brain plasticity and cognitive development.	Argumentative paper	Cognitive development (Brain plasticity)
2013	An Ecological Dynamics Approach to Skill Acquisition: Implications for Development of Talent in Sport	Davids, K., Araújo, D., Vilar, L., Renshaw, I., & Pinder, R. (2013).	This paper proposes how ecological dynamics provides a basis for understanding skill acquisition in sport. Learners are conceptualized as complex, neurobiological systems in which inherent self-organization tendencies support the emergence of adaptive behaviours under a range of interacting tasks and environmental constraints.	Argumentative paper	Cognitive skill (decision-making, creativity)

The research highlights a prevalent absence in the literature of experimental studies dealing with the subject of declination of the dynamic ecological approach for the development of Life Skills in the cognitive area in the teaching of physical activity.

DISCUSSIONS

On the one hand, from the scientific literature emerges a conspicuous presence of studies, both of a descriptive and experimental nature, which have identified the effectiveness of physical activity and sports interventions aimed at the development of transversal skills and, in particular, at the development of Life Skills (WHO) (Papacharisis et al., 2005; Pierce et. al., 2017; Holt et al., 2017; Hermens et al., 2017; Super et al., 2018).; on the other hand, studies that have investigated the effectiveness in the use of the ecological dynamics approach in the teaching of physical activities and sports for the development of Life Skills are almost completely absent.

However, probably also considering the relatively recent establishment of the ecological-dynamic perspective, studies that have investigated the effectiveness in the use of the latter in the teaching of physical activities and sports for the development of Life Skills are still lacking or almost completely absent.

In general, the literature review highlights a substantial lack of experimental studies useful for building evidence-based design models. In this sense, it is crucial to highlight how the ecological dynamics approach, considering its founding principles, refers to the need to move away from prescriptive elements in the implementation of practices.

However, in relation to the numerous advantages highlighted in the literature, deriving from the theoretical and application principles of the dynamic ecological perspective, it is desirable to promote an increase in practices consciously oriented towards these principles. In addition, it is possible to hypothesize that this ‘application gap’ can be traced back to educational motivations, in respect of which it is appropriate to rethink training for pre-service and in-service teachers, in order to provide them with suggestions useful for a redesign of practices (Davids & Rudd, 2021); secondly, it is also conceivable that principles can be applied unconsciously, especially within educational practices, on which it is intended to shed light to understand if and how educational interventions declined in the motor field already take into account some common elements between ecological design and the inclusive, promoted in a bio-psycho-social.

CONCLUSIONS

The results present in the literature, even if partially consistent with the four cognitive skills of the model developed by the WHO, are theoretically very grounded and experimentally very promising.

Although there are no studies in the literature that have investigated the potential in the implementation of the dynamic ecological approach for the development of the four skills of CLS, there are, instead, numerous studies that demonstrate that physical activity and sport represent a particularly effective disciplinary field for development of Life Skills. On the basis of this scientific evidence, this work attempts to shape the implementation of the dynamic ecological approach for the development of the cognitive skills of the Life Skills model in the educational practices in school contests. Further studies are necessary to understand the real effectiveness of the transposition of this model in the teaching of physical activity for the development of cognitive skills for life.

It is also conceivable that there already exists within educational practices, an unaware application of ecological-dynamic principles. On this particular aspect it would be appropriate to shed light to record the state of the art and to identify elements of effectiveness and repeatability, which can encourage the progressive structuring of an approach that, by its founding principles, is constituted "*in fieri*" along with the experiences.

Moreover, among the future prospects of research, there is the desire to understand if and how educational interventions declined in the motor field, especially in an inclusive perspective of customization, already take into account the effective epistemological overlap of theoretical constructs underlying the design of practices in both ecological and inclusive (Minghelli & Coppola, 2023), which in the perspective of bio-biopsycho-social, in turn attributes to the context an equally decisive role in outlining the possibilities of participation in significant movement experiences and in encouraging for all the acquisition of skills for life.

AUTHOR CONTRIBUTIONS

SC and VM designed the study, wrote the initial draft, and made revisions, formulated methods, conducted the search of the scientific literature and processed the results, managed data, created visualizations, supervised, and managed the project. CD participated in data curation, formal analysis, visualization, and manuscript revision. RV 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. and consent to its publication in JHSE.

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REFERENCES

Adolph, K. E., & Hoch, J. E. (2019). Motor development: Embodied, embedded, enculturated, and enabling. Annual review of psychology, 70, 141-164. https://doi.org/10.1146/annurev-psych-010418-102836

Araújo, D., Brito, H., & Carrilho, D. (2023). Team decision-making behavior: An ecological dynamics approach. Asian Journal of Sport and Exercise Psychology, 3(1), 24-29. https://doi.org/10.1016/j.ajsep.2022.09.005

Araújo, D., Hristovski, R., Seifert, L., Carvalho, J., & Davids, K. (2019). Ecological cognition: expert decision-making behaviour in sport. International Review of Sport and Exercise Psychology, 12(1), 1-25. https://doi.org/10.1080/1750984X.2017.1349826

Araújo, D., Davids, K., & Renshaw, I. (2020). Cognition, emotion and action in sport: an ecological dynamics perspective. Handbook of sport psychology, 535-555. https://doi.org/10.1002/9781119568124.ch25

Bernstein NA. 1996. On dexterity and its development. In Dexterity and Its Development, ed. ML Latash, MT Turvey, pp. 3-244. Mahwah, NJ: Lawrence Erlbaum Assoc.

Barsalou, L. W. (2008). Grounded cognition. Annual Review of Psychology, 59, 617-645. https://doi.org/10.1146/annurev.psych.59.103006.093639

Ballester, R., Huertas, F., Pablos-Abella, C., Llorens, F., & Pesce, C. (2019). Chronic participation in externally paced, but not self-paced sports is associated with the modulation of domain-general cognition. European journal of sport science, 19(8), 1110-1119. https://doi.org/10.1080/17461391.2019.1580318

Bean, C., Kramers, S., Forneris, T., & Camiré, M. (2018). The implicit/explicit continuum of life skills development and transfer. Quest, 70(4), 456-470. https://doi.org/10.1080/00336297.2018.1451348

Caruana, F., & Borghi, A. M. (2013). Embodied Cognition: una nuova psicologia. Giornale italiano di psicologia, 40(1), 23-48.

Chow, J. (2013). Nonlinear Learning Underpinning Pedagogy: Evidence, Challenges, and Implications. In Quest, 65, pp. 469- 484. https://doi.org/10.1080/00336297.2013.807746

Chow, J. Y., Shuttleworth, R., Davids, K., & Araújo, D. (2019). Ecological dynamics and transfer from practice to performance in sport. Skill acquisition in sport, 330-344. https://doi.org/10.4324/9781351189750-18

Chow, J.Y., Davids, K., Renshaw, I., Rudd, J. (2020). Nonlinear Pedagogy. In: Peters, M., Heraud, R. (eds) Encyclopedia of Educational Innovation. Springer, Singapore. https://doi.org/10.1007/978-981-13-2262-4_92-1

Coppola, S., Vastola, R., Scatigna, M., & Fabiani, L. (2014). Training and health in gymnastics. Journal of Human Sport and Exercise, 10(1proc), 391-398. https://doi.org/10.14198/jhse.2015.10.Proc1.30

Coppola, S., & Vastola, R. (2019). Health Pedagogy and Sport: Attitudes and Practices of Gymnastics Coaches. Journal of Sports Science, 7, 115-122. https://doi.org/10.17265/2332-7839/2019.04.003

Coppola, S., Romano, B., Albano, D., & Vastola, R. (2021). Training in young athletes: Ecological dynamics approach. Journal of Human Sport & Exercise, 16(49, 1563-1577. https://doi.org/10.14198/jhse.2021.16.Proc4.02

Correia, V., Carvalho, J., Araújo, D., Pereira, E., & Davids, K. (2019). Principles of nonlinear pedagogy in sport practice. Physical education and sport pedagogy, 24(2), 117-132. https://doi.org/10.1080/17408989.2018.1552673

Czyż, S. H., & Coker, C. A. (2023). An applied model for using variability in practice. International Journal of Sports Science & Coaching, 17479541231159473. https://doi.org/10.1177/17479541231159473

Davids, K., & Rudd, J. (2021). Time for a Rethink: Why a New Approach to Physical Literacy Is Needed. In Nonlinear Pedagogy and the Athletic Skills Model (pp. 5-19). Routledge. https://doi.org/10.4324/9781003025375-1

Davids, K., Glazier, P., Araújo, D., & Bartlett, R. (2003). Movement systems as dynamical systems: the functional role of variability and its implications for sports medicine. Sports medicine, 33, 245-260. https://doi.org/10.2165/00007256-200333040-00001

Davids, K., Araújo, D., Hristovski, R., Passos, P., & Chow, J. Y. (2012). Ecological dynamics and motor learning design in sport. Skill acquisition in sport: Research, theory and practice, 112-130.

Davids, K., Araújo, D., Vilar, L., Renshaw, I., & Pinder, R. (2013). An ecological dynamics approach to skill acquisition: Implications for development of talent in sport. Talent Development and Excellence, 5(1), 21-34.

Forte, P., Pugliese, E., Ambretti, A., & D'Anna, C. (2023). Physical Education and Embodied Learning: A Review. Sport Mont, 21(3). https://doi.org/10.26773/smj.231020

Furley, P., Memmert, D., & Schmid, S. (2013). Perceptual load in sport and the heuristic value of the perceptual load paradigm in examining expertise-related perceptual-cognitive adaptations. Cognitive processing, 14, 31-42. https://doi.org/10.1007/s10339-012-0529-x

Glenberg, A. M., Witt, J. K., & Metcalfe, J. (2013). From the revolution to embodiment: 25 years of cognitive psychology. Perspectives on psychological science, 8(5), 573-585. https://doi.org/10.1177/1745691613498098

Goudas, M. (2010). Prologue: A review of life skills teaching in sport and physical education. Hellenic Journal of Psychology, 7(3), 241-258.

Goudas M., Dermitzaki E., Leondari A. & Danish S. (2006). The effectiveness of teaching a life skills program in a physical education context. European Journal of Psychology of Education, 21, 429-438. https://doi.org/10.1007/BF03173512

Hepler, T. J., & Feltz, D. L. (2012). Take the first heuristic, self-efficacy, and decision-making in sport. Journal of Experimental Psychology: Applied, 18(2), 154. https://doi.org/10.1037/a0027807

Hermens, N., Super, S., Verkooijen, K. T., & Koelen, M. A. (2017). A systematic review of life skill development through sports programs serving socially vulnerable youth. Research quarterly for exercise and sport, 88(4), 408-424. https://doi.org/10.1080/02701367.2017.1355527

Holt, N. L., Neely, K. C., Slater, L. G., Camiré, M., Côté, J., Fraser-Thomas, J., ... & Tamminen, K. A. (2017). A grounded theory of positive youth development through sport based on results from a qualitative meta-study. International review of sport and exercise psychology, 10(1), 1-49. https://doi.org/10.1080/1750984X.2016.1180704

Holt, N. L., Deal, C. J., & Pankow, K. (2020). Positive youth development through sport. Handbook of sport psychology, 429-446. https://doi.org/10.1002/9781119568124.ch20

Kendellen, K., & Camire, M. (2019). Applying in life the skills learned in sport: A grounded theory. Psychology of Sport and Exercise, 40, 23-32. https://doi.org/10.1016/j.psychsport.2018.09.002

Kugler, A.N., Kelso, J.A. & Turvey, M.T. (1982). On the control and coordination of naturally developing systems. In J. A. S. Kelso & J. E. Clark (Eds.). The development of movement control and coordination, 5-78. New York: Wiley.

Mahon, B. Z. (2015). What is embodied about cognition?. Language, cognition and neuroscience, 30(4), 420-429. https://doi.org/10.1080/23273798.2014.987791

Matsankos, N., Gargalianos, D., Coppola, S., Vastola, R., & Petromilli, A. (2020). Investigation of skills acquired by athletes during their sporting career. Journal of Human Sport and Exercise, 15(3): 489-501. https://doi.org/10.14198/jhse.2020.153.02

Meloni, M., & Reynolds, J. (2021). Thinking embodiment with genetics: epigenetics and postgenomic biology in embodied cognition and enactivism. Synthese, 198(11), 10685-10708. https://doi.org/10.1007/s11229-020-02748-3

Minghelli V., Coppola S., (2023) from observation to educational design: the video modeling in the training of physical education teachers, Giornale Italiano di Educazione alla Salute, Sport e Didattica Inclusiva - Italian Journal of Health Education, Sports and Inclusive Didactics. Anno 7, V 1. Edizioni Universitarie Roman

Minghelli, V., D'anna, C., & Vastola, R. (2023). A biopsychosocial approach to plan inclusive learning environments in physical education. Journal of Physical Education and Sport, 23(9), 2492-2502.

Newell, KM. (1986). Constraints on the development of coordination. In: MG Wade and HTA Whiting (eds) Motor development in children: aspects of coordination and control. Dordrecht: Martinus Nijhoff, pp.341-360. https://doi.org/10.1007/978-94-009-4460-2_19

Pesce, C., Croce, R., Ben-Soussan, T. D., Vazou, S., McCullick, B., Tomporowski, P. D., & Horvat, M. (2019). Variability of practice as an interface between motor and cognitive development. International Journal of Sport and Exercise Psychology, 17(2), 133-152. https://doi.org/10.1080/1612197X.2016.1223421

Papacharisis, V., Goudas, M., Danish, S. J., & Theodorakis, Y. (2005). The effectiveness of teaching a life skills program in a sport context. Journal of applied sport psychology, 17(3), 247-254. https://doi.org/10.1080/10413200591010139

Pierce, S., Gould, D., & Camiré, M. (2017). Definition and model of life skills transfer. International review of sport and exercise psychology, 10(1), 186-211. https://doi.org/10.1080/1750984X.2016.1199727

Preatoni, E., Ferrario, M., Donà, G., Hamill, J., & Rodano, R. (2010). Motor variability in sports: a non-linear analysis of race walking. Journal of sports sciences, 28(12), 1327-1336. https://doi.org/10.1080/02640414.2010.507250

Preatoni, E., Hamill, J., Harrison, A. J., Hayes, K., Van Emmerik, R. E., Wilson, C., & Rodano, R. (2013). Movement variability and skills monitoring in sports. Sports biomechanics, 12(2), 69-92. https://doi.org/10.1080/14763141.2012.738700

Renshaw, I., Davids, K., Araújo, D., Lucas, A., Roberts, W. M., Newcombe, D. J., & Franks, B. (2019). Evaluating weaknesses of "perceptual-cognitive training" and "brain training" methods in sport: An ecological dynamics critique. Frontiers in psychology, 9, 2468. https://doi.org/10.3389/fpsyg.2018.02468

Renshaw, I., Davids, K., O'Sullivan, M., Maloney, M. A., Crowther, R., & McCosker, C. (2022). An ecological dynamics approach to motor learning in practice: Reframing the learning and performing relationship in high performance sport. Asian Journal of Sport and Exercise Psychology, 2(1), 18-26. https://doi.org/10.1016/j.ajsep.2022.04.003

Romano, B., Albano, D., & Coppola, S. (2022). The manipulation of constraints to train the complexity of soccer: the small sided conditioned games. Giornale Italiano di Educazione alla Salute, Sport e Didattica Inclusiva, 6(1).

Romano, B., Coppola, S., & Vastola, R. (2023). The Declination Of The Dynamic Ecological Approach In The Teaching And Evaluation Of Motor And Sports Education Interventions In The Developmental Age. Giornale Italiano di Educazione alla Salute, Sport e Didattica Inclusiva, 7(2).

Rudd J.R., Pesce C., Strafford B.W. & Davids K. (2020). Physical Literacy - A Journey of Individual Enrichment: An Ecological Dynamics Rationale for Enhancing Performance and Physical Activity in All. Front. Psychol. 11:1904. https://doi.org/10.3389/fpsyg.2020.01904

Seifert, L., & Davids, K. (2012). Intentions, perceptions and actions constrain functional intra-and inter-individual variability in the acquisition of expertise in individual sports. The Open Sports Sciences Journal, 5(1). https://doi.org/10.2174/1875399X01205010068

Shapiro, L. (2010). Embodied cognition. New York: Routledge. https://doi.org/10.4324/9780203850664

Shapiro, L., & Stolz, S. A. (2019). Embodied cognition and its significance for education. Theory and Research in Education, 17(1), 19-39. https://doi.org/10.1177/1477878518822149

Silva, P., Garganta, J., Araújo, D., Davids, K., & Aguiar, P. (2013). Shared knowledge or shared affordances? Insights from an ecological dynamics approach to team coordination in sports. Sports medicine, 43, 765-772. https://doi.org/10.1007/s40279-013-0070-9

Silva, P., Duarte, R., Esteves, P., Travassos, B., & Vilar, L. (2016). Application of entropy measures to analysis of performance in team sports. International Journal of Performance Analysis in Sport, 16(2), 753-768. https://doi.org/10.1080/24748668.2016.11868921

Super, S., Verkooijen, K., & Koelen, M. (2018). The role of community sports coaches in creating optimal social conditions for life skill development and transferability-a salutogenic perspective. Sport, education and society, 23(2), 173-185. https://doi.org/10.1080/13573322.2016.1145109

Thelen, E. & Smith, LB. (1994) A dynamic systems approach to the development of cognition and action. Cambridge, MA, USA: MIT Press.

Varela, F.J., Thompson, E., Rosch, E. (1991) The Embodied Mind: Cognitive Science and Human Experience. Cambridge MIT Press. https://doi.org/10.7551/mitpress/6730.001.0001

Varela, F. J., Thompson, E., & Rosch, E. (2017). The embodied mind, revised edition: Cognitive science and human experience. MIT press. https://doi.org/10.7551/mitpress/9780262529365.001.0001

Wilson, M. (2002). Six views of embodied cognition. Psychonomic Bulletin & Review, 9, 625-636. https://doi.org/10.3758/BF03196322

World Health Organization, Division of Mental Health, and Prevention of Substance Abuse. 1993. Life Skills Education for Children and Adolescents in Schools. Geneva: WHO Division of Mental Health.
World Health Organization. 2020. Life Skills Education School Handbook: Prevention of Noncommunicable Diseases. Geneva: World Health Organization.

ORIGINAL ARTICLE

Comparing the maximal horizontal deceleration demands between a novel acceleration to deceleration assessment and the 505 change of direction test

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ABSTRACT

The importance of quantifying maximal horizontal deceleration performance in athlete populations has received a considerable increase in interest over recent years. However, research is still scarce investigating movement characteristics of maximal horizontal decelerations outside of measures derived from instantaneous horizontal velocity of the centre of mass, using technologies such as radar or laser-based devices. Therefore, this study aimed to explore the biomechanical differences for measures of deceleration ability between a novel deceleration task, and the 505 change of direction test, using an inertial measurement unit-based technology. Primary findings suggested differences across several biomechanical characteristics quantified during the deceleration phase, with moderate to large between-test effect sizes. Specifically, subjects were found to exhibit significantly greater reductions in velocity and horizontal braking forces in the 505. Further, subjects showed significantly shorter stopping times and distances in the acceleration-deceleration assessment, however, these displayed insufficient levels of reliability across both assessments, which should be interpreted as a limitation. Therefore, it may be speculated that based on our data, the 505 test, which possesses a predetermined stopping/turning point, presents a greater or different biomechanical challenge to individuals, which must be met with the appropriate neuromuscular and skill-related qualities to efficiently reduce whole-body momentum. These findings may be relevant to practitioners interested in choosing the right assessment to quantify athletes' maximal horizontal deceleration performance, which can have implications for both health and performance.

Keywords: Biomechanics, Deceleration, Change of direction, Assessment.

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INTRODUCTION

Across different multidirectional sports, athletes must show proficiency in motor tasks such as sagittal plane sprinting and high-intensity running, lateral shuffling and cutting, as well as jumping (Taylor et al. 2017). Especially when performing high-intensity cuts and changes in direction, athletes are exposed to large decelerative demands, which require sufficient braking strategies. Recently, sports science literature investigating athletes' horizontal deceleration ability has gained increasing attention (Harper et al. 2020; Harper et al.2022; Harper et al. 2018; Harper et al. 2022; Philipp et al. 2023; Philipp et al. 2023). Researchers have proposed that the development of reliable deceleration metrics, and the design of corresponding training interventions, are capable of enhancing braking performance capabilities, facilitating game-specific speed abilities, and reducing predisposition to fatigue and injury, which could ultimately reflect positively on athletes' health and performance (Harper et al. 2021). What may have in part contributed to the recent interest in studying athletes' deceleration performance was a previous lack of methods, tests, and technologies to effectively quantify horizontal deceleration. Using radar technology, Harper et al. have recently proposed the use of the acceleration to deceleration assessment (ADA) to quantify athletes' maximal horizontal deceleration ability (Harper et al. 2020). This test requires athletes to sprint over a predetermined distance, followed by a rapid deceleration coming to a stop (Harper et al. 2020). The distance and therefore velocity over which athletes accelerate prior to initiating the deceleration plays a key role in the outcome of the test, and the metrics that are being calculated (Philipp et al. 2023). Philipp et al. have shown that when performing the ADA test over 20 yards (18.3 meters), compared to 10 yards (9.2 meters), athletes exhibited significantly greater magnitudes of maximal approach velocity and momentum, as well as average deceleration, braking impulse, and stopping time, therefore presenting athletes with significantly greater braking demands (Philipp et al. 2023). In a further investigation, researchers found moderate effect sizes for comparisons in deceleration metrics between the ADA test over 10 meters, and the 505 change of direction test, suggesting that different deceleration assessments may pose different biomechanical challenges to athletes, which should be acknowledged by practitioners implementing assessments (Philipp et al. 2023). Further, Graham-Smith et al. developed a method evaluating athletes' horizontal deceleration ability in relation to their self-determined limit to accelerate within a prescribed distance, which may be used by practitioners to aid in their understanding and application of appropriate stopping distances based on the distances of acceleration drills and the typical speed a player is likely to attain (Graham-Smith et al. 2018).

Considering the previously highlighted studies, it seems that when selecting deceleration assessments, practitioners may choose between tests during which athletes initiate the deceleration phase at a pre-set distance (i.e., ADA), or tests during which they stop or change direction at a pre-set distance or point (e.g., 505). However, research is scarce in describing biomechanical differences between said assessments, which ultimately limits partitioners in their understanding and selection process. Further, research is limited to investigating movement characteristics of maximal horizontal decelerations outside of measures derived from instantaneous horizontal velocity of the centre of mass (COM), using technologies such as radar or laser-based devices.

Therefore, the primary aim of this study was to investigate the biomechanical differences for measures of deceleration ability between the ADA test over 10 meters, and the 505 change of direction test, using an inertial measurement unit (IMU)-based technology. A secondary aim was to describe the intra-session reliability of respective horizontal deceleration metrics for both tests, using IMU technology.

Researchers hypothesized that tests would display differing biomechanical characteristics, which may aid practitioners in their understanding of each test, and ultimately enhance decision making with regards to which assessment to implemented when measuring horizontal deceleration performance.

MATERIAL AND METHODS

Participants

Nineteen recreationally trained, college-aged individuals (n = 14 male, age = 21.1 ± 1.8 years, height = 1.80 ± 0.05 m; body mass = 80.1 ± 9.8 kg; n = 5 female; age = 20.1 ± 2.8 years, height = 1.70 ± 0.02 m; body mass = 63.8 ± 2.3 kg) with at least four years of recent, organized playing experience in a multidirectional sport (e.g., basketball, soccer) volunteered to participate in the present study. All subjects provided their written consent as approved by the University's Institutional Review Board.

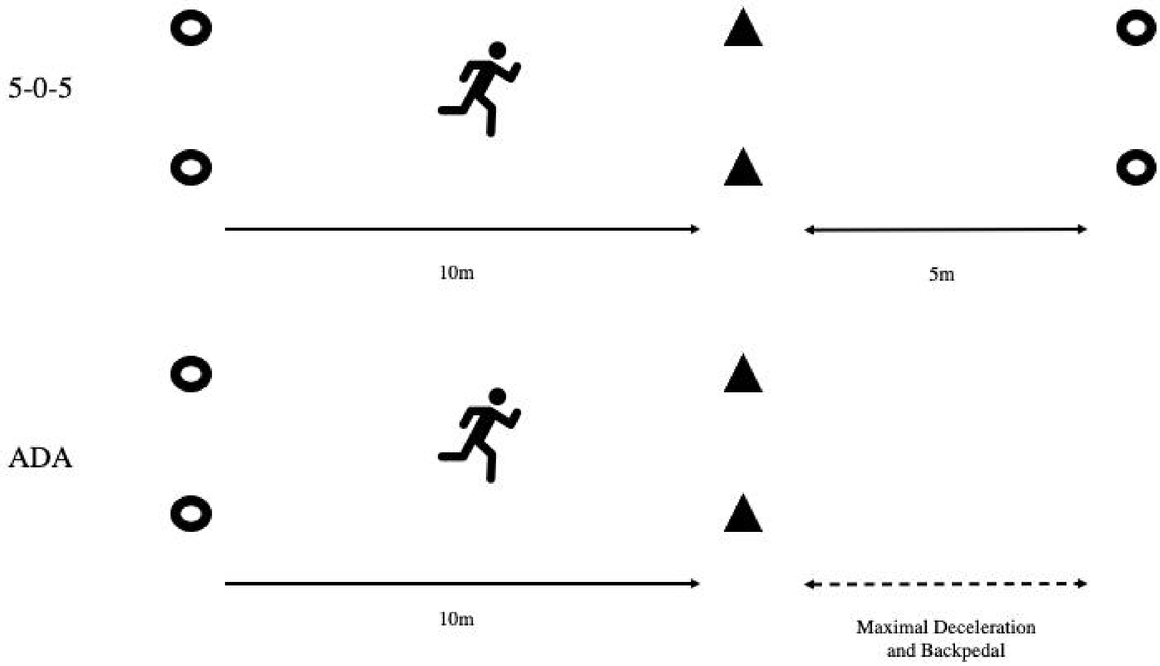
Protocol

Upon arriving to the testing facility, the participants' anthropometric data was collected (i.e., height and weight), including measurements specific to the inertial measurement unit (IMU) (Xsens MVN Awinda, Enschede, Netherlands) calibration and sensor placement process performed in line with manufacturer guidelines (Nijmeijer et al. 2023; Schepers et al. 2018). From there, the IMU-based system was calibrated according to manufacturer guidelines (Nijmeijer et al. 2023). Before the start of data collection, all subjects performed a dynamic warm-up that was led by a Certified Strength and Conditioning Specialist. Each subject performed three trials in the ADA test and four repetitions (two to each side) in the 505 change of direction test. During the warm-up, all athletes were given three to four practice attempts in each test to familiarize them with the procedures.

Procedures for the ADA were adapted from previous research (Harper et al. 2020; Philipp et al. 2023). Subjects were instructed to sprint maximally over a distance of 10 meters, following a start in a staggered stance. Upon crossing the 10-meter marker, subjects performed a maximal deceleration coming to a stop, which was followed by a backpedal to the 10-meter marker. A set of timing gates (Brower Timing Systems, Draper, UT, USA) was placed at the 10-meter marker, which made a distinct sound upon crossing, which subjects were instructed to use as a signal to initiate the deceleration phase. Subjects performed three trials with three minutes of passive rest in between each trial. If athletes were visually observed to slow down prior to the 10-meter mark, or significantly after it, the trial was repeated following three minutes of passive rest.

Similar to the ADA, procedures for the 505 tests were adapted from previous research (Draper and Lancaster, 1985), in which subjects maximally sprinted over 10 meters, with a 180-degree turn complete at the 15-meter marker, which was marked on the floor with cones and tape. Subjects crossed a single set of timing gates at the 10-meter marker, decelerated, turned at the 15-meter marker, and rapidly reaccelerated back through the set of timing gates placed at the 10-meter marker. Participants performed two trials of turning with their right leg, and two trials of turning with their left leg.

For this study, an IMU-based motion capture system (Xsens, MVN Awinda, Netherlands) was used to capture the biomechanical differences between the ADA and 505 tests. Recent research has documented that this technology displayed excellent levels of agreement with a Vicon optoelectronic motion capture system in capturing kinematics in the sagittal plane of movement (Schepers et al. 2018). Other research utilizing the Xsens IMU-based system has shown acceptable validity in assessing temporal-spatial parameters during the ADA test (Jordan et al. 2021). The individual IMUs' consisted of a three-dimensional linear accelerometer, magnetometer, gyroscope, as well as a barometer, and sampled at a rate of 100 Hz. Following manufacturer guidelines, researchers placed IMUs at strategic locations around the subject's body (secured by straps). Within the Xsens MVN software (MVN Record 2023) researchers chose the suit configuration "*lower body with sternum*", which required units to be placed around the anterior superior part of the foot, the tibia close to the knee, the middle of the lateral thigh, the posterior pelvis at a height of the anterior superior iliac spine, as well as the sternum. Raw IMU-derived data were uploaded to the Athlete Analytics software platform (Athlete Analytics, Atlanta, GA, USA) where metrics of interest were calculated based on proprietary algorithms. In this analysis, the start of the deceleration phase was identified as the point in time where the greatest change in acceleration of the centre of mass in the opposite direction (i.e., negative acceleration) occurred. Ground contact accelerations were derived from the accelerometers attached to the lower limbs of the participants, while their foot was in contact with the ground (x, y, and z directions combined), and were converted from meters per second to gravitational acceleration (g's), by dividing values by 9.81. In line with previous research (Harper et al. 2020; Morin et al. 2019), average horizontal braking force was calculated using fundamental laws of dynamics in the horizontal direction.



**Notes: Circles represent cones, and triangles represent timing gates.*

Figure 1. Visual representation of the two assessments compared in this study.

Analysis
Researchers downloaded metrics of interest for the two assessments from the Athlete Analytics software platform (Athlete Analytics, Atlanta, GA, USA), and entered data into a spread sheet (Excel), prior to importing the excel file to RStudio (Version 1.4.1106), where further data treatment and statistical analyses were performed. All data was checked for normality using a Shapiro-Wilks test. For all metrics of interest, intraclass correlation coefficients (ICC), standard errors of measurement (SEM), and minimal differences needed to be considered real (MD) were calculated. ICCs were calculated using the $ICC_{2,\,k}$(consistency) model, and were interpreted where <0.50 was deemed poor reliability, 0.50-0.74 was deemed moderate reliability, 0.75-0.90 was deemed good reliability, and >0.90 was deemed excellent reliability (Koo and Li, 2016). The SEM was calculated as the square-root of the mean square error (MS_E), which was gathered from a repeated measures ANOVA performed between the three trials performed for each metric (Cleary et al. 2022; Weir, 2005). The

SEM is also presented as a percentage of the grand mean by dividing the SEM by the mean and multiplying it by 100. The MD was calculated based on the SEM as suggested in earlier research (Weir, 2005). Finally, paired sample t-tests between metrics of interest for the ADA and 505 were performed. Means and standard deviations for each test and metric, in addition to mean differences with 95% confidence intervals (CI), and Hedge's g effects sizes (ES) with 95% confidence intervals were reported in the results. Effect sizes were classified as either negligible (<0.20), small (0.21-0.50), moderate (0.51-0.80), and large (>0.80) (Cohen, 2013). To highlight the differences between tests for selected metrics, between-group mean values and mean differences for each respective team were visualized using Gardner-Altman plots (Ho et al. 2019). Gardner-Altman plots were generated in RStudio using the 'dabestr' package. Statistical inferences were made using an α level of $p \leq .05$.

RESULTS

Reliability statistics are presented in Table 2. and suggest poor to excellent levels of consistency, as well as SEM's ranging from 2.3 to 21% of the mean. Between-test comparisons revealed statistically significant differences for six of the twelve measures of deceleration ability investigated in this study. More specifically, subjects exhibited significantly greater magnitudes of average deceleration (ES = -2.46) and average horizontal braking force (ES = -1.61) in the 505, compared to the ADA. Further, subjects showed significantly longer stopping times (ES = -0.90) and further braking distances (ES = -2.06) in the 505, compared to the ADA. Lastly, in the 505, subjects exhibited significantly shorter brake step ground contact times (ES = 0.65), as well as shorter brake steps, relative to the centre of mass (ES = 0.91). Between-test comparison statistics may be found in Table 3. Figure 1 shows a visual representation of between-test comparisons for metrics displaying significant differences.

Table 1. Names and definitions for deceleration metrics of interest.

Metric (Unit)	Definition | Calculation
Avg. Approach Velocity (m/s)	Average horizontal approach velocity of the COM
Avg. Approach Momentum (kg*m/s)	Average horizontal approach momentum of the COM
DEC Phase Avg. Deceleration (m/s^2)	Average horizontal deceleration of the CIOM
DEC Phase Avg. Horizontal Braking Force (N)	Horizontal antero-posterior ground reaction force applied to the body COM
Stopping Time (s)	Time from the start of the deceleration phase to the end of the deceleration phase
Stopping Distance (m)	Distance from the start of the deceleration phase to the end of the deceleration phase
COM Drop During DEC (cm)	Downward movement of the COM during the deceleration phase
Avg. Brake Step Ground Contact DEC (g)	Average ground contact deceleration during all steps of the deceleration phase
Avg. Brake Step Ground Contact Time (s)	Average foot ground contact time during all steps of the deceleration phase
Avg. Brake Step Hip Flexion at GC (deg)	Average brake step hip flexion during the deceleration phase
Avg. Brake Step Knee Flexion at GC (deg)	Average brake step knee flexion during the deceleration phase
Avg. Brake Step Position Relative to COM (cm)	Foot position relative to the COM for all brake steps in the deceleration phase

**Notes: "Avg." = Average, "DEC" = Deceleration, "N" = Newton, "deg" = degrees, "COM" = Centre of mass, "GC" = Ground contact.*

Table 2. Reliability statistics for all metrics of interest.

Metric	Test	ICC (CI)	SEM	MD
Avg Approach Velocity (m/s)	ADA	0.79 (0.60; 0.91)	0.10 (2.3%)	0.28
	505	0.82 (0.68; 0.92)	0.14 (3.2%)	0.39
Avg Approach Momentum (kg*m/s)	ADA	0.98 (0.95; 0.99)	8.91 (2.6%)	24.8
	505	0.97 (0.93; 0.99)	9.90 (2.9%)	27.4
Avg DEC (m/s^2)	ADA	0.34 (0.04; 0.65)	0.41 (12.1%)	1.10
	505	0.47 (0.23; 0.71)	0.28 (6.9%)	0.77
Avg Horizontal Braking Force (N)	ADA	0.80 (0.62; 0.91)	32.1 (12.8%)	88.9
	505	0.83 (0.69; 0.92)	21.3 (6.82%)	59.1
Stopping time (s)	ADA	0.51 (0.21; 0.76)	0.11 (11.9%)	0.39
	505	0.56 (0.34; 0.78)	0.22 (15.8%)	0.62
Stopping distance (m)	ADA	0.13 (-0.14; 0.47)	0.89 (21.0%)	2.48
	505	0.26 (0.04; 0.54)	0.69 (12.9%)	1.92
DEC COM Drop (cm)	ADA	0.66 (0.40; 0.84)	2.12 (16.7%)	5.83
	505	0.82 (0.67; 0.92)	2.57 (19.8%)	7.11
Avg Brake Step GCD (g)	ADA	0.81 (0.63; 0.92)	0.94 (8.4%)	2.60
	505	0.62 (0.40; 0.81)	1.09 (9.9%)	3.01
Avg Brake Step GCT (s)	ADA	0.59 (0.32; 0.81)	0.02 (9.9%)	0.06
	505	0.46 (0.22; 0.71)	0.02 (10.7%)	0.06
Avg Brake Step Hip Flexion at GC (deg)	ADA	0.96 (0.92; 0.99)	2.68 (8.2%)	7.40
	505	0.95 (0.91; 0.98)	2.39 (7.3%)	6.63
Avg Brake Step Knee Flexion at GC (deg)	ADA	0.84 (0.69; 0.94)	3.65 (10.6%)	10.1
	505	0.59 (0.37; 0.79)	4.58 (13.8%)	12.70
Avg Brake Step Position Relative to COM (cm)	ADA	0.70 (0.46; 0.87)	1.03 (6.4%)	7.20
	505	0.45 (0.21; 0.70)	3.65 (10.1%)	10.1

**Notes: "Avg." = Average, "DEC" = Deceleration, "N" = Newton, "deg" = degrees, "COM" = Centre of mass, "GC" = Ground contact, "ICC" = Intraclass correlation coefficient, "CI" = 95% Confidence interval, "SEM" = Standard error of measurement, "MD" = Minimal difference needed to be considered real.*

Table 3. Between-test comparison statistics for all metrics of interest.

Metric	ADA	505	Mean Diff (CI)	ES (CI)
Avg Approach Velocity (m/s)	4.43 ± 0.24	4.46 ± 0.28	-0.03 (-0.09; 0.03)	-0.11 (-0.34; 0.10)
Avg Approach Momentum (kg*m/s)	339 ± 52.6	341 ± 52.1	-2.05 (-6.53; 2.44)	-0.04 (-0.12; 0.04)
Avg DEC (m/s^2) *	3.32 ± 0.33	4.10 ± 0.29	-0.78 (-0.91; 0.78)	-2.46 (-3.33; 1.88)
Avg Horizontal Braking Force (N) *	252.4 ± 26.1	313.6 ± 45.8	-61.2 (-76.1; -46.4)	-1.61 (-2.21; -1.20)
Stopping time (s) *	1.20 ± 0.18	1.41 ± 0.28	-0.22 (-0.34; -0.09)	-0.90 (-1.51; -0.39)
Stopping distance (m) *	4.17 ± 0.61	5.38 ± 0.54	-1.21 (-1.44; -0.97)	-2.06 (-2.82; -1.55)
DEC COM Drop (cm)	12.6 ± 3.36	13.0 ± 5.85	-0.39 (-3.13; 2.36)	-0.08 (-0.62; 0.45)
Avg Brake Step GCD (g)	11.2 ± 2.02	11.0 ± 1.52	0.23 (-0.29; 0.75)	0.13 (-0.12; 0.39)
Avg Brake Step GCT (s) *	0.20 ± 0.03	0.18 ± 0.02	0.02 (0.01; 0.03)	0.65 (0.26; 1.12)
Avg Brake Step Hip Flexion at GC (deg)	33.3 ± 11.9	32.3 ± 10.6	1.00 (-1.43; 3.42)	0.09 (-0.11; 0.29)
Avg Brake Step Knee Flexion at GC (deg)	34.2 ± 7.02	33.1 ± 5.83	1.13 (-0.87; 3.14)	0.17 (-0.11; 0.48)
Avg Brake Step Position Relative to COM (cm) *	41.0 ± 4.28	36.1 ± 6.04	4.86 (3.19; 6.53)	0.91 (0.61; 1.31)

**Notes: "Avg." = Average, "DEC" = Deceleration, "N" = Newton, "deg" = degrees, "COM" = Centre of mass, "GC" = Ground contact, "CI" = 95% Confidence interval, "ES" = Effect size, Bold text indicated a statistically significant between-test difference.*

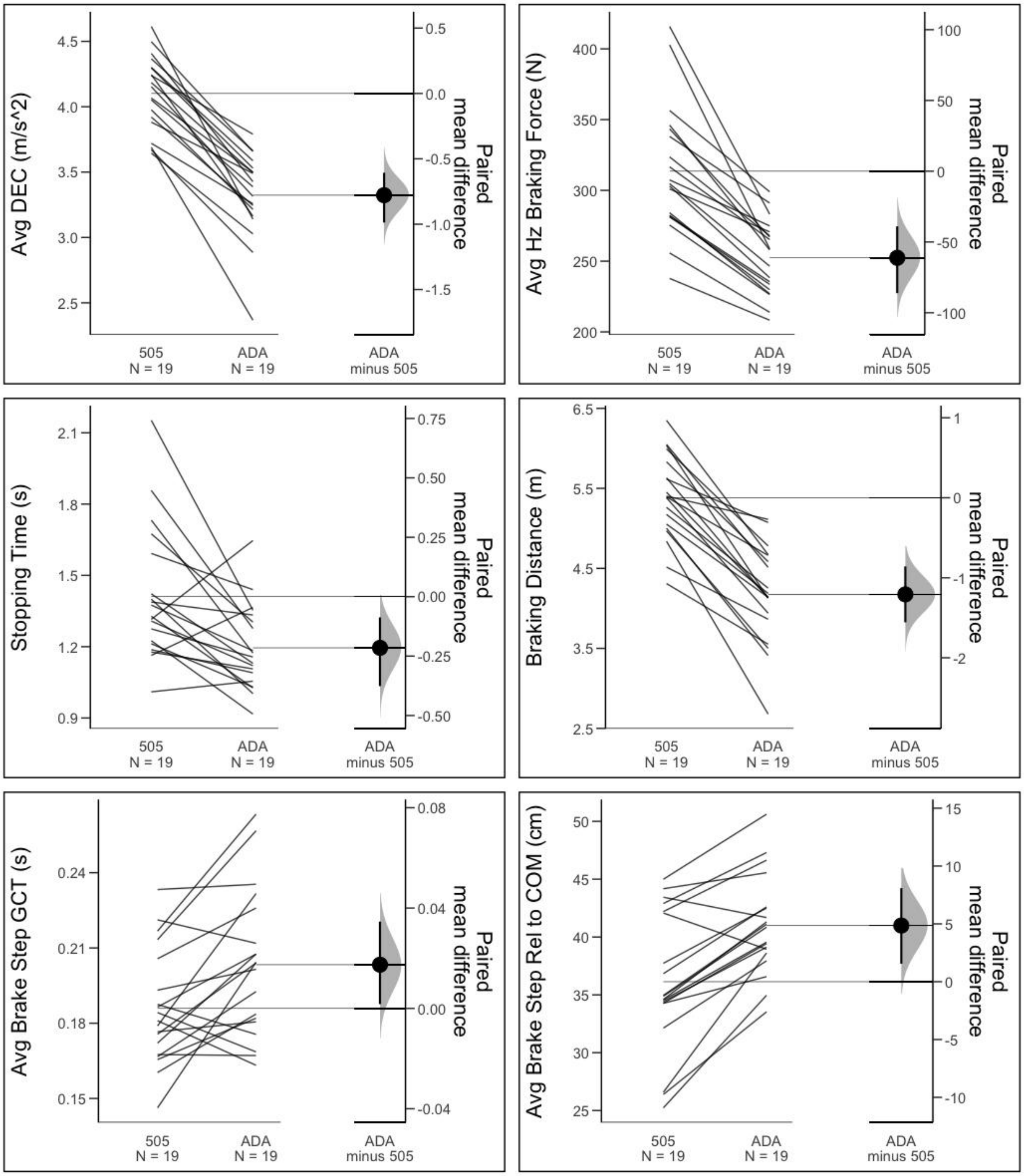


Figure 2. Gardner-Altman plots displaying between-test comparisons for metrics displaying significant differences.

DISCUSSION

The primary aim of the present study was to investigate biomechanical differences for measures of deceleration ability between the ADA test over 10 meters, and the 505 change of direction test. These tests are distinguished by the fact that the ADA possesses a predetermined point at which subjects initiate the deceleration phase, with no predetermined stopping point. On the other hand, during the 505 subjects are given a predetermined stopping/turning point. The findings suggest that six out of the twelve metrics of interest displayed significant between-test differences. Interestingly, all of these metrics came from the deceleration phase of the respective tests, while average approach velocity and momentum showed no significant differences and presenting with very small between-test effect sizes (ES = -0.04 to -0.11). This suggests that subjects initiated the deceleration phase under similar conditions. During the actual deceleration phase, between-test comparisons suggested that subjects exhibited significantly greater reductions in velocity during the 505 tests, compared to the ADA, exposing them to significantly greater magnitudes of horizontal braking force. Intriguingly, previous research comparing the ADA to the 505 suggested moderately higher magnitudes of average deceleration in the ADA, while maximal deceleration was found to be moderately larger in the 505 (Philipp et al. 2023). In our study, maximal deceleration was not analysed, however, it seems logical that the absence of a pre-determined stopping or turning point as seen within the ADA could influence the rate at which individuals reduce their running velocity. Furthermore, both stopping time and stopping distance were found to be significantly greater in the 505, compared to the ADA. With a mean stopping distance of 5.38 m, this suggests that subjects in the 505 likely initiated the deceleration phase at an earlier point in time. However, what must be acknowledged by readers is the lack of stability for both of the previously highlighted measures. Both metrics across respective tests presented with ICCs ranging from 0.13 to 0.56, and SEM values of 11.9 to 21% of the grand mean. While using a different technology to quantify these metrics, this agrees with earlier literature suggesting questionable degrees of reliability for stopping distance and stopping time (Ashton and Jones, 2019; Harper et al. 2020; Philipp et al. 2023). Readers are encouraged to refer to the MD values presented in Table 2, to conceptualize what kind of change in the said metrics of interest would be needed to be considered "*real*" or meaningful. For a decrease in braking distance performance to be considered "*real*" or meaningful, subjects would need to display reductions over 2.48 m in the ADA, and 1.92 min the 505, which in our opinion appears as high.

Furthermore, in the 505, subjects exhibited significantly shorter brake step ground contact times, as well as brake steps that were positioned significantly closer to the COM, when compared to the ADA. Previous research has shown that faster change of direction performers within the 505-test present with significantly shorter ground contact times, compared to their slower counterparts (Dos'Santos et al. 2017). However, in the aforementioned study, ground contact times were measured during the penultimate and final foot contact of the assessment, while in our study ground contact times were averaged across all brake steps during the deceleration phase. Both the previously mentioned study and the current investigation found similar findings of shorter ground contact times through different measurements. However, further research is warranted to determine if these results can be replicated. This may present as a useful addition to the body of evidence in the deceleration and change of direction space, given that most research is less concerned with the early braking steps during decelerations and change of direction manoeuvres. Nedergaard et al. proposed that investigations of lower limb loading during turning should include the sudden deceleration phase prior to turning, and not focus solely on the pivot foot-ground contact (Nedergaard et al. 2014). Previous research has investigated biomechanics of the antepenultimate, penultimate, as well as final foot contacts; however, little is known about what happens prior to that (Dos'Santos et al. 2021). Dos'Santos et al. found significantly greater peak braking forces over shorter ground contact times in the antepenultimate steps, compared to the penultimate step and final foot contact (Dos'Santos et al. 2021). This highlights the potential importance of analysing individual brake steps, in addition to calculating averages across the entire deceleration phase, which may give direction to future research questions. The shorter brake step ground contact times and brake steps that were positioned closer to the centre of mass may be due in part to the biomechanical and technical nature of the declaration phase within each respective assessment. It is probable that during the ADA, subjects exhibit a more "*traditional*" horizontal deceleration profile, which is characterized by a heel strike upon ground contact, a more posteriorly oriented torso, and a slightly flexed knee and hip, in order to efficiently reduce whole-body momentum (Hewit et al. 2011). On the other hand, during the 505, and in preparation for a 180-degree turn, subjects are likely going through additional postural adjustments in the deceleration phase, which are reflected in our results. More specifically, during the 505, subjects likely went through degrees of lateral trunk flexion, and greater internal foot progression angles, with the latter being related to significantly faster 505 completion times, and shorter final foot contact times (Dos'Santos et al. 2021). Ground contact decelerations did not reflect any significant differences between tests. However, a methodological limitation that should be taken into consideration here is that in our investigation, ground contact decelerations were calculated as the sum across the y-, x-, and z-direction, as derived from the IMU-units attached to the lower limbs, which makes it difficult to partial out further biomechanical strategies implemented by the subjects. For instance, in the work by Dos'Santos et al., in addition to shorter ground contact time, authors also suggested that greater horizontal braking and propulsive ground reaction forces during the penultimate step were found in subjects performing faster 180-degree turns (Dos'Santos et al. 2021). Similarly, as touched upon earlier, the same team of authors highlighted the importance of horizontal force production and braking strategies during the antepenultimate step, to facilitate faster change of direction performance (Dos'Santos et al. 2021). Future investigations should therefore aim to replicate methodologies, partialling out the direction of ground contact acceleration/deceleration using IMU technology or use force-plates to gather ground reaction force characteristics of the earlier brake steps. However, the latter may present as challenging, especially when trying to analyse the entire deceleration phase, in which between 4 and 6 meters of three-dimensional force plates would be needed.

In light of our findings and given the different layouts and characteristics of the ADA and the 505, a discussion of how a predetermined stopping point affects deceleration and change of direction performance deserves recognition. The present study found six out of twelve deceleration metrics (Avg DEC, Avg Horizontal Braking Force, Stopping time, Stopping distance, Avg Brake Step GCT, Avg Brake Step Position Relative to COM to have statistically significant differences between the two tests. When making a 180-degree turn, such as that during the 505, one has to undergo multiple postural changes in order to decrease their horizontal momentum to zero by not only rotating their trunk, but by planting their foot ahead of their COM to produce horizontal braking and propulsive impulse, followed by reaccelerating after horizontal momentum briefly reaches zero (Dos'Santos et al. 2017). In addition to these movement patterns, individuals must possess faster approach COM velocities along with medial trunk lean and internal pelvic and foot rotation (Dos'Santos et al. 2020). Athletes who can effectively perform the previously identified biomechanical movement patterns have the potential to achieve reduced stopping times in the 505 change of direction test. In a study by Dos'Santos et al. (2019), authors found that using external cues for cutting technique modification, was effective in improving cutting completion times, COD deficits, and movement quality in youth soccer players (Dos'Santos et al. 2019). Having a location that is already known for an individual to plant and turn at, could potentially have a similar effect of external cueing by developing motor skill retention and developing an individual's focus distance within their external focus of attention (Winkelman et al. 2018). By having the location predetermined, this forced each participant to not react, but rather prepare by taking shorter brake step ground contact times, as well as positioning brake steps closer to the COM. Understanding the role of how external cues may affect metrics identified in the present study in both the 505 and the ADA may allow for further confirmation of the motor skills needed to increase performance in these change of direction tests.

While authors believe the present study effectively adds to the body of literature, certain limitations should also be acknowledged when interpreting the findings of our investigation. For one, while test familiarization was provided during the warmup, the sample consisted of recreationally trained athletes with little prior experience in the implemented assessments, rather than higher-level athletes, who might present with more sufficiency. While speculative, this may have influenced the variability in some measures of deceleration performance. For example, while presenting with sufficient ICCs, deceleration phase COM drop being a metric reflecting the deceleration strategy, exhibited elevated SEM values displayed as a percentage of the grand mean, which may suggest substantial variability between individual subject trials. Future investigations should aim to further investigate the biological and technological reliability of the technology and assessments used in this study.

CONCLUSION

In summary, our study found differences across several biomechanical characteristics quantified during the deceleration phase when comparing the ADA to the 505 change of direction test. These differences displayed moderate to large between-test effect sizes. More specifically, subjects were found to exhibit significantly greater reductions in velocity and horizontal braking forces in the 505. Further, subjects showed significantly shorter stopping times and distances in the ADA, however, these displayed insufficient levels of reliability across both assessments, which should be interpreted as a limitation. Lastly, subjects showed significantly shorter brake step ground contact times in the 505, which were accompanied by shorter brake step distances with regard to their position relative to the COM. Therefore, it may be speculated that based on our data, the 505, which possesses a predetermined stopping/turning point presents a greater or different biomechanical challenge to individuals, which must be met with the appropriate neuromuscular and skill-related qualities to efficiently reduce whole-body momentum. Sport science practitioners may use the results presented in our study to enhance their decision-making processes in selecting assessments that target the quantification of maximal horizontal deceleration ability.

AUTHOR CONTRIBUTIONS

NMP – Conceptualization, methodology, data curation, data analysis, data visualization, writing original draft. AAS – Writing - review & editing. BRC – Writing – review & editing. DC – Writing – review & editing. QRJ – Writing – review & editing. ACF - Conceptualization, methodology, project supervision.

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DISCLOSURE STATEMENT

No potential conflict of interest were reported by the authors.

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REFERENCES

Ashton, J., & Jones, P. A. (2019). The reliability of using a laser device to assess deceleration ability. Sports (Basel), 7(8). https://doi.org/10.3390/sports7080191

Cleary, C. J., Nabavizadeh, O., Young, K. L., & Herda, A. A. (2022). Skeletal muscle analysis of panoramic ultrasound is reliable across multiple raters. PLoS One, 17(5), e0267641. https://doi.org/10.1371/journal.pone.0267641

Cohen, J. (2013). Statistical power analysis for the behavioral sciences. Routledge. https://doi.org/10.4324/9780203771587

Dos'Santos, T., McBurnie, A., Thomas, C., Comfort, P., & Jones, P. A. (2020). Biomechanical determinants of the modified and traditional 505 change of direction speed test. Journal of Strength and Conditioning Research, 34, 1285-1296. https://doi.org/10.1519/JSC.0000000000003439

Dos'Santos, T., McBurnie, A., Comfort, P., & Jones, P. A. (2019). The effects of six-weeks change of direction speed and technique modification training on cutting performance and movement quality in male youth soccer players. Sports, 7, 205. https://doi.org/10.3390/sports7090205

Dos'Santos, T., Thomas, C., Jones, P. A., & Comfort, P. (2017). Mechanical determinants of faster change of direction speed performance in male athletes. Journal of Strength and Conditioning Research, 31(3), 696. https://doi.org/10.1519/JSC.0000000000001535

Dos'Santos, T., Thomas, C., & Jones, P. A. (2021). How early should you brake during a 180° turn? A kinetic comparison of the antepenultimate, penultimate, and final foot contacts during a 505 change of direction speed test. Journal of Sports Sciences, 39(4), 395-405. https://doi.org/10.1080/02640414.2020.1823130

Dos'Santos, T., Thomas, C., McBurnie, A., Comfort, P., & Jones, P. A. (2021). Biomechanical determinants of performance and injury risk during cutting: A performance-injury conflict? Sports Medicine, 51(9), 1983-1998. https://doi.org/10.1007/s40279-021-01448-3

Draper, J. A., & Lancaster, M. G. (1985). The 505 test: A test for agility in the horizontal plane. Australian Journal for Science and Medicine in Sport, 1, 15-18.

Graham-Smith, P., Rumpf, M., & Jones, P. A. (2018). Assessment of deceleration ability and relationship to approach speed and eccentric strength. ISBS Proceedings Archive, 36(1), 8.

Harper, D. J., Cohen, D. D., Carling, C., & Kiely, J. (2020). Can countermovement jump neuromuscular performance qualities differentiate maximal horizontal deceleration ability in team sport athletes? Sports (Basel), 8(6). https://doi.org/10.3390/sports8060076

Harper, D. J., Cohen, D. D., Rhodes, D., Carling, C., & Kiely, J. (2022). Drop jump neuromuscular performance qualities associated with maximal horizontal deceleration ability in team sport athletes. European Journal of Sport Science, 22(7), 1005-1016. https://doi.org/10.1080/17461391.2021.1930195

Harper, D. J., & Kiely, J. (2018). Damaging nature of decelerations: Do we adequately prepare players? BMJ Open Sport Exerc Med, 4(1), e000379. https://doi.org/10.1136/bmjsem-2018-000379

Harper, D. J., McBurnie, A. J., Santos, T. D., Eriksrud, O., Evans, M., Cohen, D. D., et al. (2022). Biomechanical and neuromuscular performance requirements of horizontal deceleration: A review with implications for random intermittent multi-directional sports. Sports Medicine, 52(10), 2321-2354. https://doi.org/10.1007/s40279-022-01693-0

Harper, D. J., Morin, J. B., Carling, C., & Kiely, J. (2020). Measuring maximal horizontal deceleration ability using radar technology: Reliability and sensitivity of kinematic and kinetic variables. Sports Biomechanics. https://doi.org/10.1080/14763141.2020.1792968

Harper, D. J., Sandford, G. N., Clubb, J., Young, M., Taberner, M., Rhodes, D., et al. (2021). Elite football of 2030 will not be the same as that of 2020: What has evolved and what needs to evolve? Scandinavian Journal of Medicine & Science in Sports, 31(2), 493-494. https://doi.org/10.1111/sms.13876

Hewit, J., Cronin, J., Button, C., & Hume, P. (2011). Understanding deceleration in sport. Strength & Conditioning Journal, 33(1), 47. https://doi.org/10.1519/SSC.0b013e3181fbd62c

Ho, J., Tumkaya, T., Aryal, S., Choi, H., & Claridge-Chang, A. (2019). Moving beyond P values: Data analysis with estimation graphics. Nature Methods, 16(7), 565-566. https://doi.org/10.1038/s41592-019-0470-3

Jordan, A. R., Carson, H. J., Wilkie, B., & Harper, D. J. (2021). Validity of an inertial measurement unit system to assess lower-limb kinematics during a maximal linear deceleration. Central European Journal of Sport Sciences and Medicine, 33, 5-16. https://doi.org/10.18276/cej.2021.1-01

Koo, T. K., & Li, M. Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. Journal of Chiropractic Medicine, 15(2), 155-163. https://doi.org/10.1016/j.jcm.2016.02.012

Morin, J. B., Samozino, P., Murata, M., Cross, M. R., & Nagahara, R. (2019). A simple method for computing sprint acceleration kinetics from running velocity data: Replication study with improved design. Journal of Biomechanics, 94, 82-87. https://doi.org/10.1016/j.jbiomech.2019.07.020

Nedergaard, N. J., Kersting, U., & Lake, M. (2014). Using accelerometry to quantify deceleration during a high-intensity soccer turning manoeuvre. Journal of Sports Sciences, 32(20), 1897-1905. https://doi.org/10.1080/02640414.2014.965190

Nijmeijer, E. M., Heuvelmans, P., Bolt, R., Gokeler, A., Otten, E., & Benjaminse, A. (2023). Concurrent validation of the Xsens IMU system of lower-body kinematics in jump-landing and change-of-direction tasks. Journal of Biomechanics, 154, 111637. https://doi.org/10.1016/j.jbiomech.2023.111637

Philipp, N. M., Blackburn, S. D., Cabarkapa, D., & Fry, A. C. (2023). Effect of sprint approach velocity and distance on deceleration performance in NCAA Division I female softball players. Journal of Human Sport and Exercise. https://doi.org/10.14198/jhse.2023.183.03

Philipp, N. M., Cabarkapa, D., Marten, K. M., Cabarkapa, D. V., Mirkov, D. M., Knezevic, O. M., et al. (2023). Horizontal deceleration performance in professional female handball players. Biomechanics and Modeling in Mechanobiology, 3(3), 299-309. https://doi.org/10.3390/biomechanics3030026

Schepers, M., Giuberti, M., & Bellusci, G. (2018). Xsens MVN: Consistent tracking of human motion using inertial sensing.

Taylor, J. B., Wright, A. A., Dischiavi, S. L., Townsend, M. A., & Marmon, A. R. (2017). Activity demands during multi-directional team sports: A systematic review. Sports Medicine, 47(12), 2533-2551. https://doi.org/10.1007/s40279-017-0772-5

Weir, J. P. (2005). Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. Journal of Strength and Conditioning Research, 19(1), 231-240. https://doi.org/10.1519/00124278-200502000-00038

Winkelman, N. C. (2018). Attentional focus and cueing for speed development. Strength and Conditioning Journal, 40, 13-25. https://doi.org/10.1519/SSC.0000000000000266

ORIGINAL ARTICLE

Effect of three months high-intensity anaerobic treadmill-based exercise on intuitive decision-making capability: A prospective cohort study

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ABSTRACT

Background. Quick decision making capability is critical for handling critical situation. Intuitive decision making is most desirable for situations requiring quick and heedful decisions. Decision making, just like other cognitive skills can be modified through several factors like physical activity. In this study we aim to decipher the effects of high-intensity treadmill-based exercise on intuitive ability. Methods. A prospective cohort design with convenience sampling with a sample of 80 participants from various gym centres. Following ethical approval and informed consent, participants were divided in to either no exercise (NE) (n = 38) condition or treadmill-based exercise (TBE) group (n = 42). Data on socio-demographic characters, self-reported mental health history and IDM scores were obtained. Data were obtained at baseline and after 34 sessions of treadmill-based exercise for TBE and 12 weeks of normal physical activity for NE group. Mixed-factor ANOVA, paired t-test and regression analysis was used utilizing SPSS version 21. Results. A significant improvement in IDM scores was observed in TBE group after 34 exercise sessions as compared to NE group ($p < .01$). A significant interaction of time points and group was also revealed through mixed-factor ANOVA ($p < .01$). Socio-demographic characters and mental health history had no significant impact on IDM scores. Chi-square analysis of the IDM sub-categories showed a significant increase in intuitive decision making individuals in the TBE group post intervention ($p < .01$). Conclusion. Exercise training can be used as a potential training tool for improving decision making outcomes in critical settings.

Keywords: Exercise, Decision making, Intuition, Cognition, Mental health.

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INTRODUCTION

Decision making is a crucial trait in a wide variety of domains including social (Bruch & Feinberg, 2017), medical (Veldwijk et al., 2016), military (Thunholm, 2009) etc. While decision making can be spontaneous, rational, intuitive, dependent or avoidant, intuitive decision making is considered as irrational (Hassani et al., 2016), whereas, importance of intuitive decision making in evident in multiple disciplines and education and training has shown to play an important role in refurbishing intuitive decision making (Ruzsa et al., 2020). Intuitive decision making differs from rational decision making in a way that it doesn't involve logical reasoning but is rather based on past experiences and learning (Calabretta et al., 2016). Intuition is the apprehension of things in absence of logic and follows concepts or facts stored in the brain (Matzler et al., 2007). Rationality and intuition are fundamentally essential for judicious and tactical decision making however both greatly contrast with each other. Intuitive decision making provides quick processing of a large amount of information and is most likely to provide accurate judgments when based on relevant experiential learning (Patterson et al., 2013). Unlike reasoning, intuition is low effort and does not compete for central working memory resources, thereby holding importance in emergency situations. So far, researchers have also elevated the idea that making everyday life decisions intuitively facilitates a positive mental state. It also influences a patient's life and clinician decision-making and behaviour (Buetow & Mintoft, 2011). Since Intuitive Decision Making involves less time and quick coordination among experiences it can serve as a great tool in the contemporary culture for successful decision making.

Much evidence shows that physical exercise (PE) is a strong gene modulator that induces structural and functional changes in the brain, determining enormous benefits on both cognitive functioning and well-being (Mandolesi et al., 2018). Scientific evidence based on neuroimaging approaches over the last decade has demonstrated the efficacy of physical activity in improving cognitive health across the human lifespan. New evidence indicates that exercise exerts its effects on cognition by affecting molecular events related to the management of energy metabolism and synaptic plasticity. Recent studies show that exercise collaborates with other aspects of lifestyle to influence the molecular substrates of cognition (Gomez-Pinilla & Hillman, 2013).

Memory has been found to be related to intuition and intuitive processes both neuroanatomically and experimentally (Frank et al., 2006). Since memory and attention span are related to intuition and intuitive decision-making and physical exercise has profound positive effects on memory and attention (Micklewright et al., 2017), we hypothesize that physical exercise can also directly positively affect intuitive decision making. The aim of this study is to assess the impact of regular exercise on intuitive decision making in a sample of healthy population as compared to controls with active lifestyle in absence of regular exercise.

METHODOLOGY

Participant recruitment and sample selection

Eighty participants (sociodemographic characteristics of the participants are presented in Table 1), were recruited from fitness centres and clubs, after obtaining informed consent after 15 minutes of explanation of the study design and measuring variables (Figure 1). Individuals aged between 18 to 45 years (both males and females) were included while those with any known lower limb deformity, and current diagnosis of psychological disorder were excluded. Ethical approval was obtained from Institutional Review Board, DUHS (Approval No. IRB/1118/DUHS/Approval/2018/198) in accordance with the guidelines of National Bioethics Committee (NBC), consistent with the guidelines set forth in the Helsinki Declaration of 1975. Written and informed consent was obtained from participants prior to the study.

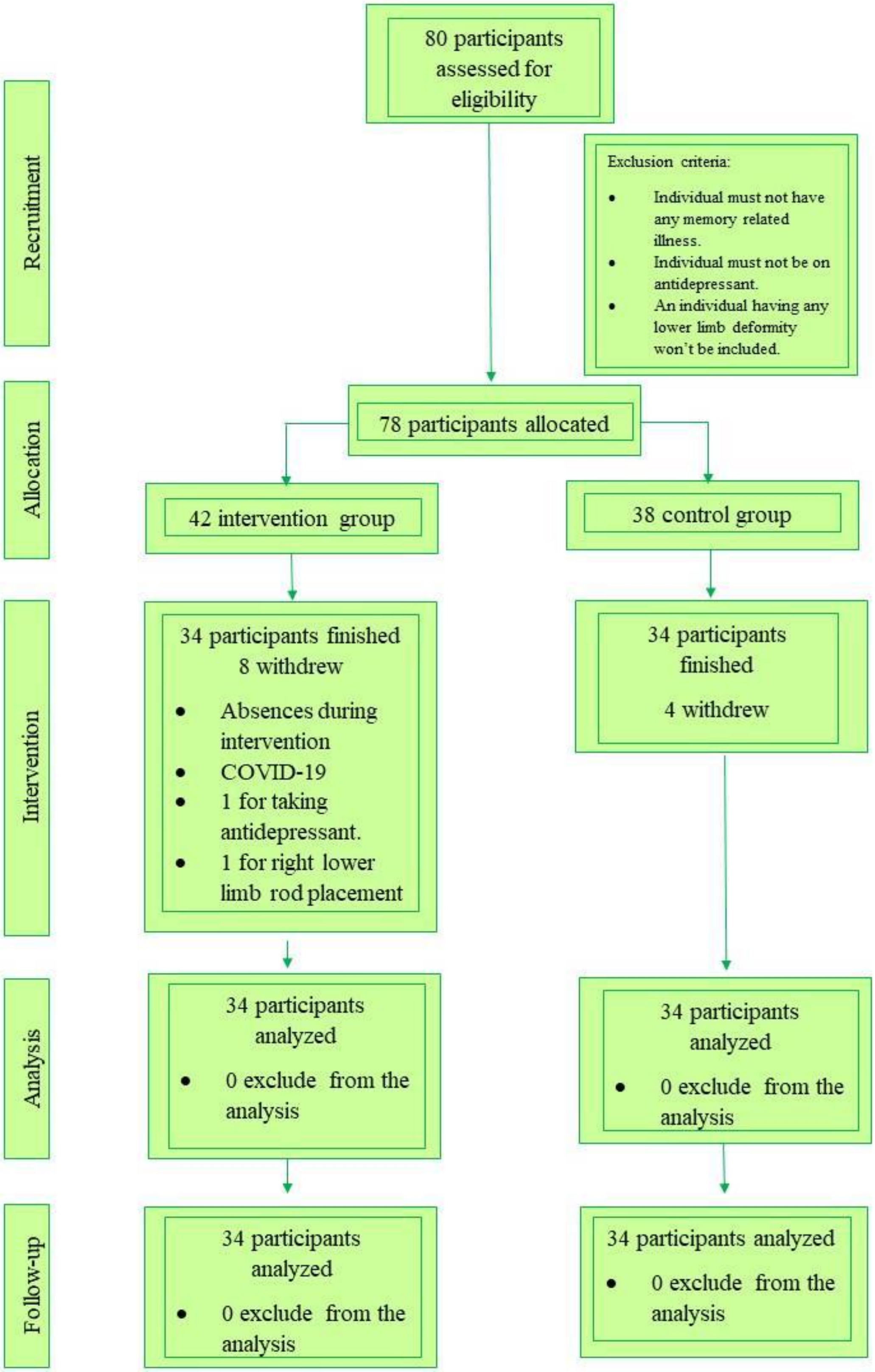

Figure 1. Flow chart for sample selection and analysis.

Table 1. Socioeconomic characteristics of study participants and self-report of mental health.

Variable		*n* (%) NE	*n* (%) TBE	*p*-value
Gender	Male	12(35.3)	26(76.5)	.001**
	Female	22(64.7)	8(23.5)	
Socioeconomic status	Upper middle	17(53.1)	23(67.6)	.422
	Middle	8(25.0)	7(20.6)	
	Lower middle	7(21.9)	4(11.8)	
Education	Intermediate	17(50.0)	17(50.0)	.927
	Bachelor	13(38.2	12(35.3)	
	Postgraduate	4(11.8)	5(14.7)	
Marital status	Single	25(73.5)	26(76.5)	.5
	Married	9(26.5)	8(23.5)	
Employment status	Student	25(73.5)	14(41.2)	.02*
	A homemaker	3(8.8)	2(5.9)	
	Employed	6(17.6)	17(50.0)	
	Unemployed	0	1(2.9)	
Family history of mental disorder	Yes	5(14.5)	8(23.5)	.269
	No	29(85.3)	26(76.5)	
Previous diagnosis of mental disorder	Yes	1(2.9)	2(5.9)	.5
	No	33(97.1)	32(94.1)	
Self-rated quality of sleep	Very poor	0	1(2.9)	.658
	Poor	6(17.6)	5(14.7)	
	Normal	17(50.0)	13(38.2)	
	Good	8(23.5)	12(35.3)	
	Very good	3(8.8)	3(8.8)	
Self-rated mental health	Poor	2(5.9)	1(2.9)	.5
	Average	16(47.1)	15(44.1)	
	Good	10(29.4)	7(20.6)	
	Excellent	6(17.6)	11(32.4)	
Medication	Yes	1(2.9)	2(5.9)	.5
	No	33(97.1)	32(94.1)	
Age (Mean ± SD)		34(24.85 ± 6.593)	34(25.41 ± 5.326)	.702

*Note. NE: Control group, TBE: Treadmill-based exercise group, * p < .05, ** p < .01).*

Study design, sampling and settings

The study was a prospective cohort and non-probability convenience sampling was used. Data were collected from various Physical Fitness Centres and Health Clubs for the exercise group, while participants for control group (NE) were selected based on the following inclusion criteria: i) a minimum higher secondary education, ii) active employment with professions incorporating less than recommended (< 150 minutes of moderate physical activity) hours as per guidelines (NHS, 2021). Sample size was calculated using effect size from following equation:

$$n = 2\frac{(Za + Z1 - \beta)2\sigma 2,}{\Delta 2}$$

with $Z1 - \beta$ = 0.8 , Zα = 0.05, and Δ = 1.05 obtained from a previous study (Loprinzi et al., 2019) measuring the temporal effect of exercise on working memory, was used to obtain a total sample size of n = 32 that was inflated to n = 80 to account for non-respondent rate. Participants were divided into control/non-exercising (NE) group and treadmill-based exercise (TBE) group for a final number of n = 34 each group.

Data collection tool and procedure

Data on sociodemographic variables and a self-report of participant's mental health history including any previous history of psychiatric disorders, current medication and quality of sleep were obtained followed by the Goldberg test of intuitive decision making developed by (Goldberg, 2006), where the score is categorized as follows: > 6: Highly intuitive, 10-15: more intuitive than analytical, 5-0: analytical and rational, < 5: systematic rational approach of decision making. Treadmill based high-intensity exercise intervention was conducted for 30-40 mins continued for 3 times per week for a total of 34 sessions. High intensity treadmill based exercise followed the following protocol:

i. *5 minutes warm up.*
ii. *Running at 7 mph for 1 minutes followed 5.5 mph for 2 minutes X 5 for 15 minutes.*
iii. *1 minute recovery walk at intrinsic pace.*
iv. *Running at 10 mph for 1 minute, followed by 4 mph at 1 minutes X 5 for 8 minutes.*
v. *Cool down walk for 5 minutes.*

Statistical analysis

Data were analysed using IBM SPSS 21. Results were presented as mean ± SD. Paired t-test was done to determine the significant differences between NE and intervention groups after complete exercise duration. Participants with missing data (including loss of follow-up) were altogether excluded from the analysis. Mixed ANOVA was done to evaluate effects of exercise on intuitive decision making in both groups. Chi-square analysis was used to examine the difference of IDM sub-categories before and after intervention in both groups. IDM was categorized as systemic and rational for scores below 5, analytical and rational for scores between 5 and 9, more intuitive than analytical for scores between 10 and 15, and highly intuitive for scores 16 and beyond 16.

RESULTS

Sociodemographic and mental health characteristics of study participants

Descriptive statistics for the study participants at baseline are summarized in Table 1. The 2 groups were equally balanced for age. All 68 participants complete the full 34 session, treadmill-based exercise sessions. History of psychiatric diagnosis in the groups were rare, where participants in both groups had been previously diagnosed for anxiety, which was maintained with medication. Linear regression analysis was done to observe the effects of these confounders (Table 3 and 5).

Effect of treadmill-based exercise intervention on intuitive decision making

Previous studies have shown significant positive effects of physical exercise on various cognitive functions including attention span and memory (Leong et al., 2015). Therefore, we aimed to assess the impact of exercise on intuitive decision-making in daily life. A mixed-factor ANOVA on the combined data was initially performed to assess the difference and effect of treadmill-based exercise on IDM scores in both NEs and TBE group (Figure 2). Test of within subject effects revealed a significant interaction between time and groups (F = 10.35, $p < .01$, $\eta_p^2 = 0.136$). Since it was 2X2 mixed-factor ANOVA, Levene's test for equality of error variances, instead of Mauchy's test of sphericity was observed which revealed no significant differences of error between two time points in the sample (Pre F = 0.861, $p > .05$, post F = 0.105, $p > .05$). Given this finding, within subject effects assuming sphericity was also observed which revealed significant effect of time (F = 10.35, $p < .01$, $\eta_p^2 = 0.136$). Test of between-subject effects revealed significant effect of group (F = 13.52, $p < .001$, $\eta_p^2 = 0.17$).

We further delineated these effects using paired sample t-test (Table 2), which shows significant improvement in IDM scores in TBE group as compared to age-matched NE group (t = 1.22, df = 33, $p < .01$) with moderate effect size of 0.6 calculated using the formula:

$$d = \frac{|\,m1 - m2\,|}{\sqrt{s1^2 + s2^2} - (2rs1s2)}$$

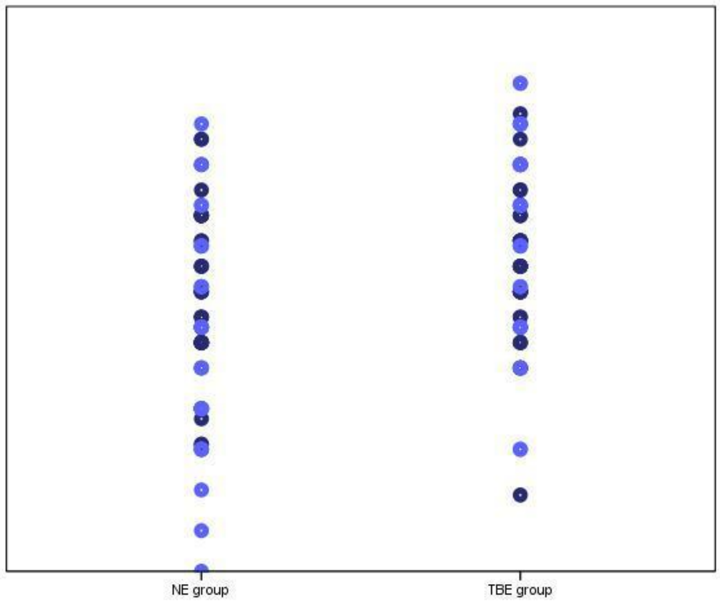

Figure 2. Scatter plots of the IDM scores in both NE and TBE group before (dark blue) and after (light blue) treadmill based exercise, built on SPSS version 21, using mixed-factor ANOVA.

Table 2. Paired sample test for IDM scores before and after treadmill-based exercise intervention.

Group	Mean ± SD (Pre-test)	Mean ± SD (Post-test)	*p*-value
NE	11.06 ± 3.08	10.38 ± 2.51	.23
TBE	11.68 ± 2.82	13.59 ± 2.36	.002**

*Note. NE: Control group, TBE: Treadmill-based exercise group, ** p < .01.*

Association of exercise with intuitive decision-making capability in study participants

Long-term exercise is associated with improved performance on various cognitive tasks including attention, executive function, and long-term memory (Winter et al., 2007). Recent studies have shown that even a single time of aerobic exercise can lead to an immediate improvement in declarative learning, attention, and memory (Winter et al., 2007), therefore we were interested study the association of exercise with intuitive decision-making capability. Table 3 shows the significant association of 30-40 mins of exercise continued for 3 times per week for a total of 34 sessions with IDM scores (B = 3.206, $p < .001$, CI = 2.25-4.386).

Table 3. Linear regression analysis of participant factors on IDM scores.

Variable	r^2	B	*p*-value	Confidence Interval
Treadmill based exercise	.308	3.206	.000**	2.25 – 4.386
Age	.011	0.052	.389	-0.068 – -0.171

*Note. r^2; correlation coefficient, B = beta coefficient, ** p < .01.*

Influence of socio-demographic characteristics and self-reported mental status on IDM

Many of the earlier studies through investigations have proved an association between socio-demographic variables and cognitive skills. Men as compared to women tend to get more cognitively affected with increasing age (Maylor et al., 2007). Similarly early life socioeconomic status (Bertola et al., 2021), marital status (Liu et al., 2020) and level of education (Lovden et al., 2020) have been shown to impact individual's cognitive abilities across their entire adult life span. Also, as significant group differences in gender and employment status were observed (Table 1), the sociodemographic characteristics were adjusted to observe the main effects on intervention ($F = 7.26$, $p < .01$) (Table 4).Also, it has been formerly proclaimed that patients with mental disorders such as major depressive disorder, schizophrenia etc have impaired cognitive skills (Hauenstein, 2003; Mihaljevic-Peles et al., 2019). Therefore, we were interested to observe whether mental disorder history in our participants influenced intuitive decision making or not. Table 4 shows no significant influence of mental health history of participants on intuitive decision-making scores.

Table 4. Covariate analysis of sociodemographic factors and self-rated mental status.

Variable	**MS**	**F**	**η^2**	***p*-value**
Gender	0.162	0.019	0	.891
Marital Status	17.307	2.04	0.037	.159
Socioeconomic	28.77	3.392	0.06	.071
Education	13.415	1.582	0.029	.214
Employment	4.752	0.56	0.01	.457
Family history of mental disorder	19.308	2.276	0.041	.137
History of mental disorder	0.461	0.054	0.001	.817
Medication	0.254	0.03	0.001	.863
Self-rated quality of sleep	29.341	3.459	0.061	.068
Self-rated mental health	17.774	2.095	0.038	.154

Note. MS; Mean Square, η^2; eta square.

Difference of IDM categories between NE and intervention group before and after exercise

Decision-making incorporates capabilities such as systemic rational decision making, analytical and rational decision making, more intuitive than analytical decision making and strong intuitive decision making. After observing significant impact of exercise on overall intuitive decision making, we intended to study the difference of individual capabilities of intuitive decision making between members of interventional and NE group. Chi-square analysis shows that TBE group gained significantly stronger intuitive decision making capability after exercise intervention as compared to individuals in the NE group. Table 4 shows that out of the four defined IDM categories the number of individuals in category 1 (from 1 to 0) and category 2 (from 6 to 2) decreased, in category 3 no changes were observed while in category 4 the number increased (from 2 to 7) post-intervention.

DISCUSSION AND CONCLUSIONS

Intuition decision making is critical for quick integration of learned facts, concepts, procedures, and abstractions stored in the long-term memory (Patterson et al., 2013), required for the challenges of the contemporary world. Intuitive decision making capability in an individual is psychologically determined by internal and external determinants which incorporate metacognitive skills and environmental factors (Malewska, 2020), while the biological determinants of decision making capability include diet (Strang et al., 2017) and exercise (Wheeler et al., 2020). Beneficial effects of resistance exercise have been shown on cognitive function by enhancement of hippocampal synaptic plasticity-related molecules (Nichol et al., 2009), while structural changes related to strength training in white matter, grey matter, and putamen volume in the healthy adult brain (Palmer et al., 2013) are also evident.

Exercise has been shown to bring positive physiological changes and enhance mental functions, such as improvement in attention, memory, cognitive thinking, and decision making, (Wassenaar et al., 2019), however, the role of exercise in intuitive decision making is unrecognized. Therefore the current study assessed the impact of exercise on intuitive decision-making. A duration of 30-40 mins of exercise continued 3 times per week for a total of 34 sessions significantly enhanced the IDM scores (Table 2) which suggests that apart from different types of decisions making exercise can greatly affect intuitive decision-making. Since exercise has demonstrated improvement in cognitive function in healthy older adults (Kelly et al., 2014), a significant difference in the IDM scores post-exercise explains that it can be utilized for decision training purposes as well. Additionally, exercise also showed strong association with IDM scores (Table 3), which indicates that a routine based exercise can serve as a predictor of good intuitive decision making capability.

Since decision making is a complex task and involves social, psychological, environmental and biological factors, we aimed to study the influence of socio-demographic characteristics on intuitive decision making to exclude the possibility of confounders. Only employment status of the participants was significantly associated with IDM scores (Table 3). It is therefore, unravelled that socio-demographic characteristics of our study participants did not influence IDM scores. Similarly, association between self-reported mental health history and IDM scores was determined to exclude possible confounders which included family history of mental disorders, a self-evaluation of overall mental health, quality of sleep and use of any psychiatric medication. We observed no influence of self-reported parameters of mental health on IDM scores (Table 4). Intuition has previously been shown to be altered in psychiatric conditions (Remmers & Michalak, 2016; Srivastava & Grube, 2009), which suggests that mental disorders present with alterations in intuitive decision making, yet we found no association of self-reported mental health parameters primarily because of exclusion of diagnosed psychological disorder, thereby rendering the sample free of such confounders, however, data on quality of sleep and family history of mental disorders among other parameters of mental health was also not significantly correlated with IDM scores (Table 3), providing a conclusion that the sample remained unaffected from such confounders.

Intuitive decision making can take different forms where a person can show either rational, analytic, intuitive or a mixture of two decision making styles. We wanted to evaluate the difference of each group between NE and TBE to determine if improvement in IDM scores resulted from improvement in rational, analytical or intuitive decision making. Chi-square analysis showed that improvement in IDM scores was mainly contributed by increased number of people falling into intuitive decision makers category (Table 5). Exercise has been shown to improve cognitive functioning (Mandolesi et al., 2018), along with improvement in memory and executive functioning (Hoffmann et al., 2021), however, to the best of our knowledge there are no studies available to evaluate a direct association of exercise with intuitive decision making. Results from the current study provide a direct link of the effects of exercise on intuitive decision making.

Exercise is an important factor in determining physical and mental health. Cognitive health forms a crucial component of mental health and decision making is an integral part of cognitive functions. This study provides recommendation of incorporating exercise as part of the training programs of employees to enhance their intuitive decision making capacity which can serve to promote quick and healthy decision making, especially in technologically loaded domains where individuals mostly remain sedentary due to the nature of their work, thereby, also reducing the complications of a sedentary work style.

Table 5. Chi square analysis on difference in IDM categories before and after exercise intervention.

Groups	IDM Categories				Total	*p*-value
	Systemic rational decision making	Analytical and rational decision making	More intuitive than analytical decision making	Strong intuitive decision making		
Pre-NE	2	11	18	3	34	.37
Pre-TBE	1	6	25	2	34	
Post- NE	1	14	18	1	34	.001**
Post-TBE	0	2	25	7	34	

*Note. NE; Control group, TBE; Treadmill-based exercise group, ** p < .01.*

Strengths and limitations of the study

The study revealed a direct and moderate effect of high-intensity exercise on intuitive decision-making capability as compared to control group with active lifestyle in the absence of regular exercise. However, the convenience sampling, limits the generalizability of the results. A detailed analysis of mental health parameters like scores on anxiety, depression or stress could also have provided valuable insights on the impact of exercise in the presence of mental or psychological disorders, however, we excluded those to minimize confounders for an initial study of the effects of exercise on intuitive decision making in psychologically healthy subjects. For a better understanding of these effects in future studies, we aim to include QEEG analysis coupled with IDM scores before and after exercise to evaluate electrophysiological changes in the brain.

AUTHOR CONTRIBUTIONS

All co-authors have contributed to the published work defined as per and International Committee of Medical Journal Editors (ICMJE) guidelines in the table below and agree to its publication in Journal of Human Sport and Exercise. The manuscript follow rules set in the frame of the Council of Science Editors (CSE) and International Committee of Medical Journal Editors (ICMJE) guidelines for authorship.

Contribution	Explanation	*Contributing Authors*
Concept	The idea for research or article/hypothesis generation	*Meha Fatima Aftab, Asbah Faisal, Tatheer Fatima*
Design	Planning the methods to generate hypothesis	*Meha Fatima Aftab, Asbah Faisal, Mabel Waqar, Tatheer Fatima*
Supervision	Supervision and responsibility for the organisation and course of the project and the manuscript preparation	*Meha Fatima Aftab*
Resources	Supplying financial resources, equipment, space, and personnelvital to the project	*Meha Fatima Aftab*
Materials	Biological materials, reagents, referred patients	*Meha Fatima Aftab, Asbah Faisal, Mabel Waqar, Tatheer Fatima*
Data collection and/orprocessing	Responsibility for conducting experiments, management of patients, organising and reporting data	*Asbah Faisal, Mabel Waqar, Tatheer Fatima*
Analysis and/or interpretation	Responsibility for presentation and logical explanation of results	*Meha Fatima Aftab, Asbah Faisal, Mabel Waqar, Tatheer Fatima, Athar Khan*
Literature search	Responsibility for conducting literature search	*Meha Fatima Aftab, Asbah Faisal, Mabel Waqar, Tatheer Fatima*
Writing manuscript	Responsibility for creation of the entire or a substantial part ofthe manuscript	*Meha Fatima Aftab, Asbah Faisal, Mabel Waqar, Tatheer Fatima,*

		Athar Khan
Critical review	Reworking the final, before submission version of the manuscript for intellectual content, not just spelling and grammar check	*Meha Fatima Aftab, Athar Khan*
Other	*For novel contributions:*	*N/A*

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DISCLOSURE STATEMENT

No potential conflict of interest were reported by the authors.

DATA AVAILABILITY

The data is available from https://osf.io/rpbqc/?view_only=419ef1694ff941a5aba0d0a1665c14b4

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REFERENCES

Bertola, L., Bensenor, I. M., Barreto, S. M., Giatti, L., Moreno, A. B., Viana, M. C., Lotufo, P. A., & Suemoto, C. K. (2021). Early life socioeconomic status predicts cognition regardless of education level. Eur J Neurol, 28(12), 3972-3978. https://doi.org/10.1111/ene.15042

Bruch, E., & Feinberg, F. (2017). Decision-Making Processes in Social Contexts. Annu Rev Sociol, 43, 207-227. https://doi.org/10.1146/annurev-soc-060116-053622

Buetow, S. A., & Mintoft, B. (2011). When should patient intuition be taken seriously? J Gen Intern Med, 26(4), 433-436. https://doi.org/10.1007/s11606-010-1576-6

Calabretta, G., Gemser, G., & Wijnberg, N. M. (2016). The Interplay between Intuition and Rationality in Strategic Decision Making: A Paradox Perspective. Organization Studies, 38(3-4), 365-401. https://doi.org/10.1177/0170840616655483

Frank, M. J., O'Reilly, R. C., & Curran, T. (2006). When memory fails, intuition reigns: Midazolam enhances implicit inference in humans. Psychological science, 17(8), 700-707. https://doi.org/10.1111/j.1467-9280.2006.01769.x

Goldberg, P. (2006). The Intuitive Edge: Understanding Intuition and Applying it in Everyday Life by Philip Goldberg (iUniverse, Ed. reprint ed.).

Gomez-Pinilla, F., & Hillman, C. (2013). The influence of exercise on cognitive abilities. Compr Physiol, 3(1), 403-428. https://doi.org/10.1002/cphy.c110063

Hassani, P., Abdi, A., & Jalali, R. (2016). State of Science, "Intuition in Nursing Practice": A Systematic Review Study. J Clin Diagn Res, 10(2), JE07-11. https://doi.org/10.7860/JCDR/2016/17385.7260

Hauenstein, E. J. (2003). Depression in adolescence. J Obstet Gynecol Neonatal Nurs, 32(2), 239-248. https://doi.org/10.1177/0884217503252133

Hoffmann, C. M., Petrov, M. E., & Lee, R. E. (2021). Aerobic physical activity to improve memory and executive function in sedentary adults without cognitive impairment: A systematic review and meta-analysis. Prev Med Rep, 23, 101496. https://doi.org/10.1016/j.pmedr.2021.101496

Kelly, M. E., Loughrey, D., Lawlor, B. A., Robertson, I. H., Walsh, C., & Brennan, S. (2014). The impact of exercise on the cognitive functioning of healthy older adults: a systematic review and meta-analysis. Ageing Res Rev, 16, 12-31. https://doi.org/10.1016/j.arr.2014.05.002

Leong, I. T., Moghadam, S., & Hashim, H. A. (2015). Aggregated effects of combining daily milk consumption and aerobic exercise on short-term memory and sustained attention among female students. Percept Mot Skills, 120(1), 57-66. https://doi.org/10.2466/22.06.PMS.120v11x3

Liu, H., Zhang, Z., Choi, S. W., & Langa, K. M. (2020). Marital Status and Dementia: Evidence from the Health and Retirement Study. J Gerontol B Psychol Sci Soc Sci, 75(8), 1783-1795. https://doi.org/10.1093/geronb/gbz087

Loprinzi, P. D., Blough, J., Crawford, L., Ryu, S., Zou, L., & Li, H. (2019). The Temporal Effects of Acute Exercise on Episodic Memory Function: Systematic Review with Meta-Analysis. Brain Sci, 9(4). https://doi.org/10.3390/brainsci9040087

Lovden, M., Fratiglioni, L., Glymour, M. M., Lindenberger, U., & Tucker-Drob, E. M. (2020). Education and Cognitive Functioning Across the Life Span. Psychol Sci Public Interest, 21(1), 6-41. https://doi.org/10.1177/1529100620920576

Malewska, K. (2020). Determinants of the Use of Intuition in Decision-making - an Empirical Study [intuicja, podejmowanie decyzji, determinanty procesu decyzyjnego, racjonalność]. 2020(5(983)), 14. https://doi.org/10.15678/ZNUEK.2019.0983.0502

Mandolesi, L., Polverino, A., Montuori, S., Foti, F., Ferraioli, G., Sorrentino, P., & Sorrentino, G. (2018). Effects of Physical Exercise on Cognitive Functioning and Wellbeing: Biological and Psychological Benefits. Front Psychol, 9, 509. https://doi.org/10.3389/fpsyg.2018.00509

Matzler, K., Bailom, F., & Mooradian, T. (2007). Intuitive Decision Making. MIT Sloan Management Review, 49, 13-15.

Maylor, E. A., Reimers, S., Choi, J., Collaer, M. L., Peters, M., & Silverman, I. (2007). Gender and sexual orientation differences in cognition across adulthood: age is kinder to women than to men regardless of sexual orientation. Arch Sex Behav, 36(2), 235-249. https://doi.org/10.1007/s10508-006-9155-y

Micklewright, D., Kegerreis, S., Raglin, J., & Hettinga, F. (2017). Will the Conscious-Subconscious Pacing Quagmire Help Elucidate the Mechanisms of Self-Paced Exercise? New Opportunities in Dual Process Theory and Process Tracing Methods. Sports Med, 47(7), 1231-1239. https://doi.org/10.1007/s40279-016-0642-6

Mihaljevic-Peles, A., Bajs Janovic, M., Sagud, M., Zivkovic, M., Janovic, S., & Jevtovic, S. (2019). Cognitive deficit in schizophrenia: an overview. Psychiatr Danub, 31(Suppl 2), 139-142.

NHS. (2021). Physical activity guidelines for adults aged 19 to 64. Retrieved from [Accessed 2024, April 21]: https://www.nhs.uk/live-well/exercise/exercise-guidelines/physical-activity-guidelines-for-adults-aged-19-to-64/

Nichol, K., Deeny, S. P., Seif, J., Camaclang, K., & Cotman, C. W. (2009). Exercise improves cognition and hippocampal plasticity in APOE epsilon4 mice. Alzheimers Dement, 5(4), 287-294. https://doi.org/10.1016/j.jalz.2009.02.006

Palmer, H. S., Haberg, A. K., Fimland, M. S., Solstad, G. M., Moe Iversen, V., Hoff, J., Helgerud, J., & Eikenes, L. (2013). Structural brain changes after 4 wk of unilateral strength training of the lower limb. J Appl Physiol (1985), 115(2), 167-175. https://doi.org/10.1152/japplphysiol.00277.2012

Patterson, R. E., Pierce, B. J., Boydstun, A. S., Ramsey, L. M., Shannan, J., Tripp, L., & Bell, H. (2013). Training intuitive decision making in a simulated real-world environment. Hum Factors, 55(2), 333-345. https://doi.org/10.1177/0018720812454432

Remmers, C., & Michalak, J. (2016). Losing Your Gut Feelings. Intuition in Depression. Front Psychol, 7, 1291. https://doi.org/10.3389/fpsyg.2016.01291

Ruzsa, G., Szeverenyi, C., & Varga, K. (2020). Person- and job-specific factors of intuitive decision-making in clinical practice: results of a sample survey among Hungarian physicians and nurses. Health Psychol Behav Med, 8(1), 152-184. https://doi.org/10.1080/21642850.2020.1741372

Srivastava, A., & Grube, M. (2009). Does intuition have a role in psychiatric diagnosis? Psychiatr Q, 80(2), 99-106. https://doi.org/10.1007/s11126-009-9094-6

Strang, S., Hoeber, C., Uhl, O., Koletzko, B., Munte, T. F., Lehnert, H., Dolan, R. J., Schmid, S. M., & Park, S. Q. (2017). Impact of nutrition on social decision making. Proc Natl Acad Sci U S A, 114(25), 6510-6514. https://doi.org/10.1073/pnas.1620245114

Thunholm, P. (2009). Military leaders and followers--do they have different decision styles? Scand J Psychol, 50(4), 317-324. https://doi.org/10.1111/j.1467-9450.2009.00714.x

Veldwijk, J., Essers, B. A., Lambooij, M. S., Dirksen, C. D., Smit, H. A., & de Wit, G. A. (2016). Survival or Mortality: Does Risk Attribute Framing Influence Decision-Making Behavior in a Discrete Choice Experiment? Value Health, 19(2), 202-209. https://doi.org/10.1016/j.jval.2015.11.004

Wassenaar, T. M., Wheatley, C. M., Beale, N., Salvan, P., Meaney, A., Possee, J. B., Atherton, K. E., Duda, J. L., Dawes, H., & Johansen-Berg, H. (2019). Effects of a programme of vigorous physical activity during secondary school physical education on academic performance, fitness, cognition, mental health and the brain of adolescents (Fit to Study): study protocol for a cluster-randomised trial. Trials, 20(1), 189. https://doi.org/10.1186/s13063-019-3279-6

Wheeler, M. J., Green, D. J., Ellis, K. A., Cerin, E., Heinonen, I., Naylor, L. H., Larsen, R., Wennberg, P., Boraxbekk, C.-J., Lewis, J., Eikelis, N., Lautenschlager, N. T., Kingwell, B. A., Lambert, G., Owen, N., & Dunstan, D. W. (2020). Distinct effects of acute exercise and breaks in sitting on working memory and executive function in older adults: a three-arm, randomised cross-over trial to evaluate the effects of exercise with and without breaks in sitting on cognition. British Journal of Sports Medicine, 54(13), 776. https://doi.org/10.1136/bjsports-2018-100168

Winter, B., Breitenstein, C., Mooren, F. C., Voelker, K., Fobker, M., Lechtermann, A., Krueger, K., Fromme, A., Korsukewitz, C., Floel, A., & Knecht, S. (2007). High impact running improves learning. Neurobiol Learn Mem, 87(4), 597-609. https://doi.org/10.1016/j.nlm.2006.11.003

ORIGINAL ARTICLE

Habits of healthy living in adults former athletes of federated competition in the modality of volleyball in the province of Jaen

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ABSTRACT

The main objective of this research is to know the healthy lifestyle habits of people who participated in federated competitions in volleyball in the province of Jaén once their competitive stage has ended. Therefore, to investigate whether people who in their adolescence and youth practiced a federated competitive sport in volleyball, maintain healthy lifestyle habits, referring to diet, quality of sleep, level of physical activity practice and their physical condition, in their stage of adulthood and seniority. This research has been carried out though a descriptive, cross-sectional, single measurement (Ato et al., 2013), and interpretive research; in which former athletes responded to a questionnaire about their daily habits related to health; In addition, to know the information through self-completed surveys by those who were captains and technicians of the volleyball clubs, in order to better understand their current healthy habits. The total number of subjects studied was 199 people, of which 18 were captains and 21 were coaches. When asking people about their eating habits, the majority values correspond to the response option "*good*", both in women (61.5%) and in men (48.8%). The different groups of participants in the research state that they attach great importance to eating habits, nutrition, and diet quality in their daily lives. 84.6% of women and 91.9% of men consider that their current level of physical fitness is based on the sports practice of their youth. Physical-sports practice as a healthy lifestyle habit is incorporated as a healthy lifestyle habit mostly in the former athletes and sports technicians participating in this research.
Keywords: Sport medicine, Former competitive athletes, Older adults, Nutrition, Quality of life.

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INTRODUCTION

When we talk about lifestyle, we refer to a set of behaviours that develop throughout the life of a human being due to the influence of various areas such as family, friends and the media, which are expressed in the daily life of human beings and therefore characterize the way of living and being of every person (Ibarra-Mora et al., 2019; López-Villar, 2011). In the case of healthy lifestyles, they are closely related to a balanced diet, maintaining body weight, bad physical activity, and abstaining from alcohol and tobacco consumption, among others (Sanabria, 2007). All of this is corroborated through research studies that demonstrate the importance of diet and bad physical activity to achieve a good quality of life (Portela-Pino et al., 2022).

Physical inactivity increases in many countries, considerably influencing the prevalence of non-communicable diseases and the general health of the world population. Humanity faces a great challenge in the coming decades, manifested in a sedentary lifestyle and lack of exercise that affect mental health and the quality of life of society (Moscoso et al., 2009), as confirmed by data from the World Health Organization (2010), revealing that at least 60% of the world's population does not carry out the physical activity necessary to obtain health benefits, becoming the fourth most important risk factor for mortality worldwide (Barbosa - Granados and Urrea-Cuéllar (2018). Therefore, if physical activity is carried out systematically and continuously, greater health protection can be achieved, as well as prevention of different disorders thanks to the physical and psychological benefits it provides. performing physical exercise (Sánchez-Barrera et al., 1995).Adopting a more active lifestyle can promote respiratory, cardiovascular and locomotor function, as well as develop and maintain muscle strength, improve postural activity, etc. (Romero-Granados et al., 2006).

In the case of our research, we want, through the triangulation of the information provided by the different instruments used, to verify the healthy lifestyle habits that the athletes in the sample practice in their daily lives. Taking into account that advances in health sciences, including human nutrition, have allowed life expectancy to be dramatically prolonged, genetics are decisive in this greater life expectancy, but there are also other series of factors that include the same, among which stands out an adequate diet, good quality of sleep and a healthy lifestyle, which includes bad exercise according to individual physical condition (Amador-Muñoz & Esteban-Ibáñez, 2015).

MATERIAL AND METHODS

Study design

We can consider that our study is a descriptive, cross-sectional, single measurement (Ato et al., 2013), and interpretive research, since it aims to collect and analyse information, in a way that allows us to know and interpret the reality studied and complement it. with the data obtained quantitatively and qualitatively (Latorre-Beltrán et. al., 2003).

A quantitative technique (questionnaire) has been used to obtain information on the personal profile, the sports itineraries followed by the subjects participating in the research, as well as to know the transfer of these learnings to daily life, and to give the broadest vision. possible to the problem posed. The use of questionnaires is the most used measuring instrument in some disciplines such as psychology, but it is also widely used in sports sciences to know the health habits of the athletes in the sample (Barbado and Martínez -Moreno, 2021; Cavas-García et al., 2021; Haro-González et al., 2018).

To prepare the questionnaire, other previous studies have been taken into account that have analysed the personal and professional profile and sporting itineraries of federated competition players in the volleyball modality. For this study, the questionnaire "*Adherence to physical-sports practice, and healthy habits of competitive athletes in the volleyball modality of the province of Jaén*" (CAPDV-1) has been designed. This questionnaire has been developed and validated through the Delphi Technique. Reguant-Álvarez and Torrado-Fonseca (2016) consider that the Delphi Technique "*is an information collection technique that allows obtaining the opinion of a group of experts through of repeated consultation*." The questionnaire has been passed and completed by the athletes participating in the research.

The information has been complemented with qualitative techniques. To this end, two Self-Completed Surveys (one for team captains and another for coaches) have been designed and validated (through the Delphi Technique) to better understand the most important aspects of the problem. The goal of qualitative studies is to provide a deep, interpreted understanding of participants based on context, experiences, and stories (Gephart, 2004; Veal and Darcy, 2014). Some researchers (Skinner et al., 2020; Veal and Darcy, 2014) have developed studies with the objective of creating, adapting and presenting research methods, data collection instruments and data analysis techniques for qualitative research on motivation topics. and adherence to physical-sports practice.

Under the name of paradigm we have encompassed methodologies shared by researchers and educators that adopt a certain conception of the educational process (De Miguel, 1988). Each paradigm is characterized by a common way of research, presenting its advantages and disadvantages and, although they are based on different assumptions, it is possible to combine the contributions from an eclectic perspective (Latorre et. al., 2003). We do not intend to contrast the data that we obtain through one research methodology and another, but rather to combine them in the same research project based on our objectives, both functioning in a complementary way (Caracuel-Cáliz, 2016; Cuesta-Santos, 2013; Martínez-Pérez , 2012; Ortega-Becerra, 2010; Ovalle-Pérez, 2011; Palomares-Cuadros, 2003; Ramírez-Arrabal, 2018; Rodríguez-Bailón, 2012; Soto-González, 2011).

Finally, methodological integration has been carried out through the concept that Denzin and Licoln (2000) call "*triangulation model*" and that Caracuel-Cáliz (2016) has proposed in previous works; Cimarro-Urbano, 2013; Collado-Fernández (2005); Cuesta-Santos (2014); Fuentes-Justicia (2011); Martínez-Pérez (2012); Ortega-Becerra (2010); Ovalle-Pérez (2011); Palomares-Cuadros (2003), Rodríguez-Bailón (2012), Torres-Campos (2008), Vílchez-Barroso (2007), among others, alluding to the possibility of being more sure of the results obtained if we use various data collection techniques. data, as each has its own advantages and biases.

Context

The context in which the research is carried out is the province of Jaén, whose capital is the Spanish municipality of the same name, located in the Autonomous Community of Andalusia. Specifically, the research has been carried out in the Sports Clubs and Entities of the towns of Andújar and Jaén.

Participants

In our research we have used the non-probabilistic sampling method called by Carrasco and Calderero (2000) "*accidental or casual sampling*". The Sample has been extracted from the total population of athletes who meet the inclusion criteria proposed for this research. To determine the size of the population that meets the proposed requirements, we have had the collaboration of the Andalusian Volleyball Federation, as well as the administrative and technical managers of the selected clubs. In total, the population that meets the requirements expressed above is 261 athletes, of which 210 are men and 51 women, aged between 41 and 72 years.

The quantitative sample (questionnaires) is distributed as shown in Tables 1 and 2.

Table 1. Distribution of the sample by age and gender groups.

	Gender/Age									
	Born before 1960		Born between 1960-1966		Born between 1967-1973		Born between 1974-1980		Total	
	N	%	N	%	N	%	N	%	N	%
Women	0	0	0	0	22	34.9	17	43.6	39	19.6
Men	52	100.0	45	100.0	41	65.1	22	56.4	160	80.4
Total	52	100.0	45	100.0	63	100.0	39	100.0	199	100.0

Table 2. Distribution by age, group, gender and totals.

	Women			Men			Total		
	N	M age	D.T.	N	M age	D.T.	N	M age	D.T.
Group 1	-	-	-	52	64.96	2.72	52	64.96	2.72
Group 2	-	-	-	45	58.15	2.02	45	58.15	2.02
Group 3	22	50.54	1.62	41	51.48	1.76	63	51.15	1.74
Group 4	17	43.35	1.76	22	44.27	2.65	39	43.87	2.33
Total	39	47.41	3.97	160	56.75	7.51	199	54.91	7.88

In relation to the type of qualitative sampling, Tójar (2006), following Patton (1990), identifies up to ten different types of sampling. For our research we have used the so-called "*logical criterion sampling*" which is based on including all available cases that meet some criterion of interest for the investigation.

Table 3. Composition of the sample of team captains.

	Age	Experience as captain	Academic degree
Captain 1	G4	3-5	Degree
Captain 2	G3	3-5	Degree
Captain 3	G4	10-15	Undergraduate degree
Captain 4	G3	3-5	Architecture
Captain 5	G2	3-5	Degree
Captain 6	G1	3-5	Undergraduate degree
Captain 7	G1	6-10	Degree
Captain 8	G2	6-10	Degree
Captain 9	G2	3-5	Engineering
Captain 10	G2	10-15	Degree
Captain 11	G2	6-10	Degree
Captain 12	G2	6-10	Undergraduate degree
Captain 13	G2	6-10	Degree
Captain 14	G4	More than 25	Degree
Captain 15	G3	6-10	Undergraduate degree
Captain 16	G3	3-5	Undergraduate degree
Captain 17	G1	3-5	Degree
Captain 18	G3	3-5	Undergraduate degree

Note. G1 = Born before 1960. G2 = Born between 1960-1966. G3 = Born/as between 1967-1973. G4 = Born/as between 1974-1980.

In the first self-completed Survey, 18 team captains (14 men and 4 women) from the clubs specified in the sample participated, with the characteristics described in Table 3. In the second self-completed survey, 21 coaches (4 women and 17 men) from the clubs and teams specified in the sample participated.

Table 4. Composition of the sample of coaches.

	Age	Level	Experience (years)	Maximum Level/Category of competition
Coach 1	65	Level II	25	National First Division
Coach 2	71	Level III	15	Andalusian First Division
Coach 3	70	Level III	24	Honorary Division
Coach 4	52	Level I	6	Provincial category
Coach 5	62	Level III	10	Regional competitions
Coach 6	51	Level II	9	Second National Division
Coach 7	50	Level III	25	Provincial selection
Coach 8	52	Level II	35	Andalusian First Division
Coach 9	69	Level II	8	Second National Division
Coach 10	52	Level I	10	Regional competitions
Coach 11	56	Level III	35	Superleague 2
Coach 12	54	Level II	15	Andalusian First Division
Coach 13	65	Level III	21	National First Division
Coach 14	56	Level III	30	Andalusian First Division
Coach 15	48	Level II	20	Andalusian First Division
Coach 16	58	Level II	10	Andalusian First Division
Coach 17	63	Level III	10	National First Division
Coach 18	67	Level II	3	Provincial category
Coach 19	50	Level I	6	Provincial category
Coach 20	72	Level IV	29	Junior national team
Coach 21	48	Level I	6	Provincial category

Instruments

As we have previously referenced, our methodology integrates two types of techniques, on the one hand, a qualitative technique (Self-completed Survey for team captains and coaches) and a quantitative technique (Questionnaire for the athletes in the sample), to collect information. , with the intention of combining this methodological structure.

Regarding the quantitative technique, we have used a questionnaire (Annex 1) prepared ad-hoc, and validated for this research through the Delphi Technique, to obtain information in different areas: on the one hand we want to know your personal profile, academic, professional and sports; On the other hand, we want to investigate the healthy and unhealthy habits of the research participants, as well as verify their adherence and motivation towards the practice of physical activity.

For the preparation and validation of the questionnaire ("*Adherence to physical-sports practice, and healthy habits of federated competition athletes in the volleyball modality of the province of Jaén*" - CAPDV-1), we have used the Delphi method, which consists of a technique for obtaining information, based on consulting experts in an area, in order to obtain the most reliable consensus opinion of the group consulted. These experts are individually submitted to a series of in-depth questionnaires that are interspersed with feedback on what was expressed by the group and that, based on an open exploration, after successive returns, produce an opinion that represents the group (Reguant-Álvarez and Torrado -Fonseca, 2016).

Once all the modifications to the questionnaire, proposed by the experts participating in the Delphi, have been made, the pilot questionnaire is prepared. The questionnaire is sent to 24 people from different areas of volleyball: athletes, referees, delegates, club and federation directors, and sports managers. 22 people respond in a timely manner, and with the suggestions they propose, the final questionnaire is prepared and sent to the study sample for completion.

For the qualitative technique we have used Self-completed surveys, with which we have sought to know the perceptions of the team captains (Annex 2) and technicians (Annex 3), and to compare, through their information, the opinions expressed by the coaches, as well as their relationship with the athletes' responses in the questionnaires that have been provided.

The self-administered survey is the survey that is carried out using self-administered questionnaires. This modality is called self-administered (self-completed) because, in general terms, it dispenses with the need for interviewers (Rodríguez-Bailón, 2012). Within the type of self-administered survey there are some characteristic subtypes: the mail survey, the mail survey and the hand-delivered survey. In all cases, the person who responds is the one who completes the questionnaire or survey form in accordance with certain instructions that must be extremely clear (Benjumea-Álvarez, 2011). The design and validation of the self-completed Surveys used in our research has been carried out through the Delphi Technique.

With the content of the questionnaire prepared by the experts participating in the Delphi Technique, four captains are sent, one from each age group in the sample, to complete it, requesting the time spent completing it and the difficulties encountered. Participants in the pilot study are instructed to respond below each question, with no length limit. The content of the pilot study is passed to the LimeSurvey computer application.

RESULTS

Following the application of the aforementioned instruments to obtain data, and after analysis, the results yielded interesting data on parameters related to healthy living habits (adequate food and nutrition, quality of sleep, adequate physical-sports activity and frequent, physical condition and health relationship), of federated competition athletes in the volleyball modality of the province of Jaén, once their competitive stage has ended, as a practice of physical sports activity, eating and postural habits, rest, and we present them triangulating the results obtained by the instruments used.

Beginning with the global analysis of healthy living habits, the participants in the research present opinions in which they relate their practice of competitive volleyball during the years they were active, with the healthy habits that they practice in their daily lives. Through self-administered surveys, they highlighted that:

Volleyball has helped me… …create healthy habits.
Player 20 GR 4 (043-044) SHS

To create healthy habits for my daily life.
Player 105 GR 3 (288-289) SHS

Have good health thanks to the habits acquired.
Player 139 GR 3 (393-394) SHS

Internalize physical and sports practice in general life habits.
Player 104 GR 3 (285) SHS

Practicing volleyball has allowed me to acquire healthy habits.
Player 2 GR 1 (005-007) SHS

Like the players participating in this research, the captains and sports technicians surveyed also express the importance that the practice of volleyball has had in incorporating healthy living habits into their daily lives.

Without a doubt none. The influence of volleyball has been totalling on my healthy living habits.
Captain 14 G4 (277-278) HEVS

Yes, of course, it totally influenced my healthy lifestyle habits.
Captain 16 G3 (279-280) HEVS

Of course, it was key in my life, it helped me in everything. To maintain a healthy lifestyle.
Captain 18 G3 (285-286) HEVS

I always tried to maintain a line of healthy lifestyle habits. Staying away from the harmful ones.
Captain 15 G3 (278-279) HEVS

Yeah! It makes you focus on healthy habits and not others.
Captain 1 G4 (257) HEVS

Being a coach and doing so much physical activity has had a very positive influence on my lifestyle habits.
Coach 3 E70 (669-670) SHS

The positive habit routines that were transmitted to the students/players were also internalized and had to be put into practice oneself.
Coach 6 E51 (677-678) SHS

Table 5. Feeding habits.

Age	Born before 1973		Born between 1974-1980		Born before 1960		Born between 1960-1966		Born between 1967-1973		Born between 1974-1980	
	N	%	N	%	N	%	N	%	N	%	N	%
Very bad	1	4.5	0	0	0	0	0	0	0	0	0	0
Bad	2	9.1	2	11.8	5	9.6	7	15.6	4	9.8	3	13.6
Normal	5	22.7	3	17.6	22	42.3	10	22.2	11	26.8	8	36.4
Good	13	59.1	11	64.7	20	38.5	24	53.3	24	58.5	10	45.5
Very good	1	4.5	1	5.9	5	9.6	4	8.9	2	4.9	1	4.5
Total	22	100	17	100	52	100	45	100	41	100	22	100

Gender	Women		Men	
	N	%	N	%
Very bad	1	2.6	0	0
Bad	4	10.3	19	11.9
Normal	8	20.5	51	31.9
Good	24	61.5	78	48.8
Very good	2	5.1	12	7.5
Total	39	100	160	100

On the other hand, when questioning athletes about their eating habits, the majority values correspond to the response option "*good*", both in women (61.5%) and in men (48.8%). The second most chosen option is to consider that their eating habits are "*normal*", 20.5% of women say this and 31.9% of men do so. In this global analysis we highlight that the sum of the values of the "*good*" and "*very good*" options in women reaches a value of 66.6% and in men 56.3%. The data leaves no room for doubt, women consider their eating habits to be healthier than those of men.

In this sense, the participants in the research state that they give great importance to eating habits, nutrition and quality of diet in their daily lives, as expressed by athletes and sports technicians.

To create healthy eating and nutrition habits.
Player 20 GR 4 (045) HEVS

Well, my status as a health professional influenced my lifestyle habits, sports, eating habits, toxins, etc. I am at my weight, I exercise, I eat few processed foods, few trans and saturated fats, few refined sugars, little salt...
Captain 17 G1 (280-284) HEVS

Internalize physical and sports practice with general life habits, especially nutrition.
Player 104 GR 3(294,295) HEVS

Some healthy habits for my daily life, food and diet quality.
Player 105 GR 3 (295) HEVS

Have good health thanks to the eating habits acquired.
Player 139 GR 3 (405) HEVS

In a very positive way, always trying to do frequent physical activity accompanied by a healthy diet.
Coach 10 E52 (688-689) SHSA

In a positive way. I always take care of food, healthy living, etc. it's a lifestyle.
Coach 13 E65 (702-703) SHSA

Table 6. Perception of sleep quality.

Age	**Born before 1973**		**Born between 1974-1980**		**Born before 1960**		**Born between 1960-1966**		**Born between 1967-1973**		**Born between 1974-1980**	
	N	%	N	%	N	%	N	%	N	%	N	%
Very bad	3	13.6	1	5.9	4	7.7	1	2.2	0	0	0	0
Bad	3	13.6	4	23.5	14	26.9	8	17.8	4	9.8	8	36.4
Normal	5	22.7	7	41.2	8	15.4	16	35.6	13	31.7	7	31.8
Good	7	31.8	4	23.5	20	38.5	18	40.0	22	53.7	6	27.3
Very good	4	18.2	1	5.9	6	11.5	2	4.4	2	4.9	1	4.5
Total	22	100	17	100	52	100	45	100	41	100	22	100

Gender	**Women**		**Men**	
	N	%	N	%
Very bad	4	10.3	5	3.1
Bad	7	17.9	34	21.3
Normal	12	30.8	44	27.5
Good	11	28.2	66	41.3
Very Good	5	12.8	11	6.9
Total	39	100	160	100

Regarding the perception of athletes about their quality of sleep, the majority option chosen by men is to consider their sleep quality "*good*" by 41.3%, while in women the majority option is to consider it as "*normal*" (30.8%). The sum of the most "*positive*" options ("*good*" and "*very good*") gives us an overall value of 41% in women and 48.2% in men. The minority values being those that correspond to the "*bad*" option, this is expressed by 10.3% of women and 3.1% of men. In view of the data, at a global level we interpret those men report having better sleep quality than women, and this aspect was always a concern of the coaches.

Regarding the age and gender groups, the majority value is found in the "*good*" option with 53.7%, in Group 3 of men. Secondly, the highest figure appears in the "*normal*" option of women in Group 3, with 41.2%. We highlight in this analysis by gender and age that none of the men in groups 3 and 4 state that their sleep quality is "*bad*".

From the qualitative analysis, the responses highlighted by the interviewees, in relation to the quality of sleep, are:

I worry about my players' rest hours.
Coach 4 E52 (671) SHSD

It has affected me to improve my lifestyle habits, especially the quality of sleep.
Coach 18 E67 (719-720) SHSD

I have always told the players that resting well was as important or more important than working.
Coach 20 E72 (782-783)

Table 7. Current level of physical-sports activity practice

Age	Born before 1973		Born between 1974-1980		Born before 1960		Born between 1960-1966		Born between 1967-1973		Born between 1974-1980	
	N	%	N	%	N	%	N	%	N	%	N	%
Very low	1	5.9	0	0	1	2.6	3	8.6	3	8.6	0	0
Low	3	17.6	3	23.1	7	17.9	10	28.6	7	20.0	2	10.5
Normal	8	47.1	7	53.8	14	35.9	13	37.1	15	42.9	9	47.4
Good	4	23.5	3	23.1	17	43.6	7	20.0	8	22.9	7	36.8
Very good	1	5.9	0	0	0	0	2	5.7	2	5.7	1	5.3
Total	17	100	13	100	39	100	35	100	35	100	19	10

Gender	Women		Men	
	N	%	N	%
Very low	1	3.3	7	5.5
Low	6	20.0	26	20
Normal	15	50.0	51	39.8
Good	4	23.5	39	30.5
Very good	1	3.3	5	3.9
Total	30	100	128	100

Within healthy lifestyle habits, the practice of adequate and frequent physical activity occupies a privileged place, thus the majority responses of the athletes in the sample who state that they currently carry out physical activity (N = 158), which represent 79 .8% of the sample. The highest values are found in the "*normal*" option, 50% of women choose it and 39.8% of men choose it. Secondly, women (23.5%) and men (20.5%) choose the "*good*" option. In the sum of the "*good*" and "*very good*" options, we obtain a value for men of 34.4% and 26.8% for women. These differences by gender are significant in the Chi-square test with a value of $p = .000$. We interpret from the analysis of the data that men report having a higher level of physical-sports activity practice.

Physical-sports practice is included as a healthy lifestyle habit for the majority in the components of our research sample, explained as follows.

It has led me, along with other sports, to the main professional dedication that has occupied my active life.
Player 32 GR 1 (068-069) MOAD

Volleyball, being my first sport, has been something very important since it has given me a habit of practicing physical activity.
Player 70 GR 1 (198-199) MOAD

Practicing sports, an activity that he considered essential in life, to feel good.
Player 80 GR 2 (218-219) MOAD

It has helped me to be more organized and to try to be in good physical condition, practicing every day.
Player 99 GR 3 (280-281) MOAD

Table 8. Current fitness level.

Age	Born before 1973		Born between 1974-1980		Born before 1960		Born between 1960-1966		Born between 1967-1973		Born between 1974-1980	
	N	%	N	%	N	%	N	%	N	%	N	%
No	3	13.6	3	17.6	7	13.5	2	4.4	3	7.3	1	4.5
Yes	19	86.4	14	82.4	45	86.5	43	95.6	38	92.7	21	95.5
Total	22	100	17	100	52	100	45	100	41	100	22	100

Gender	Women		Men	
	N	%	N	%
No	6	15.4	13	8.1
Yes	33	84.6	147	91.9
Total	39	100	160	100

When asking athletes if their current level of physical condition is related to having trained and competed in their youth, the answer is overwhelmingly affirmative. Thus, 84.6% of women and 91.9% of men choose this option. The "*No*" option is only chosen by 15.4% of women and 8.1% of men. In all age groups, we verified how men manifest more highly the relationship between their current level of physical condition, with the training and competition developed in their youth.

Team captains and coaches also express themselves along the lines of considering with respect to physical condition that:

It helped me have a very healthy adolescence and acquire healthy lifestyle habits and improve my level of physical fitness.
Captain 9 G2 (305-306) CFSA

Practicing volleyball has been very important to improve and maintain my level of physical fitness.
Captain 8 G2 (304-305) CFSA

Apart from the injuries I have had, practicing volleyball has given me general well-being and an optimal level of physical condition.
Captain 15 G3 (320-321) CFSA

It helped me a lot as a person, my physical and mental well-being and to maintain a good level of physical fitness.
Captain 16 G3 (322-324) CFSA

I think it has improved and maintained my physical condition.
Captain 4 G3 (298) CFSA

It has kept me in good physical condition.
Captain 2 G3 (294) CFSA

Now I practice other sports, but always seeking to improve health and physical condition.
Captain 5 G2 (297-298) CFSA

DISCUSSION

Eating habits have been defined as "*a line of conduct by which the set of food products present in the diets consumed by a population group are selected, used and consumed*" (Bello-Gutiérrez, 2005). One of the fundamental characteristics of eating habits is their stability, that is, their resistance to change. Most adult eating habits are customs that have been formed many years before, which is why they are difficult to change. It has been shown that, although changes occur in attitudes and intentions, they do not change (Delormier et al., 2009).

The study published in the scientific journal "*Public Health Nutrition*" (2017), coordinated by the Spanish Nutrition Foundation (FEN), tries to identify the best feeding strategies in order to contribute to reducing the prevalence of obesity. According to the results, the eating habits of women were more appropriate than those of men, since they ate a greater number of meals per day, skipped fewer meals, and spent more time on them. For their part, men consumed greater energy intake after 2:00 p.m. and during dinner. According to this study, just over half of the women (54.4%) ate more than four meals a day, while this figure was reduced to 38.8% in men, who more frequently skipped breakfast, mid-morning meal or snack. These results presented are related to the responses reported by the sample of our study, as well as with other scientific research such as that carried out by Çitozi and Bozo (2014) at the University of Tirana, which stated that the eating habits of female students They are healthier than those of the students in terms of daily intake.

Addressing the quality of sleep, the study by Ohayon and Sagales (2010), with the young and adult population in our country, showed that Spaniards sleep the appropriate hours, although due to climatic reasons and hours of light, Spaniards generally go to bed later than the populations of neighbouring countries, such as Portugal or France.

Bayán-Bravo (2017), in his doctoral thesis, proposed as one of his objectives to identify patterns of physical activity, sedentary lifestyle and sleep in older adults in Spain, he found a direct relationship between a greater number of healthy behaviours, (particularly performing more physical activity), being less sedentary and sleeping adequate hours were associated with better health-related quality of life in older adults.

Similar results have been found by Carcelén-González (2017) in his doctoral thesis carried out with the adult and older adult Valencian population. The adults over 60 years of age participating in the study presented a medium level of cognitive functioning, good quality of life, a good emotional state, good quality of sleep and a high level of motivation and enjoyment towards physical activity.

In a study carried out in a primary care centre in Lima (Peru), it was found that 33% had some problem sleeping and only 16% consulted the doctor for this reason (Rey de Castro et. al., 2005). Older adults typically take longer to fall asleep and have more frequent nighttime awakenings. More than 50% of older adults reported at least one chronic sleep complaint and the most common problem was inability to fall asleep (Harrington and Lee-Chion, 2007).

Regarding the values of physical activity practice, the data from our sample are much higher than those found by Corral-Pernía (2015) with the older adult population of the province of Seville, as well as those provided by Rodríguez-Romo et al. (2009) with the adult population of the Community of Madrid, or those in the study by Salgado-Cruz (2017) with the older adult population of Puerto Rico. If we compare the levels of physical activity practice by gender, our study provides data similar to those presented by Caracuel-Cáliz et al. (2020). In this sense, the results of a study carried out in Galicia revealed that age, sex, perceived physical competence and practicing sports with friends had a statistically significant influence on the physical activity index (Alvariñas-Villaverde et al., 2021).

Many health organizations have developed physical activity recommendations. These recommendations vary according to the intensity, frequency and duration of physical activity, depending on the established objective: health promotion, primary or secondary cardiovascular prevention, rehabilitation, weight control, etc. (Department of Health and Human Services, 1995). Statements that coincide with those of Nealen (2016) who points out in her work that all forms of exercise were associated with cardiovascular health, and cardiovascular benefits accrued depending on the amount of exercise performed, even in optimally young adults. healthy.

In the Guide of recommendations for the promotion of physical activity, published by the Health Department of the Government of Andalusia (2010), it is stated that active people are those who carry out more than 150 minutes of moderate physical activity per week. These people who already meet the minimum physical activity recommendations can achieve additional health benefits by doing 300 minutes of moderate aerobic activity per week or 150 minutes of vigorous aerobic activity and increasing muscle toning work to at least 3 days per week.

Estevez-López et. to the. (2012) state that there is a consensus regarding the type, frequency, duration and intensity of physical activity that these people should perform to reduce the risk of suffering from various diseases. It is established that they must perform cardiorespiratory physical activity of moderate intensity 150 min/week with a frequency of 5 days/week, or in the case of vigorous intensity 60 min/week with a frequency of 3 days/week.

Scientific studies (Aadahl et al., 2007; Estévez et al., 2012; Donnelly et al., 2009) do not provide any threshold duration limit beyond which additional benefits are not obtained, in fact, although the benefits obtained with practice of different durations are coincident, those obtained through longer duration of practice are more powerful. Thus, we state that the levels of participation of the athletes in our study are well above the research consulted, as we present below, some of the most relevant.

In the study by Meseguer et. to the. (2009) with the adult population of the Community of Madrid, it is concluded that around 3/4 of the people participating in the research do not comply with the recommendations. Men are more active in free time than women, both due to compliance with recommendations and consumption of MET-h/total weeks. These results agree with those of studies from other places (Bernstein et al., 1999; Martínez-González et al., 2001; Pitsavos et al, 2005). Furthermore, the differences between men and women are accentuated the greater the intensity of the physical activity performed, and is maximum for vigorous activities, in which men double the values observed in women (Martínez-Ros et al, 2003: Schroder et al, 2004).

In the 2020 Sports Habits of Spaniards Survey published by the Higher Sports Council, it shows that the increase in sports practice in the population over 65 years of age has been much greater in this population than in young people between 15 and 24. years, Spain continues to be behind the reference European countries, where the percentage of practice in this age group exceeds 60% percent.

In the international context, we also find research that investigates the recommendations of international organizations on the characteristics of healthy physical activity. The research of Arango-Vélez et. to the. (2014) carried out in the environment of the University of Antioquía (Colombia), with a sample of 176 users of a physical activity program, mostly women (69.3%); The average age was 55.7 years, the main finding of this study was that the variables that were independently associated with adherence to physical activity recommendations in this study was 63.1%, which exceeds the proportions reported in other local and national populations.

In another sense, it stands out that the physical condition related to health is focused on the well-being of the subject itself, seeks to improve the quality of life and mainly, to enhance the qualities that make it up. Through this, the risk of contracting diseases is reduced. Over the course of age, there is a decrease in physical condition, especially at advanced ages (Milanović et al., 2013), mainly due to the decline in physical activity levels, which generates a decrease in aerobic resistance, flexibility, loss of strength, speed, agility and balance (Donald et al, 2010; Paterson and Warburton, 2010).

Physical exercise has turned out to be a key element as a determinant of a healthy lifestyle, since there are numerous research works, both quantitative and qualitative, that conclude that physical exercise performed badly is a healthy behaviour that substantially improves the quality of life in the population (Batista et. al., 2019; Bonet-López, 2007; Riebe et al., 2015; Sanduvete-Chaves, 2004). However, despite the benefits of physical exercise, it is estimated that 60% of the world's population is not active enough to reap health benefits (Batista et al., 2021).

Different investigations (Baeza, et al., 2009; Chen and Lee, 2013; Liu and Latham, 2009; Pérez-Samaniego and Devís-Devís, 2003; Santos et al., 2012) confirm that physical exercise performed badly is the best way to promote the health of older people, highlighting its positive impact on human beings.

CONCLUSION

The different groups of participants in the research state that they attach great importance to eating habits, nutrition, and diet quality in their daily lives. Sports technicians show great concern to convey the importance of maintaining adequate eating and nutrition habits in their athletes.

Regarding sleep quality, the sum of the options in view of the data, at a global level we interpret those men report having better sleep quality than women, and this aspect was always a concern of the coaches.

Regarding healthy lifestyle habits, the majority of people in the sample indicate that they practice physical activity today. We can also conclude that men report having a higher level of physical-sports activity practice.

The majority of women and men consider that their good physical condition has its origins in the stage in which they were competitive athletes, being the parameters in the male case.

In short, physical-sports practice as a healthy living habit is found as a healthy living habit mostly in the athletes and sports technicians participating in this research.

AUTHOR CONTRIBUTIONS

This article is the result of the collaborative work of six authors, each of whom contributed significantly to its realisation:

1. Juan Torres Guerrero: As lead author, he led the study design, data collection and analysis, as well as the writing of the manuscript. His experience was fundamental in establishing the appropriate methodology and providing an in-depth understanding of the subject.

2. Rafael Francisco Caracuel Cáliz: He played a crucial role in the comprehensive review of the relevant literature, providing a solid basis for the theoretical framework of the article. His expertise enriched the discussion and interpretation of the results. He was also responsible for the submission of the manuscript and the handling of correspondence.

3. Diego Collado Fernández: With his experience he contributed significantly to the formulation of hypotheses and experimental design. In addition, his critical analysis of the results improved the quality and validity of the study.

4. Beatriz Torres Campos: She contributed her expertise to develop and implement advanced analytical tools and techniques. Her contribution was fundamental for the detailed interpretation of the data and the generation of solid conclusions.

5. Juan Antonio Párraga Montilla: As an expert, he provided guidance and advice throughout the process, helping to ensure the methodological coherence and practical relevance of the study. His critical perspective enriched the discussions and conclusions of the article.

6. Mar Cepero González: Contributed her expertise to the statistical analysis and interpretation of the results. Her ability to identify significant patterns and emerging trends strengthened the validity of the findings and provided important insights for future research.

In summary, the collaboration among these six authors allowed for a comprehensive and rigorous article that makes a significant contribution to the field of study. Each brought unique expertise and specialised skills, enriching the collective work and its potential impact on the academic and professional community.

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REFERENCES

Aadahl, M., Kjaer, M. & Jorgensen, T. (2007). Associations between overall physical activity level and cardiovascular risk factors in an adult population. European Journal of Epidemiology, 22(6), 369-378. https://doi.org/10.1007/s10654-006-9100-3

Alvariñas-Villaverde, M., Giménez-de Ory, E., Toja-Reboredo, B., & González-Valeiro, M. (2021). Sport practice with friends and perceived physical competence as predictors of physical activity in adolescents. Journal of Human Sport and Exercise. https://doi.org/10.14198/jhse.2023.181.05

Amador-Muñoz, L. y Esteban-Ibáñez, M. (2015). Calidad de vida y formación en hábitos saludables en la alimentación de personas mayores. Revista de Humanidades, 25, 145-168. https://doi.org/10.5944/rdh.25.2015.14374

Arango-Vélez, E. F., Patiño-Villada., F. A. y Díaz-Cardona, G. (2014). Factores asociados con la adherencia a la actividad física en el tiempo libre. Revista Educación Física y Deporte, 33(1),129-151. https://doi.org/10.17533/udea.efyd.v33n1a08

Ato, M., López, J. J. & Benavente, A. (2013). A classification system for research designs in psychology. Anales de Psicología, 29(3), 1038-1059. https://doi.org/10.6018/analesps.29.3.178511

Baeza, A. C., García-Molina, V. A. y Fernández, M. D. (2009). Involución de la con dición física por el envejecimiento. Apunts, Medicina de l'Esport, 44(162), 98-103. https://doi.org/10.1016/S1886-6581(09)70115-X

Barbado, C. y Martínez-Moreno, A. (2021). Trabajadores de centros deportivos fitness percepción de liderazgo, engagement y estrés. Revista Internacional de Medicina y Ciencias de la Actividad Física el Deporte, 22(85), 1-17. https://doi.org/10.15366/rimcafd2022.85.001

Barbosa-Granados, H. y Urrea-Cuéllar, A. M. (2018). Influencia del deporte y la actividad física en el estado de salud físico y mental: una revisión bibliográfica. Revista Katharsis, 25, 141-159.

Batista, M., Folgado dos Santos, J. M., Honório, S., Rocha, J., Serrano, J. & Petrica, J. M. (2021). Lifestyles and satisfaction with life of veteran athletes a prospective test based on the theory of self-determination. Retos. Nuevas tendencias en Educación Física, Deporte y Recreación, 39, 998-1000.

Batista, M., Leyton, M., Lobato, S. & Jiménez, R. (2019). Transcontextual Model of Motivation in the Preaching of Healthy Lifestyles. Revista Internacional de Medicina y Ciencias de la Actividad Física y el Deporte, 19(75), 463-488. https://doi.org/10.15366/rimcafd2019.75.006

Bayán-Bravo, A. (2017). Patrones de actividad física, estilos de vida saludable, calidad de vida y mortalidad en la población española. Tesis Doctoral. Universidad Autónoma de Madrid.

Bello-Gutiérrez, J. (2005). Calidad de vida, alimentos y salud humana. Fundamentos científicos. Madrid: Editorial Díaz de Santos, S.A.

Benjumea, M. A. (2011). Motivación del alumnado de segundo ciclo de Educación Secundaria de la comarca de la Vega Alta de Granada, en Educación Física escolar y en las actividades físico-deportivas extraescolares. Tesis Doctoral. Universidad de Granada.

Bernstein, M. S., Morabia, A. & Sloutskis, D. (1999). Definition and prevalence of sedentarism in an urban population, American Journal of Public Health, 89(6), 862-867. https://doi.org/10.2105/AJPH.89.6.862
Bonete-López, B. (2007). La aplicación de teoría de la conducta planeada en el ejercicio físico con personas mayores. Revista de Psicología de la Salud, 19(1), 5-23. https://doi.org/10.21134/pssa.v19i1.961
Caracuel-Cáliz, R. F. (2016). Influencia de la educación física en los hábitos saludables del alumnado de primer ciclo de educación secundaria en centros de las comarcas del sur de Córdoba. Tesis Doctoral. Universidad de Granada.
Caracuel-Cáliz, R., Padial, R., Torres, B., & Cepero, M. (2020). The influence of healthy habits acquired by school-age adolescents in relation to physical education classes. Journal of Human Sport and Exercise, 15(4proc), S992-S1012. https://doi.org/10.14198/jhse.2020.15.Proc4.02
Carcelén-González, R. (2017). Influencia de un programa de ejercicio físico de fuerza sobre la función ejecutiva, calidad de vida y estado de ánimo de los adultos mayores. Tesis Doctoral. Universidad CEU Cardenal Herrera de Valencia.
Carrasco, J. y Calderero, J. (2000). Aprendo a investigar en educación. Madrid: Rialp.
Cavas-García, F., Segarra-Vicens, E. y Díaz-Suarez, A. (2021). El gestor Deportivo en los equipamientos de golf en la Región de Murcia. Journal of Sport and Health Research, 13(3), 515-524.
Chen, J. & Lee, Y. (2013). Physical activity for health: evidence, theory, and practice. Journal of preventive medicine and public health = Yebang Uihakhoe chi, 46(Suppl 1), 1-2. https://doi.org/10.3961/jpmph.2013.46.S.S1
Cimarro-Urbano, J. (2014). Adquisición y mantenimiento de hábitos de vida saludables en los escolares del tercer ciclo de Educación Primaria en centros de las comarcas del Sur de Córdoba, y la influencia de la Educación Física sobre ellos. Tesis Doctoral. Universidad de Granada.
Çitozi, R., & Bozo, D. (2014). Habits in healthy nutrition, obesity, alcohol, smoking, among students of the Faculty of Physical Activity and Recreation. Journal of Human Sport and Exercise. 2014, 9(Proc1): S291-S299. https://doi.org/10.14198/jhse.2014.9.Proc1.12
Collado-Fernández, D. (2005). Transmisión y adquisición de valores a través de un programa de Educación Física basado en el juego motor, en un grupo de alumnos y alumnas de Primero de la ESO. Tesis Doctoral. Universidad de Granada.
Corral-Pernía, J. A. (2015). Actividad física, estilos de vida y adherencia de la práctica de actividad física de la población adulta de Sevilla. Tesis Doctoral. Universidad de Sevilla.
Cuesta-Santos, J. M. (2013). Relación entre la insatisfacción con la imagen corporal, la autoestima, el autoconcepto físico y la composición corporal, en el alumnado de tercer ciclo de Educación Primaria de la ciudad de Motril. Tesis Doctoral. Universidad de Granada.
De Miguel, M. (1988). Paradigmas de Investigación Educativa. Madrid: Narcea.
Delormier, T., Frohlich, K. L. y Potvin, L. (2009). Food and eating as social practice - understanding eating patterns as social phenomena and implications for public health. Sociology of Health and Illness, 31 (2). https://doi.org/10.1111/j.1467-9566.2008.01128.x
Denzin, N. K. y Licoln, Y. (2000). Handbook of Qualitative reserchs. Londres: Sage.
Donald, H., Paterson, D. H. & Warburton, D. E. (2010). Review Physical activity and functional limitations in older adults: a systematic review related to Canada's Physical Activity Guidelines. International Journal of Behavioral Nutrition and Physical Activity, 7(38), 1-22. https://doi.org/10.1186/1479-5868-7-38
Donnelly, J. E., Blair, S. N., Jakicic, J. M., Manor, M. M., Rankin, J. W. y Smith, B. K. (2009). Appropriate physical activity intervention strategies for weight loss and prevention of weight regain for adults.

Medicine and Science in Sports and Exercise, 41(2), 459-471. https://doi.org/10.1249/MSS.0b013e3181949333

Estévez-López, F., Tercedor, P. & Delgado-Fernández, M. (2012). Recomendaciones de actividad física para adultos sanos. Journal of Sport and Health Research, 4(3), 233-244.

Fuentes-Justicia, E. (2011). Adquisición y mantenimiento de hábitos de vida saludables en los escolares de primer ciclo de Educación Secundaria Obligatoria de Jerez de la Frontera (Cádiz). Tesis Doctoral. Universidad de Granada.

Gephart, R. P. (2004). Qualitative research and the Academy of Management Journal. Academy of Management, 47(4), 454-462. https://doi.org/10.5465/amj.2004.14438580

Haro-González, M., Pérez-Ordás, R., Grao-Cruces, A., Nuviala, R. & Nuviala, A. (2018). Female users of unisex fitness centres and of fitness centres exclusive for women: satisfaction. International Journal of Sports Marketing and Sponsorship, 19(4), 384-395. https://doi.org/10.1108/IJSMS-08-2016-0044

Harrington, J. & Lee-Chion, T. (2007). Sleep and older patients. Clinics in Chest Medicine, 28(4): 673-84. https://doi.org/10.1016/j.ccm.2007.07.002

Ibarra-Mora, J., Ventura-Vall-Llovera, C. y Hernández-Mosqueira, C. (2019). Hábitos de vida saludable de actividad física, alimentación, sueño y consumo de tabaco y alcohol, en estudiantes adolescentes chilenos. Sportis Scientific Technical Journal, 5(1), 70-84. https://doi.org/10.17979/sportis

Latorre, A., Del Rincón-Igea, D. y Arnal, J. (1996; 2003). Bases metodológicas de la investigación educativa. Barcelona: Hurtado Ediciones.

Liu, C. J. & Latham, N. K. (2009). Progressive Resistance Strength Training for Improving Physical Function in Older Adults. The Cochrane Database of Systematic Reviews, 3(1), 2759-2765. https://doi.org/10.1002/14651858.CD002759.pub2

López-Villar, C. (2011). Una propuesta para la coeducación desde el deporte y la danza. Tándem: Didáctica de la Educación Física, 37(1), 78-91.

Martinez-González, M. A., Varo, J. J., Santos, J. L., De, I. J., Gibney, M., Kearney, J. et al. (2001). Prevalence of physical activity during leisure time in the European Union. Medicine & Science in Sports & Exercise, 33(7), 1142-1146. https://doi.org/10.1097/00005768-200107000-00011

Martínez-Pérez, R. (2012). Transmisión y adquisición de valores y actitudes a través del Bloque de Contenidos de Juegos y Deportes en el alumnado de Segundo Ciclo de Educación Secundaria de la Comarca de Estepa (Sevilla). Tesis doctoral. Universidad de Granada.

Martínez-Ros, M. T., Tormo, M. J., Pérez-Flores, D. y Navarro C. (2003). Actividad física deportiva en una muestra representativa de la población de la Región de Murcia. Gaceta Sanitaria, 17(1), 11-9. https://doi.org/10.1016/S0213-9111(03)71686-0

Meseguer, C. M., Galán, I., Herruzo, R., Zorrilla, B. y Rodríguez-Artalejo, F. (2009). Actividad física de tiempo libre en un país mediterráneo del sur de Europa: adherencia a las recomendaciones y factores asociados. Revista Española de Cardiología, 62(10), 1125-1133. https://doi.org/10.1016/S0300-8932(09)72381-4

Milanović, Z., Pantelić, S., Trajković, N., Sporiš, G., Kostić, R. & James, N. (2013). Age-related decrease in physical activity and functional fitness among elderly men and women. Clinical interventions in aging, 8(1), 549-556. https://doi.org/10.2147/CIA.S44112

Ministerio de Cultura y Deporte (2021). Encuesta de Hábitos Deportivos de los Españoles del 2020. Secretaría General Técnica. Documentación y Publicaciones.

Moscoso-Sánchez, D., Moyano-Estrada, E., Biedma, L., Fernández-Ballesteros, R., Martín, M., Ramos, C., Rodríguez-Morcillo, L. y Serrano, R. (2009). Deporte, salud y calidad de vida. Colección de Estudios Sociales 26. Barcelona: Fundación Obra Social de La Caixa.

Nealen, P. M. (2016). Exercise and lifestyle predictors of resting heart rate in healthy young adults. Journal of Human Sport and Exercise, 11(3), 348-357. https://doi.org/10.14198/jhse.2016.113.02

Ohayon, M. M. y Sagales, T. (2010). Prevalence of insomnia and sleep characteristics in the general population of Spain. Sleep medicine, 11(10), 1010-1018. https://doi.org/10.1016/j.sleep.2010.02.018

Organización Mundial de la Salud (2010). Recomendaciones mundiales sobre actividad física para la salud. Ginebra (Suiza).

Ortega-Becerra, M. A. (2010). Relación entre la insatisfacción con la imagen corporal, autoestima, autoconcepto físico y la composición corporal en el alumnado de primer ciclo de Educación Secundaria de la Ciudad de Jaén. Tesis Doctoral. Universidad de Granada.

Ovalle-Pérez, J. (2011). Tratamiento del tema transversal de Educación Ambiental en el alumnado de tercer ciclo de Educación Primaria, de la comarca del Altiplano (Huéscar). Tesis Doctoral. Universidad de Granada.

Palomares-Cuadros, J. (2003). Motivaciones, hábitos físico-deportivos y usos de los espacios del Parque Periurbano Dehesas del Generalife. Granada: Reprodigital.

Paterson, D. H. & Warburton, D. E. (2010). Physical activity and functional limitations in older adults: a systematic review related to Canada's Physical Activity Guidelines. The international journal of behavioral nutrition and physical activity, 7(1), 1-22. https://doi.org/10.1186/1479-5868-7-38

Patton, M. Q. (1990). Qualitative evaluation and research methods. SAGE Publications, inc.

Pérez-Samaniego, V. M. y Devis-Devis, J. (2003). La promoción de la actividad física relacionada con la salud. La perspectiva de proceso y de resultado. Revista Internacional de Medicina y Ciencias de la Actividad Física y el Deporte, 3(10), 69-74.

Pitsavos, C., Panagiotakos, D. B., Lentzas, Y. & Stefanadis, C. (2005). Epidemiology of leisure-time physical activity in sociodemographic, lifestyle and psychological characteristics of men and women in Greece: the ATTICA Study. BMC Public Health, 5(1), 1-9. https://doi.org/10.1186/1471-2458-5-37

Portela-Pino, I., Baamonde-Paz, M.L., & Pino-Juste, M. (2022). Prevalence of the level of physical activity and adherence to the Mediterranean diet in children with special education needs. Journal of Human Sport and Exercise, 17(1), 197-210. https://doi.org/10.14198/jhse.2022.171.18

Ramírez-Arrabal, V. (2018). Diseño e implementación de un programa de actividad física basado en la metodología ABP y su influencia en las competencias y valores del alumnado de sexto de primaria. Tesis Doctoral. Universidad de Málaga.

Reguant-Álvarez, M. y Torrado-Fonseca, M. (2016). El Método Delphi. REIRE: Revista d'innovació i recerca en educació, 9(1), 87-102.

Rey de Castro, J., Álvarez, J. y Gaffo, A. (2005). Síntomas relacionados a trastornos del sueño en supuestos sanos que asisten a un centro de atención primaria de salud. Revista de Medicina Herediana, 16(1), 31-8. https://doi.org/10.20453/rmh.v16i1.861

Riebe, D., Franklin, B. A., Thompson, P. D., Garber, C. E., Whitfield, G. P., Magal, M. & Pescatello, L. S. (2015). Updating ACSM's recommendations for exercise preparticipation health screening. Medicine and Science in Sports and Exercise, 47(11), 2473-2479. https://doi.org/10.1249/MSS.0000000000000664

Rodríguez-Bailón, J. D. (2012). La materia de música en primer ciclo de ESO en Antequera y su comarca: fundamentos, motivación y proyección social. Tesis Doctoral. Universidad de Granada.

Rodríguez-Romo,.G., Boned-Pascual, C. y Garrido-Muñoz, M. (2009). Motivos y barreras para hacer ejercicio y practicar deportes en Madrid. Revista Panamericana de Salud Pública, 26(3), 244-54. https://doi.org/10.1590/S1020-49892009000900009

Romero-Granados, S., Chacón, F. y Campos, M. C. (2006). Estudio de hábitos de práctica de actividad físico-deportiva de la población adulta de Sevilla. Indicadores de salud. Sevilla: Universidad de Sevilla. (Proyecto financiado por Convocatoria M.E.C. I+D).

Salgado-Cruz, O. (2017). Factores de motivación de los adultos mayores que promueven la participación en un programa de actividad física. Tesis Doctoral. Universidad Internacional de Catalunya.

Sanabria, G. (2007). El debate en torno a la Promoción de Salud y la Educación para la Salud. Revista Cubana de Salud Pública, 33(2), 1-7. https://doi.org/10.1590/S0864-34662007000200004

Sánchez-Barrera, M., Pérez, M. y Godoy, J. (1995). Patrones de actividad física de una muestra española. Revista de Psicología del Deporte, 4(2), 51-71.

Sanduvete-Chaves, S. (2004). Calidad de vida en las personas mayores. Apuntes de Psicología, 22(2), 277-288.

Santos, D. A., Silva, A. M., Baptista, F., Santos, R., Vale, S., Mota, J. & Sardinha, L. B. (2012). Sedentary behavior and physical activity are independently related to functional fitness in older adults. Experimental gerontology, 47(12), 908-912. https://doi.org/10.1016/j.exger.2012.07.011

Schroder, H., Marrugat, J., Covas, M., Elosua, R., Pena, A., Weinbrenner, T., et al. (2204). Population dietary habits and physical activity modification with age. European Journal of Clinical Nutrition, 58(2), 302-311. https://doi.org/10.1038/sj.ejcn.1601782

Skinner, J., Edwards, A. & Smith, A. C. T. (2020). Qualitative research in sport management (2nd ed.). London: Routledge. https://doi.org/10.4324/9780367854249

Soto-González, J. I. (2011). Conocimientos y creencias sobre la formación en valores y técnicas de intervención del alumnado de magisterio de Granada. Tesis Doctoral. Universidad de Granada.

Tójar, J. C. (2006). Investigación cualitativa: comprender y actuar. Madrid: La Muralla.

Torres-Campos, J. A. (2008). Efectos de un programa basado en el juego y el juguete como mediadores lúdicos en la transmisión y adquisición de valores y actitudes en el alumnado de 5 años. Tesis Doctoral. Universidad de Granada.

Veal, A. J. & Darcy, S. (2014). Research methods in sport studies and sport management: a practical guide. London: Routledge. https://doi.org/10.4324/9781315776668

Vílchez-Barroso, G. (2007). Adquisición y mantenimiento de hábitos de vida saludable en los escolares de Tercer Ciclo de Educación Primaria de la comarca granadina de los Montes Orientales y la influencia de la Educación Física sobre ellos. Tesis Doctoral. Universidad de Granada.

ORIGINAL ARTICLE

Technological advances in artistic gymnastics and the impact on its development

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ABSTRACT

This paper looks at the history of technology development in Artistic Gymnastics (AG) by reviewing patent registrations, test procedures for the AG competition equipment by the official control laboratory of the International Federation of Gymnastics (FIG), and major apparatus advances by manufacturers. Equipment became lighter and more resistant with synthetic materials, with a clear tendency to increase elastic (repulsive) capacity. It is noteworthy that the testing laboratory becomes an arbiter for the industry and the FIG when the technological developments and equipment of manufacturers are evaluated for official use. Only 23 companies have equipment approved by the FIG, 12 of them manufacturing AG apparatuses. Suppliers are located in nine different countries (2 in Asia; 4 in Europe; 2 in America; 1 in Oceania). There is still an unequal distribution of access to technologies, which are concentrated in the northern hemisphere. More access to the actual technology is clearly required when we consider that 156 national member federations are affiliated with the FIG as of this writing.
Keywords: Sport history, Sport industry, Sport technology, Patents, Artistic gymnastics.

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INTRODUCTION. THE TECHNOLOGY REVOLUTION ON SPORTS

Technology development has been generating a profound impact on modern society (Jerónimo et al., 2013), including sports (Ullman, 1977). Historical studies investigate how this technological revolution has evolved to the present times (Gross & Roeder, 2022; Vigarello, 1988).

This tendency can be clearly noticed in the specific case of the Artistic Gymnastics (AG) coordinated by the International Gymnastics Federation (FIG) in partnership with a limited number of manufacturers and developers. This process has been guided by the goal of increasing the safety of gymnasts through improved quality, durability and the use of new materials and designs for competitive equipment.

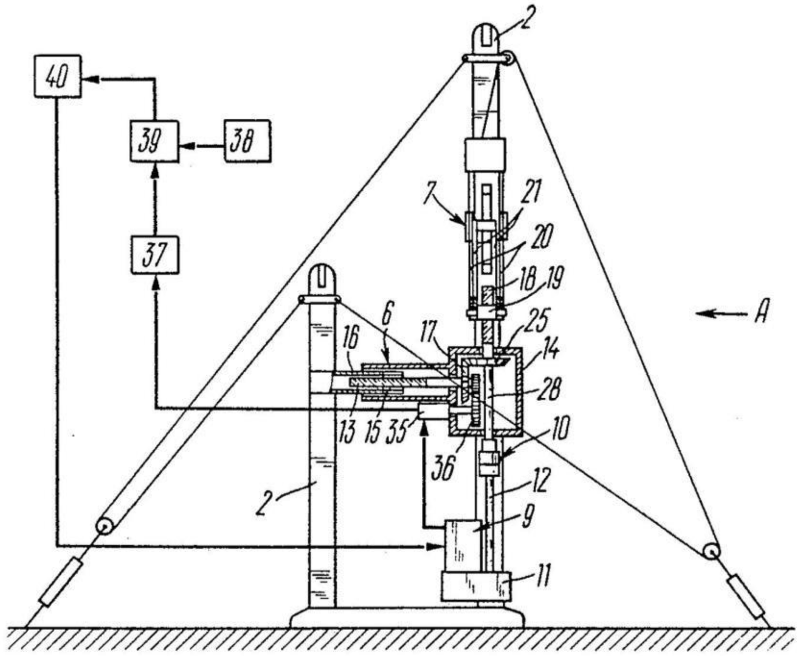
Our study analyses three different categories of source material: 1) apparatus patent registration; 2) the standardisation of test procedures by two official control laboratories of the FIG (GYMLAB in Freiburg and Tokyo Institute of Technology); 3) major apparatus advances from manufacturers that have obtained FIG's certification. A longitudinal study of technical information documented in the AG apparatuses registered Patents was combined with a review of the process of standardized test procedures for the competition equipment in gymnastics, including an analysis of the constitution of the official testing institute GYMLAB for the FIG in the second half of the 20th century as a moderating system for technological development (Fouché, 2017). Some of the main technological advances certified and later officially adopted by the FIG, including the Vaulting Table (VT), the floor exercise system (FX) and the horizontal bar (HB), are studied in more detail as examples of this development. Finally, we examine decades of the official FIG Bulletins to systematize the manufacturers received apparatus approval in order to become potential suppliers for official events observing geographical distribution.

HISTORICAL ANALYSIS OF ARTISTIC GYMNASTICS APPARATUS REGISTERED PATENTS

Technology has become a prominent symbolic, political and economic capital for modern sport, becoming a central aspect of this phenomenon (Bourdieu & Wacquant, 1992). As a catalyst for the sportification process, aspects such as the standardization and certification of equipment and measuring devices used in sports have been consolidated, with particular attention to the high-performance competition context (Fouché, 2017).

The registration of technological advances since the 19th century, through property protection (patents), has become a fundamental device for sports development (Barnett, 2021). Increasingly, patent registration (Figure 1), as part of the process of protecting and dominating the market, was incorporated into sport, becoming an important source for sport history study (Kukkonen, 1998).

Technology development has accompanied the sport throughout modernity, being an important element since the 19th century gymnastics manuals, such as those written by Francisco Amóros y Ondeano (Vázquez, 2006) and even more so as competitive practice expanded in the twentieth century, as seen in the historical records of FIG (Fédération Internationale de Gymnastique (FIG), 2006b, 2006a). This impact of technology on AG was amplified from the second half of the 20th century onwards (Bortoleto, 2018). It is worth noting that this process required the testing, regulation and subsequent certification by FIG for all apparatus, in conformity with the Apparatus Norms (Fédération Internationale de Gymnastique (FIG), 2022a). This process takes many years from the development of the technology to its use in official events.



Source : https://patents.google.com/patent/US4491314. (Retrieved on May 01, 2024).

Figure 1. Uneven Bars. Belyavsky et al. Patent: Jan. 13, 1982 U.S.S.R. 3392651; Jan. 1, 1985 US 4,491,314.

During more than a decade we have investigated hundreds of patents for AG devices, among which we have selected some examples (Table 1), through which we try to analyse the logic of technological development. Other dozens of patents on auxiliary training devices were located (A63B69/0064; US20170296856A1; US20060234833A1, CN204798693U; among others) (Cambia, [s.d.]), however, they were not analysed for the purpose of this article.

Table 1. AG apparatus registered patents*

Title	Patent	Date
Vaulting horse or buck for gymnasiums – Frederick Medart	US 243456A	1881
Portable gymnastic apparatus - Edwin F. Shaw	US 425636A	1890-1907
Vaulting horse – Robert Reach	US 438640A	1890
Gymnastic apparatus - Ira R. Nelson, Frederick W. Lambie	US1503550A	1921
Parallel bar gymnastic apparatus - Nissen Corporation	US 3232609 A	1962
Jumper's landing pit - Jerry W. Sconce	US 3369808 A	1965-67
Roll-fold floor mat for gymnastic and athletic purposes	US 3636576	1972
Resilient floor, especially for gymnasiums	US 3828503 A	1973
Movable support structure for rings gymnastic exercises - Richard Reuther	DE 2330184A1	1973-75
Balance beam with a resilient coating - Richard Reuther	US 3990697A	1975-76
Arrangement for Floor Gymnastics/Floor Panel System	US 4135755	1977
Spring element for gymnastic springboard - Richard Reuther - Spieth Verwaltung	DE 2839477 A1	1978-80
Gymnasium apparatus Uneven Bar supporting - Parry Charles G. & Sherwood David L.	US 4334675A	1979-82
Tumbling floor - John K. Geist - Nissen Corporation	US 4316297 A	1980-82

Springboard Reuther System - Richard Reuther. Tremplin de gymnastique - Sprungbrett zum Turnen.	EP 0086274B1 - DE 2234640 DE A-2329038 DE B-2725401 DE 3203172	1982-84
Suspended uneven parallel bars for competitive women's gymnastics - Frederick H. Lohman	US 4402501 A	1981-93
Vaulting apparatus, especially vaulting horse - Schmalkalden Sport Veb	DE 3426112 A1	1983-85
Gymnastic floor structure having vertical elasticity	US 4648592	1985
Springboard for gymnastics - Otto Benz & Benz Turngeraete	DE 3602784 A1	1985-87
Shock absorbing mounting arrangement for gymnastic rings - Gerald E. Linden	US 4738444 A	1986
Gymnastics bar and method of making the same. - Nichols-Ketchum, M. - American Sports International, Ltd.	US 6475118	1988
Gallows for sport gymnastics with rigid ring suspension - Gérard Barbifieri Henri Miceli - Gymnova	EP 0504235B1 – FR 8916756A – WO 91/08800	1989-91
Gymnastics floor	JP 2535234Y2	1989
Portique de gymnastique sportive a suspension d'anneaux rigides - Gérard Barbifieri & Henri Miceli - Gymnova	FR 8916756A – FR 655551B1	1989-91
Springboard System - Gérard Barbifieri & Henri Miceli - Gymnova	EP 0 572 518 B1 - FR 9102434 – 1991 – WO 1992014516A1	1992-93
Ring frame for hanging the rings for gymnastic exercises - Rolf Daehne - Reuther Turn Und Sportgeraete	DE 4217197C2	1992-94
Parallel bars - Ted Winkel	US 5720697 A	1994
Gymnastic balance beam with articulated beam portions - Gerald J. Lahmann	US 5616102 A	1995-96
Gymnastic apparatus for performing vaulting exercises - Helmut Hödlmoser - Spieth Gymnastic GmbH	EP 0885634A2	1997
Gymnastics springboard with adjustable elasticity designed for training and competition - Gymnova	DE 2103315 A1	2003
Gymnastics springboard - Tremplin de gymnastique réglable en élasticité destiné à l'entraînement et à la competition - Gymnova	EP 1314454 A1 - FR 0115404	2003
Gymnastics floor - Janssen and Fritsen Holding BV - Jacques Marinus Janssen	NL 1026548 A - EP1611930A1	2004-06
Gymnastic equipment - balance beam - Benz Turngeraete - Gotthilf Benz Turngeratefabrik & Co KG GmbH	DE 202005014583U1	2005
Gymnastic floor structure	US 7849646 B2	2007
Air-cushion floor	CN 201099969 Y	2007
Gymnastics springboard with adjustable elasticity designed for training and competition - Gymnova	US 7175567 B2	2007
Flexible mat with multiple foam layers	US 20130017372 A	2011
Pommel horse training device for group gymnastics	CN 213724601U	2020-21
Gallows for sport gymnastics with rigid ring suspension	RU 2021128666U	2021

**EP – European patent; DE – German patent; RU – Russian patent; CN – China patent; US United States of America patent; NL – Nederland patent; FR – France patent; JP – Japan patent; WO – World Intellectual Property Organization.*

It is possible to say that the engineering of gymnastic equipment was, initially, based on the use of natural materials, such as wood and leather, combined with metallic alloys, such as iron. In the second half of the 20th century, new compounds, such as stainless steel, aluminium, fibreglass and other synthetic materials such as Fibre-Reinforced Polypropylene (FRPP), fibre leather and carbon fibre, began to be used in the construction of equipment, such as we see in the Uneven Bars' (UB) technical description of a recent model from the GYMNOVA brand (Ref. 3265) (Gymnova, 2014):

> *Round fibreglass handrail covered with natural fibre.*
> *This material, which is more malleable than wood, allows for a more homogeneous coating, which increases the hand-rails lifespan.*
> *The texture provides an efficient grip with less time required to prepare the bar, as these handrails need much less chalk during use.*
> *The handrails show no wear even after several routines and therefore provide better protection for the gymnasts hands, thus enabling high quality routines. They can be safely cleaned with water.*

This trend is corroborated by the recent study of the development of HB (Kaimakamis et al., 2018), as well as by the analysis of the evolution of the Ring Frame for men's AG (US425636A 1980; DE2330184A1– 1973; RU2021128666U – 2021). The emergence of the logic of efficiency is remarkable, a feature pointed out by Jacques Ellul (Jerónimo et al., 2013) and which gives a meaning beyond the technical-practical functionality of the apparatus (Slater & Barry, 2005).

Most patents aim to "*optimize the gymnast's performance*" (Middelkoop & Stone, 2019) and, at the same time, develop safer equipment, as we see in excerpts like these: "*The object of the present invention is to improve the safety of gymnastic equipment used to support one or more raised exercise bars [...]*" (US4334675A); "*The Invention has for its object to improve the safety of gymnastic equipment [...]*" (DE202005014583U1). The advancement of technology was also accompanied by studies that suggested a direct relationship between them and some recurrent injuries (Armstrong & Relph, 2021).

The design of AG equipment was gradually resulted in lighter structures, easier to install and transport and with greater durability (Oliveira et al., 2023). The technological modifications of springboards represent a good example of the important change in the design of the apparatus, drastically modifying the impulse that gymnasts can achieve, as shown by several studies (Coventry et al., 2006; Cuk et al., 2011; Lehmann et al., 2020; Yeadon et al., 2006; Zanevskyy & Zanevska, 2023). The "*protection*" of gymnasts is constantly mentioned in the technical arguments presented in patent applications.

The importance of safety in gymnastics equipment development is particularly evident with the introduction of the vaulting able (EP 0 572 518 B1), promoting a disruptive change in technology, when compared to the previous model (vaulting horse) patented at the end of the 19th century (US 243456A; US 438640A) (Table 1).

The Vaulting Table was officially used by the FIG for the first time in 2001 in Ghent (Belgium) at the FIG World Championships. The main intention was to significantly improve safety compared to the previously used vaulting horse (VH). Accidents on the VH, like what happened to the Chinese Gymnast Sang Lan in 1998[1] (Los Angeles Times, 1998), were crucial in accelerating this development. Developers and biomechanics principles contributed to the development of a new Vaulting Table (VT), one of the most representative technological modifications observed in modern AG (Schärer et al., 2019).

[1]*Several other accidents, like the ones with the American gymnasts Brian Meeker (1981) and Trend Dimas at US National Championships, were widely reported in the media. Other issues with the AG apparatus that resulted in accidents like Tyler Williamson's when the Rings broke during his routine at the Men's NCAA Gymnastics Championships, certainly reinforced discussions about the apparatus safety. (Source: USGF Gymnastics Magazine, Sept./Oct. US Gymnastics Federation, Fort Worth -TX, 1981).*

Concomitantly, a greater capacity to absorb the impact is highlighted in the patents, seeking to minimize the effects of intense and prolonged training that is required to achieve high performance in AG.

> *"The object of the present invention is to provide a gymnastic floor whose resilient and damping properties are relatively constant across the diagonals of the gymnastic floor" (NL1026548C2);*
> *"The present invention is to provide a gymnastic floor capable of easily changing a repulsive force according to a use and an actor." (JP2535234Y2).*

It is clear that equipment has modified with more malleable and resilient materials[2] (Oliveira & Bortoleto, 2011). These aspects are often mentioned in the sport's most important technical document, the FIG Apparatus Norms (Fédération Internationale de Gymnastique (FIG), 2022a). For example from parallel bars (PB): "*The bars must have elasticity; 3.2. To assure the efficiency of this elasticity the fixing points of the bars on the uprights must be articulated*" (Fédération Internationale de Gymnastique (FIG), 2022c, 2022d); and from horizontal bar (HB): "*3. Functional properties: 3.1. The horizontal bar must be elastic and be secured against breaking through; 3.2. The elasticity is not just determined by the bar but also by the apparatus, acting as a whole*" (Fédération Internationale de Gymnastique (FIG), 2022d).

Innovative scientific advances from engineering to work safety were incorporated, including metal alloys for the bar used in HB or fiberglass in UB (Pekkeriet, 2017). The evolution of biomechanics (Yeadon et al., 2012) and much other scientific evidence, contributed to the improvement of official equipment used in competitions and to the development of numerous training devices. The catalogues of the main specialized companies show hundreds of technological innovations.

The protection of technology commercial rights through patent registration requires significant financial resources, and it has become necessary for technology protection before its regular diffusion/use (Barnett, 2021). Thus, registration has been carried out by the private sector, by a small number of inventors, mostly linked to companies already consolidated in the field of gymnastics. In the case of gymnastics, the application of the patents shows an initial dispute between European and North American engineers and developers, connected to a small group of corporations (manufactures). The patent requests are usually made in the country of origin of the inventors or companies responsible for the technology. After the second half of the 20th century, multiple applications became common in order to guarantee the privilege of the international market (example: FR 9102434 in 1991 and EP 0 572 518 B1 in 1992). Patents were most frequently required in the USA and Germany in the 19th century, and in other countries throughout the 20th century (France, Holland, Japan, Russia and Australia). The participation of China has grown notably in the beginning of the 21st century, revealing a more competitive industry and different market distribution.

The development of new technologies and the registration of the commercial exploitation copyright (patent) was sufficient for companies in the sector until the mid-1980s, when the FIG began to require the certification

[2]*The term 'elastic technologies adapted to humans' for gymnastics apparatuses or parts thereof is used in this article more comprehensively than could be derived from a purely mechanical definition of 'elasticity': Here, 'elastic construction' for gymnastics apparatuses refers to structural optimizations with regard to the following 4 aspects: a) In accordance with the design specifications of the gymnastics apparatus (e.g. height of the springboard), the greatest possible unobstructed path of movement is available in the contact phase with the athlete for compression and the subsequent decompression; b) In the decompression phase of the gymnastics apparatus, as much mechanical impulse as possible is returned to the gymnast from the impact introduced by the athlete during compression; c) Moving parts of the 'elastic construction' include as little mechanical mass as possible to minimize peak forces; and d) The gymnastics apparatus has an adapted oscillation behavior of the elastic components in relation to the biomechanical requirements of the gymnast.*

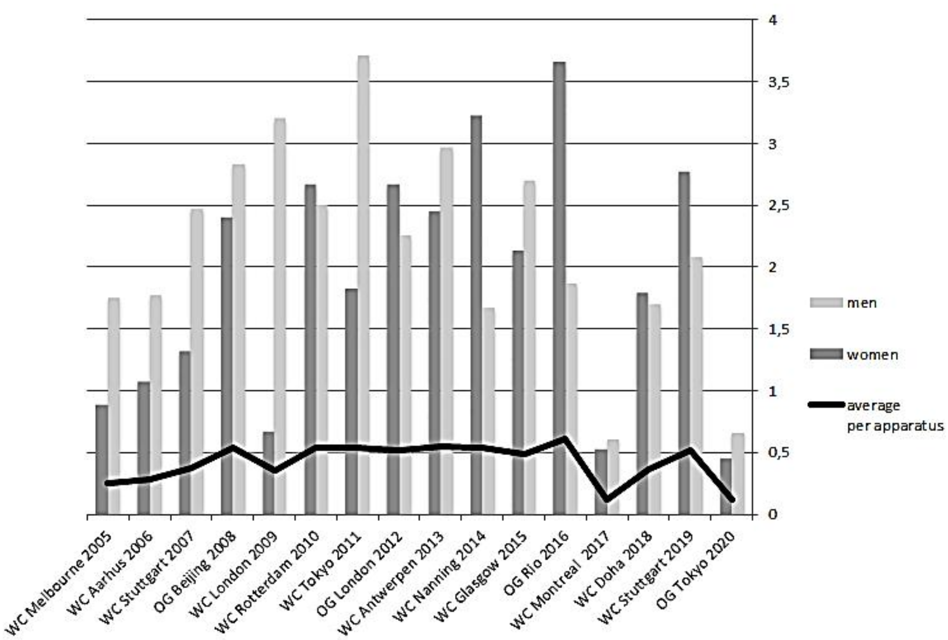
of equipment for use in official events.

STANDARDISATION OF THE TEST PROCEDURES FOR COMPETITION EQUIPMENT IN GYMNASTICS

The FIG has published norm-requirements for gymnastics equipment for more than 60 years (Fédération Internationale de Gymnastique (FIG), 1960). Since 1984 the FIG has officially relied on the expertise and assistance of specialized testing institutes for the development, verification, and control of these standards. The reasons for these measures:

a) To guarantee a certain safety standard for gymnastics equipment in view of the athlete’s health.
b) Useful and necessary aid for insurance and legal questions after a serious accident with recourse claims by the athletes.
c) To ensure equal opportunities for all athletes.
d) Objective admission procedure for gymnastic equipment.
e) To prevent undesired or uncontrolled changes in the character and the contents of the exercises.

The performance level of the world's elite AG gymnasts has always been evolving (Fédération Internationale de Gymnastique (FIG), 2000). Some of the most difficult skills were not even thought possible by outside experts before the first performance at a competition. In addition to the individual difficulty, the accumulation and density of such skills within one single exercise has increased enormously in recent years (Ferreirinha et al., 2009). This has also increased the risk of injury due to a fall or repeated high mechanical impacts during training. The FIG feels responsible for guaranteeing a certain safety standard for gymnasts using official gymnastics equipment. Therefore, properly designed standardisation tests for the gymnastics equipment are a central building block in this endeavour. This does not only result from the obvious moral obligation towards the competitors, but also from financial and legal positions towards insurance companies, which in the case of a catastrophic accident, would quickly have immense financial claims at hand.



Source: Non-published internal Database GYMLAB 2021.

Figure 2. Difference in Results of All Around Finals between 1st and 4th place in FIG Competitions of Artistic Gymnastics. The black line indicates the average difference between first and fourth place per apparatus.

An analysis of the "*All Around Finals*" at the most important FIG competitions of the last 16 years shows the average difference between first and fourth place for individual apparatus, was 0.5 points or less (Figure 2).

Such a small difference of 0,5 points already corresponds to the point deduction to be made according to the current evaluation guidelines for "*any major or severe deviation from the perfect end position and from perfect technical execution or for any major or severe adjustments to hand, foot, or body position*" (Fédération Internationale de Gymnastique (FIG), 2022g, 2022h). In this context, just imagine a gymnast who practices his vault in his national training centre in preparation for upcoming Olympic Games on another continent. He might use a vaulting board which was produced in a company of his home country and with elastic properties completely different from those used during the competition. This athlete would clearly be at a disadvantage, as she/he would not be able to practice with the competition vaulting board. Standardisation testing, therefore, should guarantee the existence of only a limited bandwidth in the differences of functional properties of all official gymnastic equipment. Therefore, certified equipment is an essential component to ensure safety and equal opportunities for all athletes.

The market for gymnastic equipment, although small, is extremely competitive in some countries. Exactly defined norm test procedures make the work for the FIG easier when approving gymnastics equipment for international competitions. When norm tests are carried out by a neutral institute, independent of companies or national federations, an objective admission procedure can be ensured.

The development of gymnastics skills has always been influenced by the development of gymnastics equipment (Sands et al., 2003). This can easily be seen, for example, in the technical development of the vault having relevant improvements introduced already between 1940 and 1980. During these years, Richard Reuther and Rolf Daehne in Germany developed the "*Reuther board*" (i.e. EP 0086274B1) (Daehne, 1975), which was well known worldwide to all gymnasts in those days (Figure 3) (Göhler & Spieth, 1989). Only these improvements of the gymnastics apparatus made the most difficult vaults at that time possible.

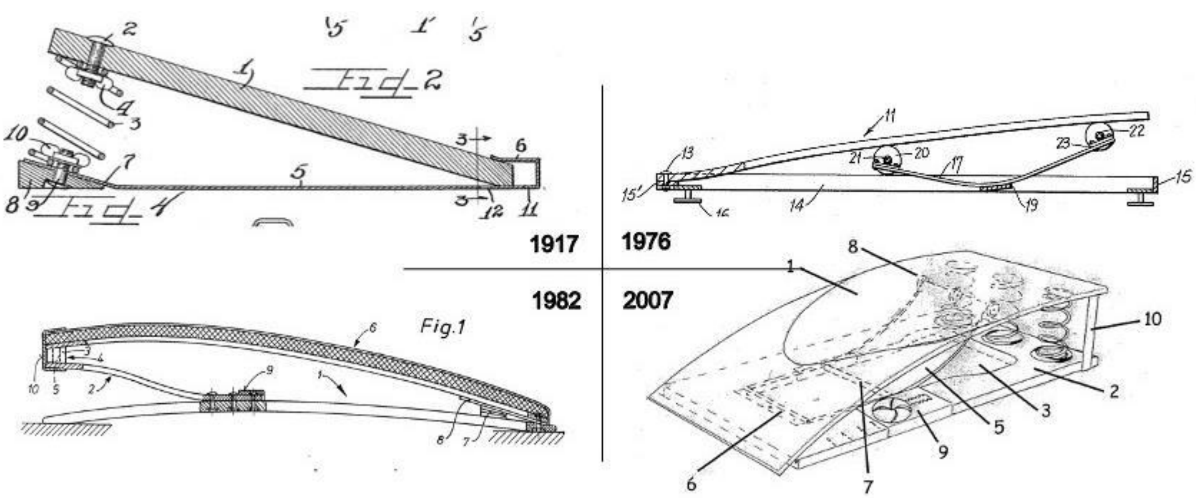


Figure 3. Springboard patents.

In recent times, new materials and components in gymnastics equipment have resulted in skills being possible only because of these changes. The FIG can fulfil its responsibility with regard to desired development tendencies only, when control is kept on such changes. Standardisation tests can help the FIG in preventing undesired or uncontrolled changes in the character and the contents of the exercises.

THE EMERGENCE OF THE OFFICIAL TESTING INSTITUTE GYMLAB

In recognition of the reasons above, the FIG sought contact with the Institute for Sport and Sports Sciences at the University of Freiburg in Germany in 1984. As a consequence of first cooperative projects and the constantly growing requirements and experiences an official testing institute (GYMLAB) was founded at the University of Freiburg.

Up to 1985, the FIG standards only contained specifications on the shape and dimensions of the gymnastics equipment. At major competitions, objection procedures from the delegations were initiated about the competition equipment and led to internal discussion within the FIG. It was obvious that the high importance of the biomechanical interactions between gymnastics apparatus and athletes had to be reflected for an improvement of the apparatus norms. As a basis, the biomechanical interaction between the athlete and the gymnastics equipment was scientifically researched for all competition equipment using classical biomechanical methods (3D-Kinematography, 3D-Dynamography, Electromyography, etc.). Depending on the problem, measurement projects were carried out in the laboratory, training halls and at major competitions. Based on these measurement results and considering many practical and sport-specific requirements, suitable standardisation test procedures were developed. Depending on the gymnastics equipment, so-called "*artificial athletes*" have been developed that can simulate the central dynamic effects on the gymnastics equipment (mechanical deflections and impacts) and can be used repeatedly for standard tests under constant conditions (Figure 4).

Source: GYMLAB.

Figure 4. FIG Testing Device for landing mats. Low-friction guided drop mass for standardised impact tests on landing mats. Electronic sensors record mechanical parameters such as braking forces, deformations, rebound height.

The improvement and adaptation to new requirements for the equipment tests is always an ongoing process. A central task for the GYMLAB is therefore the development and improvement of standardisation tests for competition equipment of the International Gymnastics Federation. After periodic revisions by a "*FIG Apparatus Commission*", the current apparatus specifications and, above all, the newly developed mechanical test procedures were precisely described and published at the Apparatus Norms:

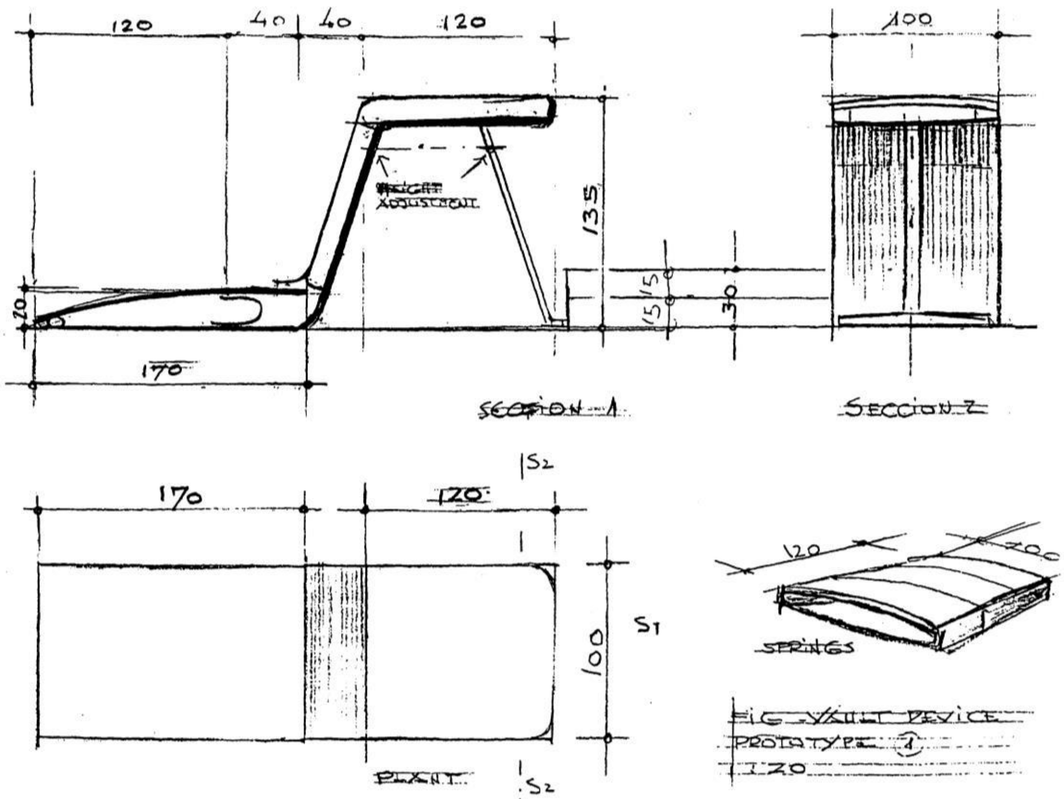
> *The purpose of these Apparatus Norms is first, to have equivalent apparatus at all competitions. It is essential for the competitors to have the same, optimal conditions for the preparations for competitions and at competitions all over the World. This is necessary for practical reasons, for competition fairness and comparison and for safety. All apparatus used at official FIG events; the Olympic Games and the World Games must have a valid FIG Certificate. This Certificate will be issued by the FIG, provided the apparatus has been tested successfully (Fédération Internationale de Gymnastique (FIG), 2022a).*

GYMLAB and another testing laboratory at the Tokyo Institute of Technology (TIT) have taken on the task of testing prototypes for all equipment used in international competitions according to the standardised procedures (Fédération Internationale de Gymnastique (FIG), 2022e). These tests are an integral part of an equipment approval system for FIG competitions: The authorised FIG bodies will only approve the equipment for use after the company has submitted an official application and two steps were successfully passed. First a positive result with all specified mechanical tests at one of the two official institutes and second a practical gymnastics test at a training centre which must be specified by the FIG. The first procedure must be repeated after a specified period, even if the company states that no change has been made in the manufacture of the equipment. The list of all gymnastics equipment currently approved for FIG competitions is published periodically by the FIG. In a database with individual access rights, equipment manufacturers, organisers of competitions, judges and interested parties can inform themselves about the status of an approval procedure.

To ensure that the extensive regulations regarding the apparatus at the competition site all comply with the specifications, the area of responsibility of a "*FIG Apparatus Commissioner*" was defined. At all World Championships and Olympic Games, a representative of the GYMLAB is usually entrusted with supporting the responsible authorities of the FIG (Technical Commission presidents - TCP) via defined checklists. A competition inspection of the equipment at the major events must also include that the equipment on site corresponds exactly to the prototypes submitted for the laboratory tests, according to the FIG regulations (Fédération Internationale de Gymnastique (FIG), 2022b).

Beyond these defined tasks for GYMLAB, the many experiences gained in connection with gymnastics equipment issues led to more and more requests for advising the FIG Committees on biomechanical issues relating to gymnastics equipment. One of the most outstanding examples of this is the introduction of the Vaulting Table around the year 2000 (Schärer et al., 2019). GYMLAB was heavily involved in the introduction of this completely new device from the very beginning: The disadvantages of the vaulting horse used until then were becoming more and more obvious to the FIG. Based on several biomechanical safety-related and practical requirements, the FIG with the full support of its vice-president at the time, the Brazilian Mr. Siegfried Fischer, called on the industry to develop an improved solution for the vault in the early 1990s (Figure 5).

Three different prototypes were selected to be tested in training in selected international training centres supported by biomechanical measurements. Following these preparatory steps, the Vaulting Table could be introduced at the World Championships 2001 in Ghent (Belgium) after prior determination of dimensions and standard test procedures. Looking back at the successive versions of the FIG norms from then until the current edition (August 2022), it can be seen that the standards of the functional characteristics for the Vaulting Table established before the 2001 World Championships have been maintained without significant adjustments (Spieth Gymnastics, [s.d.]).



Source: Family collection. Cordially shared by Mr. Erlo Fisher.

Figure 5. Proposal for a Prototype of a Vaulting Table (1995) by Siegfried Fischer, presented during a Gymnastics Apparatus Manufacturers Meeting in Munich in 1995.

Apart from the VT just mentioned several improvements have been introduced to the AG equipment in the last decades. Some changes have been made to the internal structure, unrecognisable to a layperson from the external appearance. These improvements have had a significant impact on gymnastics and are largely thanks to the equipment manufacturers, dedicated coaches, the apparatus commission and the two testing laboratories coordinated by the International Gymnastics Federation. Based on that we agree with Vigarello when saying:

> *Les opérations corporelles changent avec les modifications de leurs conditions spatiales ou instrumentales. Impossible de les étudier sans évoquer leur solidarité avec chaque élément de leur environnement. Une réciprocité ente les mouvements et les objets qui les portent ou avec ceux qu'ils animent. Une technique corporelle qui est aussi bien l'écho, le reflet, que l'activation de tels objets (Vigarello, 1988).*

Considering only the companies (12 in 2012 and 13 in 2022) with equipment approved by the FIG (Table 2), the AG equipment market is centralized in nine different countries, located 2 in Asia, 4 in Europe, 2 in America

(North) and 1 in Oceania.

Table 2. FIG recognized suppliers (2012-2022).

Manufacturer	Country	2012	AG Apparatus	2022	AG Apparatus
AMERICAN ATHLETIC, INC. AAI	USA	Yes	FX, BB, PB, HB, UB, RF, VT, PH	Yes	FX, PH, RF, VT, PB, HB, VB, UB, BB;
BAENFER GmbH	Germany	Yes	FX, VT, UB, RF	Yes	FX, PH, PB, BB, RF
CHUNHE ATHLETIC GOODS CO., LTD	China	No		Yes	FX, PH, PB, UB, BB, RF
GYMNOVA	France	Yes	FX, HB, PH, VT, PB, BB, UB	Yes	FX, PH, RF, PB, VT, HB, VB, UB, BB
SA SPIETH AMERICA	Germany - Canada	No		Yes	FX, PH, VT, HB, VB, UB, BB, RF
SPIETH GYMNASTICS GmbH	Germany	Yes	FX, VT, HB, BB, UB, RF, PH, PB	Yes	FX, VT, PB, HB, RF, UB, BB, PH
SENOH CORPORATION	Japan	Yes	FX, VT, VB, PH, RF, PB, HB	Yes	FX, PH, VT, PB, H, UB, BB, RF
SHANDONG CANNICE SPORTS (France corporation ABEO Group; German incorporation ERHARD Sport)	China	Yes	FX, RF, VT, BB, UB, HB, PB	Yes	FX, PH, VT, PB, HB, UB, BB, RF
SHANDONG TAISHAN SPORTS EQUIPMENT Co., Ltd.	China	No		Yes	FX, PH, VT, PB, HB, VB, UB, BB
ZHEJIANG SPORTING GOODS CO., LTD., (GAOFEI BRAND)	China	Yes	FX	Yes	FX, PH, VT, PB, HB, RF, UB, BB
ACROMAT	Australia	Yes	VT, PB, FX	Yes	PH, HB, BB, RF
CONTINENTAL SPORTS LTD.	UK	Yes	FX, PH, RF, HB, UB, PB, BB	Yes	PH, PB, HB, UB, RF, BB
NOVAN SPORT	France	Yes	RF, VT	No	
JENSEN	Netherland	Yes	FX, PHVT, PB, HB, UB, BB, RF	No	
SA SPORT	Canada	Yes	VT, RF, PB, FX	No	
PIGNATTI & CO. S.R.L	Italy	No		Yes	FX

Source: Prepared by the authors based on data available on the following websites: https://www.gymnastics.sport/site/apparatus/app_view.php and https://www.gymnastics.sport/site/pages/bulletins.php (Retrieved on May 01, 2024).

These data show a dynamic market, with the emergence of new companies, the merger of some of them, and the departure of some from the sector, with a clear rise of devices certified by Chinese suppliers. This condition, according to Sterling & McDonald (2020), contributes to changes in the sports technology access and, gradually, in development conditions in different regions and countries.

In September 2023, the new GYMLAB headquarters was inaugurated in Teningen (Germany), with a clear signal from FIG to maintain collaboration with the laboratory in search of improving the certification processes mentioned above (FIG News, 2023).

CONCLUSIONS

All the official AG apparatuses incorporate technological advances by the use of non-natural materials, with a modern architecture and renewed layout including diverse colours and adornments. Equipment became lighter and more resistant with synthetic materials, with a clear tendency to increase elastic (repulsive) capacity. Through a slow but constant historical process, including the technological advances in patent registrations and in the certification (approval) process of the laboratories accredited to the FIG, a safer sport has evolved.

It is also noteworthy that the testing laboratory becomes an arbiter for the industry and the FIG when the technological developments and equipment of manufacturers are evaluated for official use. It is possible to note, therefore, the centrality of the FIG in the governance and development of AG, as already indicated by other studies (Cervin et al., 2017).

Our findings demonstrate that technological development modulates the training and competition process in gymnastics and produces changes in the rules (Code of Points - CoP) of AG. These advances are influenced by the culture of gymnastics, modifying it reciprocally. We argue that the evolution of technology favours the development of a more acrobatic sport based in the incremental use of sophisticated "*elastic*" technologies. These innovations facilitate the development of more complex gymnastics skills that are regularly incorporated in the CoP. Therefore, coaches need to be aware of new equipment to optimize training and increase the safety of all gymnasts considering the long-term process (Bortoleto, 2018). Thus, the technological regulation, through the standardization and certification of apparatus, adds a relevant normative layer to the practice of GA, adding to the layer strictly delimited in the Code of Points for gymnastics skills. A double notarization that makes the sport even more controlled and expressive and constituting, in a simplistic allusion to Thomas Kuhn's concept of paradigm, a new paradigm for this sport. In fact, both layers required many decades for their conception and implementation and are still undergoing constant improvements, showing that there is a dynamic that requires constant monitoring and discussion.

There is still an unequal distribution of access to technologies, which are concentrated in the northern hemisphere of the globe. Africa, Central and South America, for example, have no suppliers recognised by the FIG. Thus, important economic sources guide gymnastics tech access and leads to the sport's unequal development. This scenario reinforces the current hegemony of some countries as evidenced by numerous historical studies, which reveal the urgent need for more equitable representation and inclusion of other countries in the global effort to refine and better distribute technological advances. A more balanced development and distribution is clearly required when we consider that more than 156 national member federations are affiliated with the FIG as of this writing (Fédération Internationale de Gymnastique (FIG), 2022a). In fact, the FIG, recognising this historical problem, has been developing an equipment donation program for developing countries since 2016 (Fédération Internationale de Gymnastique (FIG), 2022f).

Although patent registrations show a constant technological innovation since the 20th century, accentuated in the last decades, we also note that it is necessary to validate them so that the equipment can be used in official FIG events. In this way, the certification process acquires a prominent role. There has been a notable increase in FIG certification requests. The international market has been guided by the FIG Apparatus Norms which in the past was a simple certification, but now is a sophisticated, extensive and standardisation test process at the official testing laboratories. The rise of companies with many certified AG apparatus has further increased the competition to become official suppliers of international events, especially the World Championships and Olympic Games. At the Rio de Janeiro Olympic Games in 2016, two traditionally competing companies (GYMNOVA and SPIETH) (Janssen-Fritsen, 2014) came together in a *consortium* as official suppliers. It is evident, as mentioned before, that there is a clear challenge to improve the equipment distribution, making it possible worldwide, as well as reducing costs for greater accessibility.

The standardisation of AG equipment, through the approval of laboratories and testing processes seems to be reducing the differences in equipment and, as a consequence, to be facilitating the adaptation of gymnasts who participate in different competitive events. This process was built under the argument of offering greater safety to athletes.

Finally, we understand that different changes on apparatus have not yet been integrated into the certified equipment, showing that the history of technological development is ongoing.

AUTHOR CONTRIBUTIONS

The article was written by both authors in its entirety. The empirical data (historical analysis of patents and equipment providers) was carried out by the first author; while the analysis of GYMLAB historical documents by the second author.

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REFERENCES

Armstrong, R., & Relph, N. (2021). Screening Tools as a Predictor of Injury in Gymnastics: Systematic Literature Review. Sports Medicine - Open, 7(1), 73. https://doi.org/10.1186/s40798-021-00361-3

Barnett, J. M. (2021). Innovators, Firms, and Markets: The Organizational Logic of Intellectual Property. Oxford University Press. https://doi.org/10.1093/oso/9780190908591.001.0001

Bortoleto, M. A. C. (2018). The Impact of Elastic Technologies on Artistic Gymnastics: A special case study from Brazil. Em M. Jemni, The Science of Gymnastics - Advanced Concepts (2o ed, p. 266-277). Routledge.

Bourdieu, P., & Wacquant, L. J. D. (1992). An Invitation to Reflexive Sociology (1o ed). University of Chicago Press.

Cambia. ([s.d.]). The Lens. Lens Patent Database. Free & Open Patent and Scholarly Search. The Lens - Free & Open Patent and Scholarly Search. Retrieved from [Accessed 2024, May 01]: https://www.lens.org/lens

Cervin, G., Nicolas, C., Dufraisse, S., Bohuon, A., & Quin, G. (2017). Gymnastics' centre of gravity: The Fédération Internationale de Gymnastique, its governance and the Cold War, 1956-1976. Sport in History, 37(3), 309-331. https://doi.org/10.1080/17460263.2017.1363081

Coventry, E., Sands, W. A., & Smith, S. L. (2006). Hitting the vault board: Implications for vaulting take-off - a preliminary investigation. Sports Biomechanics, 5(1), 63-75. https://doi.org/10.1080/14763141.2006.9628225

Cuk, I., Penic, S., & Krizaj, D. (2011). Towards a smart springboard (case study). Science of Gymnastics Journal, 3(3), 29-42.

Daehne, R. (1975). Das neue Reuther-Brett. Olympische Turnkunst, 1.

Fédération Internationale de Gymnastique (FIG). (1960). Masse, Vorschriften und Formen der Wettkampfgeraete. FIG.

Fédération Internationale de Gymnastique (FIG). (2000). Objectif An 2000. FIG. Retrieved from [Accessed 2024, May 01]: https://www.gymnastics.sport/site/rules/#9

Fédération Internationale de Gymnastique (FIG). (2006a). FIG the story goes on: 125 years 1881-2006. FIG. Retrieved from [Accessed 2024, May 01]: https://www.gymnastics.sport/site/rules/#9

Fédération Internationale de Gymnastique (FIG). (2006b). We are gymnastics! The FIG in pictures. FIG. Retrieved from [Accessed 2024, May 01]: https://www.gymnastics.sport/site/rules/#9

Fédération Internationale de Gymnastique (FIG). (2022a). Apparatus Norms Part I to IV. FIG. Retrieved from [Accessed 2024, May 01]: https://www.gymnastics.sport/site/rules/#9

Fédération Internationale de Gymnastique (FIG). (2022b). Apparatus Norms Part II. FIG. Retrieved from [Accessed 2024, May 01]: https://www.gymnastics.sport/site/rules/#9

Fédération Internationale de Gymnastique (FIG). (2022c). Bulletin no 43. FIG.

Fédération Internationale de Gymnastique (FIG). (2022d). Bulletin no 45. FIG.

Fédération Internationale de Gymnastique (FIG). (2022e). Bulletin no 177. FIG.

Fédération Internationale de Gymnastique (FIG). (2022f). Bulletin no 258. FIG.

Fédération Internationale de Gymnastique (FIG). (2022g). Code of points men's artistic gymnastics. FIG. Retrieved from [Accessed 2024, May 01]: https://www.gymnastics.sport/site/rules/#2

Fédération Internationale de Gymnastique (FIG). (2022h). Code of points women's artistic gymnastics. FIG. Retrieved from [Accessed 2024, May 01]: https://www.gymnastics.sport/site/rules/#3

Ferreirinha, J., Marques, A. T., Alves, F., Carvalho, Côrte-Real, C., & Silva, A. J. (2009). Evolution of body position in uneven bars routines: Influence of "in bar" elements. Motricidade, 5(3), 75.

FIG News. (2023, setembro 20). The Apparatus Commission meets in Teningen. FIG News. Retrieved from [Accessed 2024, May 01]: https://www.gymnastics.sport/site/news/displaynews.php?urlNews=4007268

Fouché, R. (2017). Game Changer: The Technoscientific Revolution in Sports. Johns Hopkins University Press. https://doi.org/10.1353/book.52712

Göhler, J., & Spieth, R. (1989). Geschichte der Turngeräte. Spieth.

Gross, R. S., & Roeder, C. F. (2022). Gearing Up: Materials and Technology in the History of Sport. The International Journal of the History of Sport, 39(1), 1-6. https://doi.org/10.1080/09523367.2022.2040931

Gymnova. (2014, outubro 30). Fibre Hand-Rails. Gymnova. Retrieved from [Accessed 2024, May 01]: https://www.gymnova.com/es/

Janssen-Fritsen. (2014, outubro 30). Gymnastics suppliers Olympic Games 2016. Janssen-Fritsen. Retrieved from [Accessed 2024, May 01]: https://www.janssen-fritsen.com/newsitem/~/item/suppliers-games-2016/

Jerónimo, H. M., Garcia, J. L., & Mitcham, C. (Orgs.). (2013). Jacques Ellul and the technological society in the 21st century. Springer. https://doi.org/10.1007/978-94-007-6658-7

Kaimakamis, V., Dallas, G., & Kaimakamis, D. (2018). Forms of and exercises on the horizontal bar during the secon half of the 19th century. Science of Gymnastics Journal, 10, 91-98.

Kukkonen, C. A. (1998). Be a good sport and refrain from using my patented putt: Intellectual property protection for sports related movements. J. Pat. & Trademark Off Society, 80, 808-829.

Lehmann, T., Lorz, A., Schleichardt, A., Naundorf, F., Knoll, K., Eckardt, F., & Witte, K. (2020). A multi-body model of a springboard in gymnastics. Science of Gymnastics Journal, 12(3), 265-275. https://doi.org/10.52165/sgj.12.3.265-275

Los Angeles Times. (1998, julho 22). Accident Leaves Chinese Gymnast Paralyzed. Los Angeles Times.

Middelkoop, C., & Stone, R. (2019). Gymnastics Vault Board Design: A Comparison of Spring Configuration and Style of Spring - Preliminary Study. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 63(1), 1354-1357. https://doi.org/10.1177/1071181319631439

Oliveira, M. S., & Bortoleto, M. (2011). Notes on historical, material and morphological evolution of men's artistic gymnastics apparatus. Journal of Physical Education, 22(2). https://doi.org/10.4025/reveducfis.v22i2.9986

Oliveira, M. S., Souza, A. S. S. de, Costa, A. R., & Nunomura, M. (2023). The balance beam as an artistic gymnastics apparatus for women: From origin to consolidation. Science of Gymnastics Journal, 15(2). https://doi.org/10.52165/sgj.15.2.269-284

Pekkeriet, D. (2017). Improvement of grip and durability of uneven bars [Master Degree Dissertation, University of Twente]. Retrieved from [Accessed 2024, May 01]: https://essay.utwente.nl/74330

Sands, W. A., Caine, D. J., & Borms, J. (2003). Scientific Aspects of Women's Gymnastics. Karger. https://doi.org/10.1159/isbn.978-3-318-00894-4

Schärer, C., Lehmann, T., Naundorf, F., Taube, W., & Hübner, K. (2019). The faster, the better? Relationships between run-up speed, the degree of difficulty (D-score), height and length of flight on vault in artistic gymnastics. PLOS ONE, 14(3), e0213310. https://doi.org/10.1371/journal.pone.0213310

Slater, D., & Barry, A. (2005). Technological Economy. Routledge. https://doi.org/10.4324/9780203022450

Spieth Gymnastics. ([s.d.]). Vaulting Table "Ergojet Rio". Retrieved from [Accessed 2024, May 01]: https://www.spieth-gymnastics.com/vaulting-table-ergojet-rio/1407210

Sterling, J. J., & McDonald, M. G. (Orgs.). (2020). Sports, Society, and Technology: Bodies, Practices, and Knowledge Production. Palgrave Macmillan. https://doi.org/10.1007/978-981-32-9127-0

Ullman, J. (1977). De la gymnastique aux sport modernes. Ed. Librairie Philosophique J. Vrin.

Vázquez, J. L. H. (2006). Francisco de Paula Amorós Ondeano (1770-1848). Innovador, sistematizador y promotor de la educación física en Francia y en España. Revista Internacional de Ciencias del Deporte, 2(4), Artigo 4. Retrieved from [Accessed 2024, May 01]: https://www.cafyd.com/REVISTA/ojs/index.php/ricyde/article/view/78

Vigarello, G. (1988). Une Histoire culturelle du sport. Techniques d'hier... et d'aujourd'hui. R. Laffont.

Yeadon, M. R., Kong, P. W., & King, M. A. (2006). Parameter determination for a computer simulation model of a diver and a springboard. Journal of Applied Biomechanics, 22(3), 167-176. https://doi.org/10.1123/jab.22.3.167

Yeadon, M. R., Rosamond, E. L., & Hiley, M. J. (2012). The biomechanical design of a gymnastics training aid for a handstand on the rings. Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology, 226(1), 24-31. https://doi.org/10.1177/1754337111424682

Zanevskyy, I., & Zanevska, L. (2023). Mechanical and mathematical modeling of a gymnastics springboard' stiffness. Sports Engineering, 26(1), 4. https://doi.org/10.1007/s12283-022-00396-z

ORIGINAL ARTICLE

Movement games from the point of view of primary education teachers in Slovakia

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ABSTRACT

The main goal of the survey carried out by us is to find out the current opinions of teachers at the primary level of education in Slovakia for teaching the thematic unit activities in nature and seasonal movement activities with a focus on the place of movement games in their teaching. Using a survey, they obtained data from 1,363 teachers of primary education who teach physical and sports education in 75 elementary schools from 8 regions of Slovakia. As many as 15% of all respondents answered that they do not teach the thematic unit outdoor activities and seasonal physical activities at all. Overall, the most commonly taught activity in nature is hiking and spending time in nature. The least respondents like teaching cross-country skiing. Despite the broad and demanding focus of teachers in the primary level of education, we consider it necessary that the teaching of the thematic unit outdoor activities and seasonal physical activities (due to their importance from the point of view of health and the creation of a future lifestyle) is implemented either in winter or summer with 100% occupancy. The obtained results are applicable for compensation of identified deficiencies and subsequent optimization of the educational process in this important period of children's development. Since the results of our study are from the whole of Slovakia, they have a nationwide social impact and significance.

Keywords: Physical education, Outdoor activities, Seasonal physical activities, Summer, Winter, Primary level of education.

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INTRODUCTION

Since the beginning of the 90s, we can observe the gradual promotion of the educational field, which is generally defined by the term outdoor, or outdoor activities. In the educational field in Slovakia, we collectively refer to them as seasonal physical activities. These are mostly short-term and longer-term (multiple day) exercise activities that take place outside closed spaces, experiential activities in nature or way of spending free time outside the home or school. According to study Jensen and Guthrie (2006) these are primarily activities performed for the purpose of increasing physical activity, general well-being, recreation, but also mental health. This field of education is very widespread in the countries of the European Union, the USA, Canada, Australia, and New Zealand, mainly because of its high efficiency, achieved with the help of experiential learning models, the use of a wide range of activities, new work methods, but also thanks to the tools and programs used for educational opportunities (Volkova, 2015). Seasonal exercise activities, carried out outside closed spaces, in summer or winter, have a huge potential to significantly influence the lives of children and adults. They can have a positive impact on negative civilizational influences, stimulate health, contribute to the development of physical fitness, and can also have a positive effect on the child's psyche (Gray et al., 2015). With their content, they contribute to the development of one's abilities, skills, knowledge, and insights, and at the same time support the emotional side of the child (Bubeliniova, 1999).

According to study Adamcak and Nemec (2010) an essential component of a person's healthy lifestyle is physical activity, which he uses to ensure his optimal psychological and physical development. Opportunities to establish contact with nature, to recognize and cope with its pitfalls, but especially staying with peers and adults in this responsive environment can contribute to better educational experiences and positively influence children's motivation and enthusiasm for learning and school. Parents, educators and creators of social strategies and policies should offer children projects that will provide this age group with a varied palette of the best possible experiences (Bento and Dias, 2017). Seasonal exercise activities can also be included among the so-called experiential activities, as they are based on the element of adventure and assume movement with a certain degree of risk. Subjective sense of risk and danger activates the individual, allows him to survive the unknown and expand his experiences so much that they become new knowledge (Andreasen et al., 2018).

According to Boaventura et al. (2013), outdoor activities implemented at school are important not only for supporting meaningful theoretical education, but also for the development of children's practical skills and abilities. Yildirim and Akamca (2017) also see the importance and method of implementing outdoor activities in the fact that such activities help students to change theory into practical knowledge and skills, but especially to record them in long-term memory. They consider important not only the strength of the stimulus and the means used, but also the environment in which the activity takes place. In this context, the findings of study Jakovleva and Rudzinska (2017), which state that up to 40% of leisure-time physical activities are carried out outside in nature and only 36% in the home environment, should be viewed positively in this context.

The connection of the natural environment with a suitable stimulus, which can be cooperation, competition, a strong experience, etc., has a significantly more intensive effect on the child in shaping his attitudes and interests. Baskova (2009) consider different forms of games (especially cooperative, creative games) from this point of view, because feelings of belonging, or the common commitment towards others, but also towards the group, which the participants experience during the game are important for the mutual reciprocity of opinions. The same opinion is presented by Parker et al. (2022) who claim that learning through play proves to be an important strategy supporting the involvement of pupils in the development of their skills and abilities and developing inclusion in the group. Within the state educational program ISCED 1 (primary education), the educational field Health and movement is divided into three parts, where five thematic units are allocated within the part called Sports activities of the movement regime. One of them is the thematic group Activities in nature and seasonal physical activities, where the following types of sports and recreational activities are included in the content of the education of younger school-age pupils - skating (in-line and on ice), skiing (downhill and cross-country), swimming, hiking, and staying in nature, scootering, and cycling. The state educational program leaves individual schools with the option of choosing which sports and recreational activity is more suitable for them, due to the diverse conditions of individual regions and, of course, the possibilities of the schools themselves. In the same way, this choice is certainly influenced by the willingness, interest, qualifications, abilities, and skills of the implementer of school education, i.e., the teacher. Novotna and Rozim (2014) shows that the implementation of seasonal exercise activities in Slovak elementary schools at the primary level of education also depends on the spatial of the school and its surrounding nature.

The main goal of the survey carried out by us is to find out the current opinions of teachers at the primary level of education in Slovakia for teaching the thematic unit activities in nature and seasonal movement activities with a focus on the place of movement games in their teaching.

MATERIALS AND METHODS

Participants

The survey sample consisted of teachers teaching physical and sports education at the primary level of education from 75 elementary schools from eight regions of Slovakia: Bratislava, Trnava, Nitra, Trencin, Zilina, Banska Bystrica, Presov and Kosice. In total, more than 1,500 respondents were contacted. Out of the mentioned number, 1363 correctly and completely filled out the survey forms and were included in the evaluation. Sufficient sample sizes were ensured by adhering to the following conventional criteria: the known size of the total population of primary education teachers in the territory of the Slovakia in the 2020/2021 academic year (14,090), the estimation error (±5%), the variance of 50%, and the reliability of the estimate of 99% ($1 - \alpha$). We analysed the teachers' answers from two aspects (Table 1):

1. From the aspect of the length of their teaching experience (experience of 0-10 years and experience longer than 11 years),
2. From the aspect of the residential environment of the school (the so-called type of school), i.e., urban schools (in a settlement with more than 5,000 inhabitants) and rural schools (in a settlement with less than 5,000 inhabitants).

The reason for choosing the mentioned two aspects was our assumption that when teaching such a specific TU as Activities in nature and seasonal movement activities, the length of pedagogical practice, or residential environment of the school significantly influences their teaching. A similar opinion is held by Saracaloglu et al. (2012) and Volterrani (2023). The addressed respondents willingly agreed to fill out the questionnaire without the expectation of any reward or financial gain. Concurrently, they consented to the inclusion of their completed data in the research study and its subsequent publication in relevant analyses and publications.

Table 1. Characteristics of the survey group (n = 1363).

Type of school/pedagogical experience in years	0-10 years	11 and more	Total
Urban school	309 (41.37%)	438 (58.63%)	747 (100%)
Rural school	258 (41.88%)	358 (58.12%)	616 (100%)
Total	567	796	1363

Survey timeline and data collection methods used

The survey was conducted in the form of an electronic online survey via Google Forms software (Google LLC, CA, USA) in 2020 and 2021. The online version of the survey was chosen due to the epidemic situation of COVID-19 when it was not possible to carry out the face-to-face form of the survey. The non-standard survey was of its own design (due to the specificity of the survey itself) and consisted of two areas:

a) From demographic items (age, gender, length of teaching experience, regional seat of the school and residential environment of the school, i.e., urban, or rural school),
b) From items directly related to the aim of the survey.

Data analysis

The data evaluation was processed according to the methods Hadley and Grolemund (2017) so that the collected data were summarized in an internal database, where they were checked (cleaning of erroneous, extreme, or missing records) and subsequently subjected to further statistical processing. We quantified the results of our study using the arithmetic mean, percentage frequency analysis, and the method of inductive statistics - chi-square test (χ^2). The probability of type I error (alpha – α) was set at 0.05 and 0.01. The probability of type II error (beta – β) was eliminated by the high number of chosen samples. The statistical processing itself was carried out using the software IBM® SPSS® Statistics V28, the image attachment was prepared in the Microsoft® Office Excel 11.

RESULTS

According to survey responses, we can state that during teaching of thematic unit of outdoor activity and seasonal physical activity, <50 % of survey group taught all types of seasonal sports. We recorded the highest frequency of survey responses among the survey group with the pedagogical practice in interval of >10 years (55.38%). Almost 15 % of survey group did not teach the thematic unit of outdoor activity and seasonal physical activity. In addition, we recorded the highest frequency of such negative survey responses among the survey group of village schools (16.23%), as well the survey group with the pedagogical practice in interval of <10 years (15.70%). When dividing the content of thematic unit of outdoor activity and seasonal physical activity, we found that the survey group who taught that thematic unit (whether in terms of length of pedagogical practice and school location) more inclined towards the outdoor activity, rather than indoor activity. Within the statistical evaluation of survey question, we found that both in terms of length of pedagogical practice and school location, there was significant difference in the survey responses of survey group at the level of $p < .01$ (Table 11).

Table 2. Teaching of thematic unit outdoor activities and seasonal physical activities.

	0-10 years	**11 and more years**	**Urban schools**	**Rural schools**
I only teach indoor activities from TU of outdoor activity and seasonal physical activity	14.99	17.09	18.74	13.15
I teach only outdoor activities from TU of outdoor activity and seasonal physical activity	16.75	19.72	15.26	22.40
I teach sports activities according ISCED 1	55.38	47.49	52.88	48.21
I don't teach the TU of outdoor activity and seasonal physical activity	12.87	15.70	13.12	16.23

In the following questions, we were interested in the popularity of teaching individual seasonal physical activities among teachers. We focused on three winter and three summer outdoor activities. Despite the currently considerably high popularity of downhill skiing in Slovakia due to the popularity of Petra Vlhova, we found (Table 3) that on average up to 48.75% of teachers do not teach it at all. The highest percentage (63.19%) was reported by teachers from the group with more than 11 years of teaching experience. It was mentioned by 19.40% of teachers from the group with up to 10 years of experience as the most popular activity within the investigated TC. From the aspect of the type of school, we noticed a significant difference in the answers only in the item "*most favourite activity*", where the frequency of responses of urban schoolteachers was 18.34% and rural 10.88%. During the statistical evaluation, we found that there are significant differences in the answers of teachers at the level of $p < .01$, both from the point of view of the length of teaching practice and from the point of view of the type of school (Table 11).

Table 3. Popularity of teaching downhill skiing within thematic unit outdoor activities and seasonal physical activities.

	0-10 years	**11 and more years**	**Urban schools**	**Rural schools**
Least favorite activity in thematic unit	11.46	3.77	7.23	6.66
Most popular activity in thematic unit	19.40	11.81	18.34	10.88
As popular sports activity as the others, within the thematic unit	37.74	21.23	26.77	29.71
I do not teach it	31.39	63.19	47.66	52.76

Cross-country skiing is generally considered one of the healthiest winter sports. Through our survey, we found that more than 65% of all teachers do not teach it at all (Table 4). The least proactive are teachers with more than 11 years of teaching experience (76.88%). We consider it surprising that cross-country skiing is not taught to a higher extent in rural schools (68.02%) compared to urban schools (65.73%). The popularity of teaching cross-country skiing as the most popular activity within TC did not exceed the value of 10% in any monitored group. In the statistical evaluation, we found that significant differences in the respondents' answers (at the $p < .01$ level) are only from the aspect of the length of their teaching experience (Table 11).

Table 4. Popularity of cross-country skiing lessons within the thematic unit outdoor activities and seasonal physical activities.

	0-10 years	**11 and more years**	**Urban schools**	**Rural schools**
Least favorite activity in thematic unit	8.99	3.14	5.89	5.19
Most popular activity in thematic unit	9.88	5.90	7.23	7.95
As popular sports activity as the others, within the thematic unit	28.57	14.07	21.15	18.83
I do not teach it	52.56	76.88	65.73	68.02

Ice skating (Table 5) is not taught at all by more than 42% of all interviewed teachers. From the point of view of the type of school, it is up to 50% of teachers from the countryside. From the point of view of the length of teaching experience, it is not taught by 45.35% of teachers with more than 11 years of teaching experience. More than 38% of all teachers said that ice skating belongs to the equally popular activities from TC. The frequency of responses "*most popular activity*" reached the value of 10.59%. During the statistical evaluation, we found that there are significant differences in the answers of teachers at the level of $p < .01$, both from the point of view of the length of teaching practice and from the point of view of the type of school (Table 11).

Table 5. Popularity of ice-skating lessons within the thematic unit outdoor activities and seasonal physical activities.

	0-10 years	11 and more years	Urban schools	Rural schools
Least favorite activity in thematic unit	9.17	8.04	8.97	7.95
Most popular activity in thematic unit	10.93	10.43	12.05	8.93
As popular sports activity as the others, within the thematic unit	40.92	36.18	42.30	33.12
I do not teach it	38.98	45.35	36.68	50.00

In relation to the focus of our research, in the next question, we found out how in winter exercise activities in nature (downhill and cross-country skiing and ice skating) the addressed teachers use movement games (Table 6). Movement games are most often used in the preparatory part of the lesson (43.83%). We recorded the fewest answers when it was possible to evenly divide each part of the lesson (7.26%). Pedagogical practice has shown that teachers with longer experience like to use them in the main part of the lesson in addition to the preparatory part (36.68%). From the point of view of the type of school, all answers were relatively balanced, slightly in favour of urban schools. In the statistical evaluation, we found that significant differences in the respondents' answers (at the $p < .01$ level) are only from the aspect of the length of their teaching experience (Table 11).

Table 6. The place where movement games are most often implemented as part of teaching winter movement activities in nature.

	0-10 years	11 and more years	Urban schools	Rural schools
Equally in every part of the lesson	9.17	5.65	7.23	6.98
In the final part of the lesson	21.34	14.32	17.94	16.40
In the main part of the lesson	24.87	36.68	29.18	34.90
In the preparatory part of the lesson (warm-up)	44.62	43.34	45.65	41.72

Only 26.71% of the teachers of all monitored groups do not teach tourism and staying in nature (Table 7). Teachers with more than 11 years of experience (19.85%) and teachers working in rural schools (20.62%) consider tourism and staying in nature to be the most popular activity within TU. Teachers with up to 10 years of experience (8.47%) identified tourism and being in nature as the least popular activity. During the statistical evaluation, we found that there are significant differences in the answers of teachers at the level of $p < .01$, both from the point of view of the length of teaching practice and also from the point of view of the type of school (Table 11).

Table 7. Popularity of teaching tourism and staying in nature within the thematic unit activities in nature and seasonal physical activities.

	0-10 years	11 and more years	Urban schools	Rural schools
Least favorite activity in thematic unit	8.47	5.15	5.09	8.28
Most popular activity in thematic unit	14.99	19.85	15.53	20.62
As popular sports activity as the others, within the thematic unit	49.91	48.24	52.74	44.32
I do not teach it	26.63	26.76	26.64	26.79

In-line skating (Table 8) belongs to the least taught activities (59.81%). Teachers with more than 11 years of experience (66.96%) are the least active in this regard. This activity is most popular among teachers with up to 10 years of experience (7.41%). Teachers from rural schools more often included this activity in the area "*I do not teach*" (62.50%). In the statistical evaluation, we found that significant differences in the respondents' answers (at the $p < .01$ level) are only from the aspect of the length of their teaching experience (Table 11).

Table 8. Popularity of teaching in-line skating within the thematic unit activities in nature and seasonal physical activities.

	0-10 years	**11 and more years**	**Urban schools**	**Rural schools**
Least favorite activity in thematic unit	11.82	7.41	9.50	8.93
Most popular activity in thematic unit	7.41	4.65	5.22	6.49
As popular sports activity as the others, within the thematic unit	29.63	20.98	26.64	22.08
I do not teach it	51.15	66.96	58.63	62.50

Opinions on the popularity of two activities combined within TU into one whole - riding a scooter or bicycle (Table 9) are as follows - more than 57% of teachers do not teach these activities at all. The least active are teachers with more than 11 years of experience (60.43%). The greatest popularity of these two activities (scootering or cycling) was recorded among rural schoolteachers (7.14%), while among this group we also recorded the highest frequency of responses in the item "*as popular sports activity as the other, within the thematic unit*" (32.63%). In the statistical evaluation, we found that the teachers' answers from the aspect of length of teaching experience were significant at the $p < .01$ level. From the point of view of the type of school, the significance of the differences in answers was at the $p < .05$ level (Table 11).

Table 9. Popularity of learning to ride a scooter or bicycle within the thematic unit activities in nature and seasonal physical activities.

	0-10 years	**11 and more years**	**Urban schools**	**Rural schools**
Least favorite activity in thematic unit	9.88	4.15	7.10	5.84
Most popular activity in thematic unit	6.17	5.15	4.28	7.14
As popular sports activity as the others, within the thematic unit	30.51	30.28	28.51	32.63
I do not teach it	53.44	60.43	60.11	54.38

In the last question, we found out how in summer movement activities in nature (hiking and staying in nature, in-line skating and scootering and cycling) the addressed teachers use movement games (Table 10). They use them most often in the main part of the lesson (47.92%). We recorded the most answers (54.67%) from teachers with a shorter length of teaching experience (up to 10 years). We recorded the fewest answers for the option in the final part of the lesson (6.04%). Teachers with longer teaching experience (more than 11 years) like to use them equally in all parts of the lesson (24.87%). Teachers from urban schools least like to use movement games in the final part of the lesson (3.75%). During the statistical evaluation, we found that there are significant differences in the answers of teachers at the level of $p < .01$, both from the point of view of the length of teaching practice and also from the point of view of the type of school (Table 11).

Table 10. The place where movement games are most often implemented as part of teaching summer movement activities in nature.

	0-10 years	11 and more years	Urban schools	Rural schools
Equally in every part of the lesson	13.05	24.87	18.61	21.59
In the final part of the lesson	5.64	6.16	3.75	8.60
In the main part of the lesson	54.67	42.34	48.73	45.94
In the preparatory part of the lesson (warm-up)	26.63	26.63	28.92	23.86

Table 11. Statistical evaluation of the differences in teachers' answers from the aspect of the length of their teaching experience and from the aspect of the type of school.

	Length of teaching practice		Type of school	
	$\chi^2_{(3)}$ value	*p*-value	$\chi^2_{(3)}$ value	*p*-value
Table 2	8.360*	.039	19.525**	.0002
Table 3	140.017**	3.74 E-30	15.517**	.001
Table 4	91.253**	1.178 E-19	1.697	.637
Table 5	5.676	.128	24.990**	1.550 E-05
Table 6	29.894**	1.452 E-06	5.158	.160
Table 7	10.146*	.017	15.071**	.001
Table 8	35.091**	1.16 E-07	4.758	.190
Table 9	20.092**	.00016	9.564*	.022
Table 10	33.958**	2.021 E-07	18.686**	.0003

*Note. ** = Statistical significance at the level p < .01; * = Statistical significance at the level p < .05.*

DISCUSSION

As important, we need to emphasize that the issue of teaching thematic units in the subject of physical and sports education at the primary level of education has been addressed by a minimum of authors in recent decades, and therefore the comparison of our findings is quite problematic. Several foreign studies, e.g. Alderman et al. (2012), Long et al. (2013) indicate that the level and nature of daily and weekly physical activity among children and youth is significantly influenced by school physical and sports education. The basics of movement skills, related to the activities that make up the content of this TU and which should prospectively occupy an important place in a person's life, should be at the forefront of the teacher's interest in this period of education. Activities such as ice baths, staying and moving in nature or on roads, combined with safety rules, create important prerequisites for the gradual development of knowledge in the field of health and injury prevention or life protection. It is about the development and acquisition of such movement abilities, skills and activities that should constitute the largest representation of all-day activities in childhood (Sujova and Vladovicova, 2016). In particular, the period of the global pandemic COVID-19 pointed out that exercise activities carried out outdoors on the playground, in the yard or in nature certainly have higher benefits compared to activities carried out in closed spaces. Our findings regarding the division of TU content into outdoor and indoor activities pointed to the fact that teachers who teach this TU (either from the point of view of the length of teaching experience or the location of the school) are more inclined to outdoor activities. When evaluating the popularity of teaching individual seasonal sports and recreational activities, we found that the most popular activities are hiking and spending time in nature and swimming. This finding correlates with the claim of Adamcak and Nemec (2010), that tourism and sports in nature belong to the optimal psychological and physical development of a person. The least popular seasonal activities among our teachers are inline skating and ice skating. There can be several reasons, organizational problems with the selection of suitable premises, material security, but also a high risk of injury and considerable demands for individualized learning of these activities. Of course, it is also necessary to accept the fact that this TU is broadly conceived and, as one of the few, must significantly respect the real conditions of individual schools (Novotna and Rozim, 2014).

The use of movement games in the teaching of seasonal movement activities from the point of view of their place in the lesson brought an interesting finding that within the framework of winter movement activities, teachers most often implement them in the preparatory part of the lesson and in the summer most often in the main part of the lesson. Parker et al. (2022) state that if a teacher wants to implement playful teaching, he must understand what playing and learning is and what benefits it brings to the quality of learning. At the same time, they claim that the game is an important and legitimate means of learning. The inclusion of games in the main part of the lesson, which is the longest in its scope, is recommended by e.g. Dilkes et al. (2014) who state that just such an approach can help avoid fatigue, especially when learning new things. Dean and Kuhn (2007) claim that learning in more playful conditions brings more lasting results and faster learning progress. It means that the use of games in the main teaching time (the main part of the lesson) can be considered more effective. If we look at the results through the selected contextual variables, teachers with more than 11 years of teaching experience significantly often presented the opinion that they do not teach individual seasonal movement activities at all compared to their younger colleagues. The finding that this thematic unit is not primarily taught by teachers with more than 11 years of teaching experience (15.70%) did not surprise us greatly. Teaching seasonal movement activities is demanding in terms of time, preparation, and implementation, but it is also characterized by high risk. These are attributes that an experienced teacher is already fully aware of and can undoubtedly have a significant negative impact on their willingness to accept such threats. From the point of view of the type of school, we noted a less significant difference in answers among teachers of the primary level of education, which also confirms their statistical expression, when we found no significant difference in this parameter three times, at the $p < .05$ level only once and only three times at the $p < .01$ level. In the parameter length of teaching experience, we found significant difference twice at the $p < .05$ level and up to six times at the $p < .01$ level.

In 2015, the National Project "*Increasing the qualifications of physical and sports education teachers*" was implemented in Slovakia (National project, 2023), the aim of which was to make the process of teaching physical and sports education more attractive and to improve the quality, so that the teaching is more experiential and motivating for the current generation of children and youth. The main tools were movement games, cooperative activities and experiential learning. In addition to the main goal, this project was supposed to ensure adaptation of the process of informal as well as formal education to the current needs of society. Also, in our investigation, we found that teachers like to use this motivating tool, but they don't always do so completely adequately in terms of time. We believe that if physical activities for children at school are supported by a suitable element of play, it can instil in them the desire to engage in these activities more often during their free time, leading to various positive benefits, especially from a health perspective.

Based on our findings, we recommend the implementation of the thematic unit activities in nature and seasonal movement at the primary level of education in every elementary school, despite its complexity. To enhance the quality of teaching in this thematic unit, we suggest that primary-level teachers incorporate playful activities, such as movement games, into the main part of the instruction for individual seasonal movement activities.

We believe that this is the most suitable way for teachers to provide students with their first, and often positive, experience with these sports and recreational activities, which they may not have encountered within their family or leisure spaces.

A limiting factor in our study may be the self-reporting of results, lack of motivation, and the potential lack of complete trustworthiness in respondents filling out the survey. Participation in the survey was voluntary, without financial reward, and it was conducted only in electronic form due to the COVID-19 pandemic.

Additional limitations include the absence of evaluation of the obtained results based on the participants' education in the field of preschool and elementary pedagogy, related teaching fields, or other educational domains, as well as the participants' achieved career levels. However, these limitations also present opportunities for further exploration and deeper investigation of the issue.

CONCLUSION

In our survey, we concentrated on a specific educational domain within primary education called 'Health and Movement.' This area is expected to serve not only as an essential source of information and development but also has a direct impact on influencing children's health. We focused on the thematic unit 'Activities in Nature and Seasonal Physical Activities,' which is intended to occupy 15% of the total time allocated for teaching the subject of Physical and Sports Education. During our investigation, we gathered opinions from primary-level teachers on the teaching of seasonal (summer and winter) physical activities in nature, as well as the incorporation of movement games in their instructional practices. When summarizing the achieved results, it is essential to highlight the least favourable finding: up to 15% of all teachers, particularly those in rural schools (16.23%), reported not teaching this thematic unit at all. Furthermore, in terms of teaching experience, we observed that teachers with more than 11 years of experience are less likely to teach this thematic unit. In winter, the most commonly taught activities include ice skating, downhill skiing, and cross-country skiing. During the summer, teachers focus on hiking, spending time in nature, riding scooters or bicycles, and inline skating. Overall, cross-country skiing is the least popular among the studied group. When investigating the role of movement games in the teaching of seasonal activities, we found that teachers primarily use games in the preparatory part of the lesson during winter and most often incorporate them in the main part of the lesson during summer. These findings can be utilized to address the identified shortcomings and optimize the educational process during this crucial period of children's development.

AUTHOR CONTRIBUTIONS

MN: Study Design, Data Collection, Manuscript Preparation. SA: Study Design, Data Collection, Statistical Analysis, Manuscript Preparation. PP: Statistical Analysis, Manuscript Preparation. All authors have read and agreed to the final version of the manuscript.

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REFERENCES

Adamcak S, and Nemec M. (2010). Movement Games and Physical Education (1st ed.). Banska Bystrica, SK: Matej Bel University.

Alderman BL, Benham-Deal T, Beighle A, Erwin HE, and Olson RL. (2012). Physical education's contribution to daily physical activity among middle school youth. Pediatr Exerc Sci. 24: 634-648. https://doi.org/10.1123/pes.24.4.634

Andreasen T, Fedorko V, Gerka V, Jackson M, Jadvisova V, Kahan J, Kadri K, Kaosaar, Kondimae K, Kovacova A, Lilienthal M, Markeprand SM, Minova M, Robinson M, Staples-Rolfe R, Sykorova J, Sepelakova L, Tiits T, and Valachovicova M. (2018). Take me Out. How to Support Children in Spending Time Outdoors and in Nature (1st ed.). Kremnica, SK: INAK.

Baskova M. (2009).Education for Health (1st ed.). Martin, SK: Osveta.

Parker R, Thomsen BS, and Berry A. (2022). Learning Through Play at School - A Framework for Policy and Practice. Front Educ. https://doi.org/10.3389/feduc.2022.751801

Bento G, and Dias G. (2017). The importance of outdoor play for young children's healthy development. Porto Biomed J 2017; 2: 157-160. https://doi.org/10.1016/j.pbj.2017.03.003

Boaventura D, Faria C, Chagas I, and Galvao C. (2013). Promoting science outdoor activities for elementary school children: Contributions from a research laboratory. Int J Sci Educ. 35: 796-814. https://doi.org/10.1080/09500693.2011.583292

Bubeliniova M. (1999). Changes in Learning in Nature (1st ed.). Bratislava, SK: Iuventa.

Dean Jr D, and Kuhn D. (2007). Direct instruction vs. discovery: the long view. In Sci Educ. 91: 384-397. https://doi.org/10.1002/sce.20194

Dilkes J, Cunningham C, and Gray J. (2014). The New Australian Curriculum, Teachers and Change Fatigue. Aust J Teach Educ. 39: 45-64. https://doi.org/10.14221/ajte.2014v39n11.4

Gray C, Gibbons R, Larouche R, Sandseter EB, Bienenstock A, Brussoni M, Chabot G, Herrington S, Janssen I, Pickett W, Power M, Stanger N, Sampson M, and Tremblay MS. (2015). What Is the Relationship between Outdoor Time and Physical Activity, Sedentary Behaviour, and Physical Fitness in Children? A Systematic Review. Int J Environ Res Public Health. 12: 6455-6474. https://doi.org/10.3390/ijerph120606455

Hadley W, and Grolemund G. (2017). R for Data Science: Import, Tidy, Transform, Visualize, and Model Data (1st ed.). Sebastopol, CA: O'Reilly Media, Inc.

Jakovleva M, and Rudzinska I. (2017). Regularities of youngster free time physical activity in a Latvian secondary school. Balt J Sport Health Sci. 2: 20-26. https://doi.org/10.33607/bjshs.v2i105.21

Jensen CR, and Guthrie S. (2006). Outdoor Recreation in America. Champaign, IL: Human Kinetics. https://doi.org/10.5040/9781492597438

Long MW, Sobol AM, Cradock AL, Subramanian SV, Blendon RJ, and Gortmaker SL. (2013). School-day and overall physical activity among youth. Am J Prev Med. 45: 150-157. https://doi.org/10.1016/j.amepre.2013.03.011

National project. (2023). Retrieved from [Accessed 2024, June 10]: https://www.minedu.sk/specialny-vzdelavaci-program-pre-ucitelov-telesnej-vychovy-a-sportu/

Novotna N, and Rozim R. (2014). Fundamental Locomotions and Seasonal Movement Skills. Banska Bystrica, SK: Belianum.

Saracaloglu AS, Varol SR, and Ozsaker M. (2012). Teaching strategies preferred by the teachers of physical education and sports. Int J Acad Res. 4: 57-64. https://doi.org/10.7813/2075-4124.2012/4-5/B.8

Sujova L, and Vladovicova N. (2016). The Influence of Physical Education on the Development of Physical Performance and Physical Fitness of 3rd Year Elementary School Students in Banska Bystrica in the Slovak Republic. Tel kultura; 39: 48-59. https://doi.org/10.5507/tk.2015.019

Volkova T.(2015). Outdoor Activities in Extracurricular Education (1st ed.). Bratislava, SK: MPC.

Volterrani V. (2023). School Education Gateway. Retrieved from [Accessed 2024, June 10]: https://school-education.ec.europa.eu/en/insights/viewpoints/what-it-means-be-rural-school-europe

Yildirim G, and Akamca GO. (2017). The effect of outdoor learning activities on the development of preschool children. S Afr J Educ. 37: 1-10. https://doi.org/10.15700/saje.v37n2a1378

ORIGINAL ARTICLE

Case study based on ball trajectory and motion analysis of international long-drive distance golf player

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ABSTRACT

This study aimed to measure the ball trajectory, club face control, and body movements of a long-drive distance golf player (LDP) who excels in international competitions. The participant randomly executed 10 shots of three trajectory types—straight, draw, and fade—using a driver in an indoor facility. The results indicated that the fade shot exhibited a significantly longer ball carry distance (S: 329.7 ± 31.7, D: 301.8 ± 30.6, F: 345.7 ± 18.4 yards). The offline distance also showed a significant increase (S: 3.6 ± 37.3, D: −12.0 ± 26.4, F: 30.8 ± 42.2 yards) for the fade shot. If shots exceeding the 60-yard width of the offline distance resulting in invalid attempts were counted, there were 2 of 10 attempts for straight, 0 of 10 attempts for draw, and 4 of 10 attempts for fade. Analysis of the ball trajectory of draw shots revealed a statistically significant trend towards lower peak height and descent angle. In all three trajectories, there were no significant differences observed in ball speed (S: 189.3±6.3, D: 192.1±5.0, F: 193.3±4.1 mph) and club head speed (S: 137.2 ± 1.6, D: 137.0 ± 1.2, F: 137.7 ± 2.2 mph). For the draw shots, the club path exhibited in-to-out trajectory, moving the club face, and the face angle was open during the ball impact. It is evident that even in golf players aiming for the maximum distance in a single shot, club head speed and grip speed tend to remain relatively constant. The findings indicate that the LDP executes precise movement and face control tailored to the three ball trajectories, demonstrating sophisticated motor control.
Keywords: Performance analysis, Golf, Club head speed, Ball carry, Long-drive distance player.

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INTRODUCTION

Golf is a sport in which players compete to achieve the lowest score. Sam Snead (1912–2002, USA), who holds the tied record for the most wins in Professional Golfers' Association of America (PGA) Tour history with 82 wins, emphasized the importance of the short game by stating, "*60 percent of golf scores are made within 125 yards*." In the past, it was believed that even if the first shot did not cover a great distance, players could compensate for a less-than-ideal score with their ability to execute shots beyond the initial one. Furthermore, Dave Pelz, a putting researcher, analysed that regardless of a golfer's skill level, "*43% of the score is determined by putting*" (Pelz & Mastroni, 2004). Masashi Ozaki, born in 1947 in Japan, holds the world professional tour record for the most victories, with 113 wins. He expressed the sentiment that "*distance provides the first advantage,*" embodying the idea that in the competitive world of professional golf, having a longer driving distance can give a player a strategic edge over others. Studies have shown that in the PGA (men's division), the longer and more accurate the first shot, the better the score (within the top 40) (Broadie, 2014; Pelz & Mastroni, 2004). Research investigating the relationship between performance in PGA, LPGA (women's), and SPGA (senior) events and various golf statistics has revealed that in PGA, driving distance contributes the most to performance. In LPGA, green in regulation, representing the percentage of times a player hits the green (e.g., three or fewer strokes for Par 5, two or fewer strokes for Par 4, and one stroke for Par 3), was identified as the most influential factor, with driving distance ranking second (Pfitzner & Rishel, 2005). However, in senior PGA, the scramble rate (the probability of making a par or birdie on a hole when not hitting the green) was reported to have the highest contribution, with driving distance ranking fourth (Fried et al., 2004). For international male golfers, a longer driving distance from the first shot is a crucial performance factor in modern golf. Achieving a greater driving distance is closely tied to the clubhead speed (CHS), and there is a strong correlation between the CHS just before impact and the distance the ball carries with the driver (Fletcher & Hartwell, 2004; Keogh et al., 2009).

Golf competitions specializing in driving distance have become popular in recent years. Similar to track-and-field throwing events, these competitions involve competing to achieve the maximum distance within specified boundaries for the ball to stop, and such events are regularly held worldwide. The Pro Long Drive World Championship uses a competition format in which players hit six balls within 2 min and 30 s and compete for the longest distance. Bryson DeChambeau, a prominent figure representing the PGA (USA), has participated in the Long Drive World Championship during breaks from regular golf tours. His involvement sparked controversy, leading to debates about the introduction of golf balls designed to limit maximum distance, potentially influencing golf rules (Edgar, 2023). Jamie Sadlowski (CAN), a two-time champion of the World Long Drive Championship, stands out for achieving the personal best of 445 yards despite his slender build, with a height of 178 cm and weight of 76 kg (Holt & Holt, 2013). However, only a few studies have been published on long-drive distance players (LDPs), and research on ball trajectories at speeds of approximately 200 mph, which is above the speed of PGA Tour players, is scarce (Broadie & Henrikson, 2022; Holt & Holt, 2013). We are conducting preliminary experiments targeting Japanese LDPs involving indoor motion and ball trajectory analyses. As a result, we repeatedly observed that markers attached to the clubhead for motion analysis are damaged upon impact when subjects strike the driver with ball speeds approaching 200 mph. Additionally, we found that these players often used long golf tees exceeding 100 mm for ball setting and striking, which is uncommon among regular golfers. Consequently, in the indoor trajectory measurements, we identified instances where infrared ball trajectory analysers which functioned from behind were ineffective owing to their unique LDP setup. The reasons mentioned above could explain why the analysis of LDP has not progressed significantly. In addition, the game requires appropriate ball control because wind conditions and directions always change. Athletic skills are also required to control three different trajectories (straight [S], draw [D], and fade [F]) and the flying distance. An LDP may have a gap in the subjective and objective sense in obtaining the maximum distance and may need to conduct movement analysis under a research protocol that does not provide knowledge of the results. We aimed to address this gap by employing measurement protocols that can accurately accommodate the LDP, striving to conduct both ball trajectory and motion analyses. Therefore, this study investigated the shot performance characteristics of a nationally represented LDP in Japan, who was instructed to randomly hit three different shots in an indoor environment.

MATERIALS AND METHODS

The study participant was Taiga Tazawa, a representative Japanese player ranked 13th (longest distance: 428 yards) in the Pro Long Drive World Championship 2021 (height: 182.5 cm, weight: 106 kg, age: 27 years). The golf club used was a JLIDEN YS-01J beam driver (Jbeam Red Max: X shaft with a length of 47.5 inches: static loft angle was 6.1º, static lie angle was 59.6º). Driver shots (S, D, and F) were performed in three random trials of 10 sets each to record the data for 30 balls. The participant was asked to imagine the trajectory described on the card and perform the shots, and no feedback was provided. The ball trajectory analysis equipment used was GC2 (Foresight Sports, USA) placed in front of the participant (Figure 1). GEARS (Gears Sports, USA) was used for body and clubhead movement analyses. Gears is a golf-specific motion analysis system, an optical camera-based tracking system with eight 1.7-megapixel cameras operating at 360 frames per second. The participant wore a motion-capture suit, 14 golf club-mounted reflective markers, and an automatically detected golf ball to capture the swing data. Table 1 presents the club and body data.

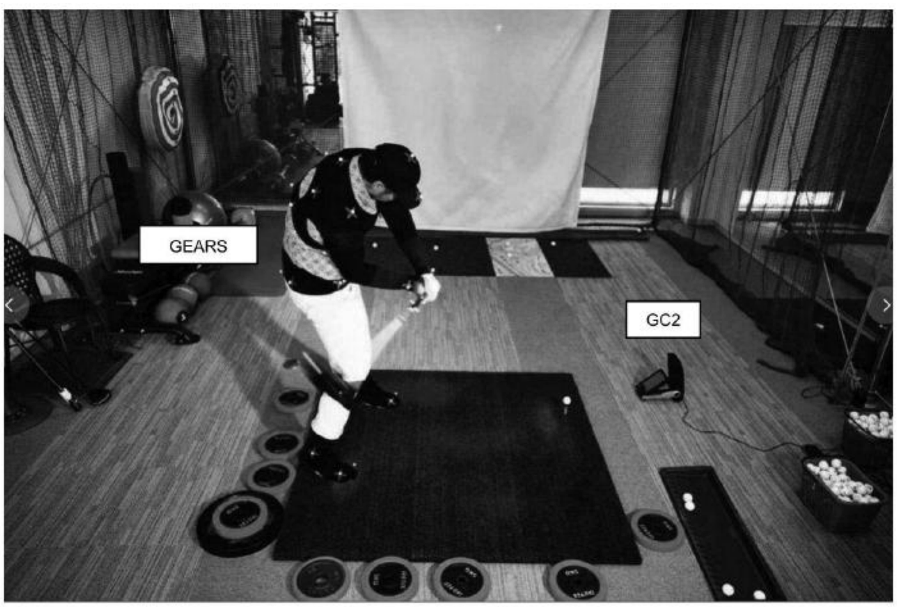

Figure 1. Experimental setup (GEARS and GC2).

The face angle was relative to the target line at the ball impact. The club path angle was the entry of the club just before impact, with in-to-out indicated by plus and out-to-in indicated by minus. The face-to-path angle was defined as the club-path angle minus the face-to-target angle. Positive attack angle values indicated an upward club angle of impact, and negative values indicated a downward club angle of impact (Bishop et al., 2024). This study was approved by the Academic Research Ethics Review Board of the Tokyo International

University (2022-15). To prioritize respect for human rights and safety in all phases of research involving human participants, we abided by the principles of the Declaration of Helsinki regarding the protection of human rights. IBM SPSS Statistics version 28 (IBM Corp., Armonk, NY, USA) was used for all statistical analyses, with statistical significance set at 5%.

RESULTS

All data were reported as the mean value and standard deviation (SD). A one-way analysis of variance (ANOVA) of shot types (S, D, and F) was performed for the ball trajectory, club, and body data. Post-hoc tests involved multiple repeated-measures t-tests with Bonferroni correction (S vs. D, S vs. F, and D vs. F). Ball speed (S: 189.3 ± 6.3, D: 192.1 ± 5.0, F: 193.3 ± 4.1 mph) and CHS (S: 137.2 ± 1.6, D: 137.0 ± 1.2, F: 137.7 ± 2.2 mph) were not significantly different among the three types of shots (Table 1). However, the fade shot had a significantly further carry distance (S: 329.7 ± 31.7, D: 301.8 ± 30.6, F: 345.7 ± 18.4 yards) and significantly larger offline distance (S: 3.6 ± 37.3, D: −12.0 ± 26.4, F: 30.8 ± 42.2 yards; positive values indicate the right direction) compared to the draw shot. The carry distance (Y) was also significantly correlated with the offline distance (X) (Y = 322.84 + 0.387 × X, $p < .05$, Figure 2). Back spin (rpm) with draw shots was significantly smaller than that with straight shots (D: 1054.7 ± 269.8 vs. F: 1548.2 ± 422.2 rpm), and side spin (rpm: positive values indicate a clockwise spin) with draw shots was smaller (counter clock spin) than that with fade shots (D: −870.9 ± 450.9 vs. F: 148.0 ± 459.8 rpm). Ball peak height and decent angle (angle of impact on the ground) with draw shots was significantly smaller than that with straight shots (S: 41.8 ± 14.7 vs. D: 24.0 ± 6.0 yards, S: 38.1° ± 8.5° vs. D: 24.9° ± 5.9°). The fade shot had a significantly smaller club path angle (S: 2.0° ± 0.9°, D: 5.7° ± 1.1°, F: −0.2° ± 0.9°), face-to-path angle (S: 2.0° ± 2.3°, D: 3.4° ± 2.2°, F: −0.9° ± 1.6°), and attack angle (S: 7.9° ± 1.0°, D: 8.2° ± 1.1°, F: 6.6° ± 0.7°) compared to the straight and draw shots. In contrast, there were no significant differences in the launch angle (S: 13.9° ± 2.7°, D: 13.1° ± 1.3°, F: 13.9° ± 1.9°; positive values indicate an upward ball launch direction) or attack angle (S: 7.9° ± 1.0°, D: 8.2° ± 1.1°, F: 6.6° ± 0.7°; positive values indicate an upward club head face direction) among the three groups. In addition, there were no significant differences in the kinematic sequences of the pelvis, torso, and arm during ball impact.

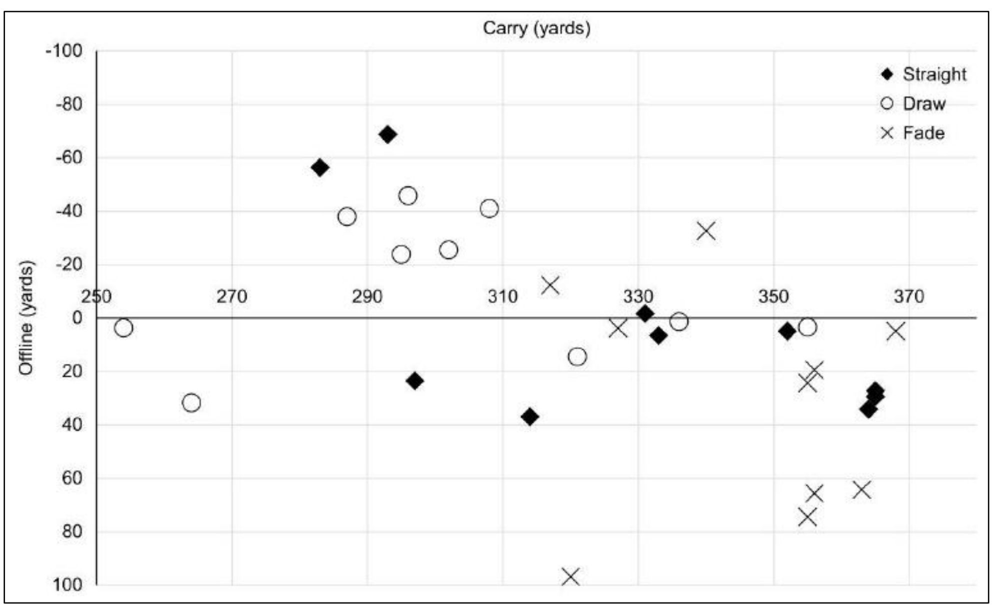

Figure 2. Results of carry and offline distance.

Table 1. Ball trajectory, club head, and body kinematic data at straight, draw, and fade shots.

		Straight: S	Draw: D	Fade: F	ANOVA
Ball	Ball speed (mph)	189.3 ± 6.3	192.1 ± 5.0	193.3 ± 4.1	n.s
	Launch angle (deg: + is up)	13.9 ± 2.7	13.1 ± 1.3	13.9 ± 1.9	n.s
	Back spin (rpm)	1945.3 ± 681.8	1054.7 ± 269.8	1548.2 ± 422.2	S > D
	Side spin (rpm: + is clockwise)	-292.1 ± 636.6	-870.9 ± 450.9	148.0 ± 459.8	D < F
	Carry (yards)	329.7 ± 31.7	301.8 ± 30.6	345.7 ± 18.4	D < F
	Offline (yards: + is right)	3.6 ± 37.3	-12.0 ± 26.4	30.8 ± 42.2	D < F
	Peak height (yards)	41.8 ± 14.7	24.0 ± 6.0	35.1 ± 11.4	S > D
	Decent angle (deg)	38.1 ± 8.5	24.9 ± 5.9	32.2 ± 9.6	S > D
Club	Club head speed (mph)	137.2 ± 1.6	137.0 ± 1.2	137.7 ± 2.2	n.s
	Grip speed (mph)	22.1 ± 0.7	22.1 ± 0.8	22.0 ± 0.7	n.s
	Face angle (deg)	0.0 ± 2.3	2.4 ± 2.9	0.7 ± 1.6	S < D. S < F. D > F
	Club path (deg)	2.0 ± 0.9	5.7 ± 1.1	-0.2 ± 0.9	S < D. S > F. D > F
	Face to path (deg)	2.0 ± 2.3	3.4 ± 2.2	-0.9 ± 1.6	S > F. D > F
	Attack angle (deg: + is up)	7.9 ± 1.0	8.2 ± 1.1	6.6 ± 0.7	S > F. D > F
Body	Pelvis kinematic sequence (deg/sec)	325.0 ± 50.1	283.9 ± 51.5	297.7 ± 71.1	n.s
	Torso kinematic sequence (deg/sec)	649.5 ± 63.9	609.9 ± 88.3	621.7 ± 35.4	n.s
	Arm kinematic sequence (deg/sec)	479.7 ± 28.2	465.6 ± 56.2	460.0 ± 34.0	n.s

Note: Values are mean ± SD, one-way analysis of variance (ANOVA), p < .05.

DISCUSSION

This study analysing a representative player in Japanese professional golf long driving showed no significant differences in ball speed and CHS for the three trajectories, but the carry distance increased with offline distance. For the participant, ball carry was longer for fade shots, which was considered closer to the ideal value in terms of club face and shaft control. However, in an actual competition, there is a rule that the ball must stop at a grid 45–60 yards wide to the left or right to be recorded. The offline distance was over 60 yards two out of 10 times for straight shots, zero times for draw shots, and four times for fade shots.

Based on the above results, the participant was most likely to be deemed invalid in the case of a fade shot during a competition. Therefore, considering the constraint of six shots in the regulations of a match, it may be advisable to start with draw shots, which tend to have a smaller offline distance in the early stages, to ensure valid attempts. Subsequently, transitioning to fade shots could be part of a strategic approach to achieve an even greater maximum distance. The subjective kinematic feedback obtained from the participant after the experiment indicated that draw shots provided the longest distances in a competition. The discrepancy between the objective data of this study and the subjective kinematic feedback from the participant can be attributed to several factors. First, the participant's extensive experience with successful attempts, as indicated by shorter offline distances, may have influenced his perception. In addition, the tendency of the draw shots to have a significantly lower peak height and descent angle may have contributed to a more stable and less negatively affected trajectory under various wind conditions, thus influencing the feedback. Furthermore, long-drive events often occur in large sports complexes where the ground surface is generally dry and firm. These conditions could affect the behaviour of the ball and, consequently, the player's experiences during the experiment. In tournaments where scores are competitive, the wet-bulb temperature, serving as an indicator of ground hardness, significantly influences the scores (Jowett & Phillips, 2023). Furthermore, considering outdoor settings without windbreaks, the wind direction substantially impacts the ball. It is presumed that headwinds or tailwinds and hitting against the wind from the side might result in reduced distance. Therefore, prior observations of the external factors in the surrounding environment are crucial (Malik & Saha, 2021; Thornes, 1977). For the reasons mentioned above, it is plausible that the subjective kinematic feedback of LDPs is influenced by their experiences of success with draw shots that are slightly lower and have a lower spin. To effectively plan for competition days, LDPs must conduct detailed investigations into landing areas at tournament venues and prevailing wind conditions, allowing them to plan for optimal ball trajectories, accounting for both elevation and lateral movement.

Controlling club faces is crucial for managing the three ball trajectories: straight, draw, and fade (Ichikawa et al., 2022). In the participant's draw shots, the club path exhibited a characteristic in-to-out trajectory towards the ball, with the face angle noticeably open at impact. In contrast, in fade shots, there was a significant tendency for a smaller attack angle, indicating a slightly out-to-in path and a tendency to strike the ball more shallowly. Surprisingly, even when altering various ball trajectories, LDPs competing for the maximum distance in a single shot maintained an almost constant CHS and grip speed. No significant differences were observed in the angular velocities of the pelvis, torso, or arm. This suggests that in the vicinity of the impact, the LDP in this study could differentiate ball trajectories by precisely controlling the club face path without altering trunk movement. In other words, the LDP exhibited precise control of the club face near impact and the skill to differentiate between three ball trajectories, a technique essential for adapting to external factors such as surfaces and wind conditions in competitive environments.

Although it is commonly believed that increased driver distance leads to decreased accuracy, research comparing tour players and amateurs has reported evidence suggesting the opposite, where the dispersion of ball landing positions converges closer to the centre of the fairway for tour players than for amateurs (Broadie, 2008). This phenomenon is thought to be because individuals who can hit the ball farther tend to have more efficient swings, leading to higher accuracy. This implies that for LDPs, beyond the ability to contribute to maximum distance, face control is an essential motor skill intricately related to finesse in golf. It has become evident that, as a foundation, striking a balance between skill-related face control and physical fitness is crucial when devising a training plan.

The contribution of lifting weights in exercises such as bench presses and squats to increase the CHS has been highlighted in previous studies (Brennan et al., 2024; Fletcher & Hartwell, 2004; Johansen et al., 2023). However, strengthening the arms and trunk requires a significant amount of time, and the effectiveness of such training may not always translate into increased CHS (Hume et al., 2005). As previously mentioned, Jamie Sadlowski, who reported a CHS of over 150 mph, emphasized the importance of lifting speed using a human ballistic move that utilizes muscle reflection as a training method (Holt & Holt, 2013). This paper also discusses Tiger Woods' attempt to increase CHS by gaining 30 pounds (13.6 kg) in 2008, which led to a knee injury. Sadlowski attempted a similar weight gain strategy, but it resulted in minimal changes in CHS. Considering the risks and lack of significant improvements in CHS, this study suggests that such weight-gain strategies are not recommended for a long golf career. Therefore, the height of the CHS depends on factors such as initial muscle function and age, and achieving meaningful results requires consistent and appropriate training.

Understanding the motion mechanism of normal acceleration may allow for the transient increase in the CHS in a teed-up driver shot. This swing theory suggests that by pulling the grip end inward (normal direction) just before impact, the club head accelerates through the increase in the shaft's rotational acceleration, known as "*parametric acceleration*" (Miura, 2001). This movement is similar to the technique used in hammer throws in track and field events. In the hammer throw, athletes pull the grip inward against the opposing weight of the distal hammer, reducing the rotation radius and obtaining normal acceleration to propel the hammer over a great distance. However, it is important to note that any shift in the hand position may complicate face control during ball impact in golf. Therefore, careful attention is required to maintain proper face control during impact when mastering this technique. Furthermore, the feasibility of intentionally acquiring the skill of parametric acceleration and its applicability to LDPs remain uncertain. Future research focusing on the motor-learning aspect of this technique could provide insights into its practical use in LDPs.

CONCLUSION

This study focused on an international LDP and analysed ball trajectories, club face control, and body movements when performing straight, draw, and fade shots. The results, particularly regarding distance, indicate that fade shots achieved the longest distance. However, considering the strategic aspects for an actual competition, draw shots exhibited the most stable tendencies. In distance-based golf competitions, it is important to fully understand an individual's kinematic characteristics and use different trajectories according to the wind and field-of-view environments. Therefore, it is crucial that LDPs make trajectory choices based on crosswind and against-the-wind conditions during competition. This study found no differences in CHS and grip speed across different trajectories; therefore, LDPs need to analyse external factors, such as the constantly changing natural environment. This highlights the need for LDPs to assess and adapt to these conditions during competition. Conducting outdoor experiments and analyses during actual competitions is essential to validate these findings.

AUTHOR CONTRIBUTIONS

Daisuke Ichikawa (Drafting the work or revising, agreement to be accountable for all aspects of the work). Akihiko Sakai (The conception or design of the work). Takeru Suzuki (Drafting the revising). Taiki Miyazawa (Analysis of data). Isao Okuda (Interpretation of data for the work). John Patrick Sheahan (English editing and research support).

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DISCLOSURE STATEMENT

No potential conflict of interest were reported by the authors.

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REFERENCES

Bishop, C., Wells, J., Ehlert, A., Turner, A., Coughlan, D., Sachs, N., & Murray, A. (2024). Trackman 4: within and between-session reliability and inter-relationships of launch monitor metrics during indoor testing in high-level golfers. J Sports Sci, 41(63), 1-6. https://doi.org/10.1080/02640414.2024.2314864

Brennan, A., Murray, A., Mountjoy, M., Hellstrom, J., Coughlan, D., Wells, J., Brearley, S., Ehlert, A., Jarvis, P., Turner, A., & Bishop, C. (2024). Associations between physical characteristics and golf clubhead speed: a systematic review with meta-analysis. Sports Med. https://doi.org/10.1007/s40279-024-02004-5

Broadie, C., & Henrikson, E. (2022). Determining optimal launch and spin to maximize driver distance. 10th World Scientific Congress of Golf, Sanford Sports Science Institute (USA), 38. Retrieved from [Accessed 2024, June 10]: https://www.golfscience.org/wp-content/uploads/2022/12/Determining-Optimal-Launch-and-Spin-to-Maximize-Driver-Distance-Chris-Broadie.pdf

Broadie, M. (2008). Assessing golfer performance using golfmetrics. Science and Golf V: Proceedings of the 2008 World Scientific Congress of Golf, 253-262. Retrieved from [Accessed 2024, June 10]: http://www.columbia.edu/~mnb2/broadie/Assets/broadie_wscg_v_200804.pdf

Broadie, M. (2014). Every Shot Counts: Using the Revolutionary Strokes Gained Approach to Improve your Golf Performance and Strategy. New York: Avery.

Edgar, A. (2023). A dispute over golf balls. Sport Ethics Philos, 17(2), 125-126. https://doi.org/10.1080/17511321.2023.2200114

Fletcher, I. M., & Hartwell, M. (2004). Effect of an 8-week combined weights and plyometrics training program on golf drive performance. J Strength Cond Res, 18(1), 59-62. https://doi.org/10.1519/00124278-200402000-00008

Fried, H. O., Lambrinos, J., & Tyner, J. (2004). Evaluating the performance of professional golfers on the PGA, LPGA and SPGA tours. Eur J Oper Res, 154(2), 548-561. https://doi.org/10.1016/S0377-2217(03)00188-7

Holt, L. E., & Holt, J. (2013). Long driving: the Sadlowski case. Int J Golf Sci, 2(1), 86-91. https://doi.org/10.1123/ijgs.2.1.86

Hume, P. A., Keogh, J., & Reid, D. (2005). The role of biomechanics in maximising distance and accuracy of golf shots. Sports Med, 35(5), 429-449. https://doi.org/10.2165/00007256-200535050-00005

Ichikawa, D., Suzuki, T., Sheahan, J. P., Miyazawa, T., & Okuda, I. (2022). Relationship between variability in clubhead movement using a Doppler radar launch monitor and golf strokes across 15 driver shots. Int J Kinesiol Sports Sci, 10(4), 7-15. https://doi.org/10.7575/aiac.ijkss.v.10n.4p.7

Johansen, M., Aagaard, P., Gejl, K., Kvorning, T., & Bojsen-Møller, J. (2023). Influence of muscle strength, power, and rapid force capacity on maximal club head speed in male national level golfers. J Sports Sci, 41(9), 912-924. https://doi.org/10.1080/02640414.2023.2245998

Jowett, H., & Phillips, I. D. (2023). The effect of weather conditions on scores at the United States Masters golf tournament. Int J Biometeorol, 67(11), 1897-1911. https://doi.org/10.1007/s00484-023-02549-6

Keogh, J. W., Marnewick, M. C., Maulder, P. S., Nortje, J. P., Hume, P. A., & Bradshaw, E. J. (2009). Are anthropometric, flexibility, muscular strength, and endurance variables related to clubhead velocity in low- and high-handicap golfers? J Strength Cond Res, 23(6), 1841-1850. https://doi.org/10.1519/JSC.0b013e3181b73cb3

Malik, S., & Saha, S. (2021). Golf and Wind: The Physics of Playing Golf in Wind. https://doi.org/10.1007/978-981-15-9720-6

Miura, K. (2001). Parametric acceleration-the effect of inward pull of the golf club at impact stage. Sports Eng, 4(2), 75-86. https://doi.org/10.1046/j.1460-2687.2001.00071.x

Pelz, D., & Mastroni, N. (2004). Putt Like the Pros: Dave Pelz's Scientific Way to Improving Your Stroke, Reading Greens, and Lowering Your Score. London, UK: Aurum.

Pfitzner, C. B., & Rishel, D. T. (2005). Performance and compensation on the LPGA Tour: a statistical analysis. Int J Perform Anal Sport, 5(3), 29-39. https://doi.org/10.1080/24748668.2005.11868335

Thornes, J. E. (1977). The effect of weather on sport. Weather, 32(7), 258-268. https://doi.org/10.1002/j.1477-8696.1977.tb04568.x

ORIGINAL ARTICLE

The impact of visual occlusion during small-sided games on youth football players

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ABSTRACT

This study aimed to investigate the effects of playing with visual occlusion (OCC) during small-sided games (SSG) performed under different pitch sizes on youth players' physical and technical performance. The purpose was to understand how visual occlusion may influence players' behaviour and performance in game-based scenarios. Thirty youth football players from a U14 football academy participated in the study. The design involved a repeated-measures approach, with players exposed to different experimental conditions: normal situation (NOR) without OCC; OCC with an eye patch on the dominant foot's corresponding eye. The SSGs were performed on both small and large pitch sizes. Time-motion variables were computed using positional data, and technical analysis was based on video footage. A repeated measures analysis of variance was conducted to identify differences in the considered variables between the conditions. Although no significant effects were found in technical performance between NOR and OCC conditions, suggesting adaptability to OCC constraints, some trends were observed. Increasing pitch size in the NOR scenario led to higher physical demands and more touches with the dominant foot, while smaller pitches led to an increase in the number of passes. Larger pitches with OCC increased physical demands. Players tended to use their non-dominant foot more in smaller pitches with OCC. Furthermore, OCC in larger pitches significantly reduced the game pace, movements, and dribbling frequency, allowing more time for decision-making based on environmental information. Playing with visual occlusion may impact players' behaviour and performance, leading to adjustments in the use of dominant and non-dominant feet.

Keywords: Youth football, Visual occlusion, Dominance.

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INTRODUCTION

Football can be defined as a visually complex sport because, due to its highly situational nature, players must frequently adapt to rapidly changing dynamics (D'Isanto, 2019; Erickson, 2007). It is a sport that provides numerous opportunities to stimulate the visual system dynamically, given the need to make immediate decisions based on the demands of different phases of play (Alesi et al., 2015; Esposito & Raiola, 2020). To progressively improve players' decision-making and, consequently, their performance on the field, it could be very beneficial to start training visual skills from a young age (D'Elia, 2023; González-Víllora et al., 2015). Experienced footballers rely on perceptual-cognitive skills to recognize opponents' action patterns, triggering rapid selection of response and motor execution (De Waelle et al., 2021; Fadde & Zaichkowsky, 2018). Training such skills not only helps to better calculate the trajectory of the ball or anticipate the movements of teammates and opponents; it also greatly enhances peripheral vision, reaction times, and, above all, the ability to remain focused throughout the duration of the game (Esposito et al., 2019; 2020).

Although several studies have highlighted the importance of perceptual-cognitive skills prior to executing the pass and the influence of passing on overall performance in football (McGuckian et al., 2018; 2019; Müller & Abernethy, 2014), the number of studies examining the impact of perceptual-cognitive skills training on the technical fundamentals of passing is limited. A frequently used method to train perceptual-cognitive skills is visual occlusion, which involves limiting part of an athlete's vision while they are engaged in performing a specific motor task (Mann et al., 2010).

Visual occlusion is a concept that can be examined from various theoretical perspectives in the fields of perception and motor control (D'Elia et al., 2023). Two of these important perspectives are the ecological-dynamic approach and the Constraints-led approach (CLA). The ecological-dynamic approach emphasizes the importance of the surrounding environment and sensory information in organizing motor behaviour (Araujo et al., 2006; Correia et al., 2013). In this context, visual occlusion can be seen as a variation in the visual environment that affects how we perceive and respond to stimuli. This approach highlights how visual information is actively utilized by the motor system to guide behaviour (Raiola, 2017).

On the other hand, CLA focuses on the restrictions or constraints that influence motor behaviour. These constraints can be biomechanical, cognitive, or perceptual in nature (Altavilla, 2020; Newcombe et al., 2019). Visual occlusion can represent one of the perceptual constraints shaping motor behaviour. In this case, CLA examines how the presence of opponents and visual occlusion influence player choices and motor execution. Both of these theoretical perspectives provide a useful framework for understanding visual occlusion and its impact on motor behaviour. The choice of approach often depends on the specific study context and research objectives, but both underscore the importance of visual information and environmental or motor constraints in motor control.

Laterality in football is another relevant aspect to consider, as it can influence players' performances during the practice of this sport (Petro & Szabo, 2016). Laterality indicates the tendency to use one side of the body predominantly over the other, such as in the case of the dominant hand, foot, and eye. These aspects are closely related to motor coordination and can have a significant impact on agility, precision, and speed of actions on the field.

Several studies have investigated laterality in football players, focusing primarily on the use of the dominant foot in performing technical gestures (Bozkurt & Kucuk, 2018; Frontani et al., 2022; Zago et al., 2014).

However, attention to ocular dominance in football is limited, despite its potential crucial role in visual perception and reaction abilities during the game (Laksono & Rachman, 2020).

Some studies suggest that ocular dominance may be correlated with the ability to capture and process information more rapidly, providing players with an advantage in reading the field and making immediate decisions (Laby & Kirschen, 2011; Zouhal et al., 2018). However, despite these advantages, it can be beneficial to also train the non-dominant eye in young football players through occlusion of the dominant eye. This type of training aims to reduce any asymmetries in visual perception, improving peripheral vision and the ability to effectively use both feet during gameplay. A pronounced asymmetry between the dominant and non-dominant eye may also lead to a higher risk of injuries, as the body may not react adequately to unforeseen situations.

However, it is important to emphasize that the effectiveness of occlusion may vary significantly from one individual to another. Some footballers may benefit more from it, while for others, it may have a negligible or even negative impact on performance. Laterality is a highly individual aspect, and its influence on performance is subject to multiple variables, including the player's level of experience, the type of action performed, and the context of the game. Coaches and players should carefully consider the individual aspects of laterality and evaluate whether the use of visual occlusion could be helpful in enhancing specific performances during training sessions and matches (Vaeyens et al., 2007).

This study aimed to investigate the effects of playing with visual occlusion (OCC) during small-sided games (SSG) performed under different pitch sizes on youth players' physical and technical performance. The purpose was to understand how visual occlusion may influence players' behaviour and performance in game-based scenarios.

MATERIAL AND METHODS

Participants

Twenty Under-14 amateur football players (age: 12.6 ± 0.4; height: 170.5 ± 3.0; weight: 70.6 ± 3.8) who belonged to the same team competing at the regional level participated in this study. Each participant had a normal or corrected-to-normal vision and about 6 years of experience in the sport. The experimental procedure, risks and benefits were explained to the parents before participation. Informed consent was signed by the subjects' parents or legal guardians. The study adhered to the ethical code of the Declaration of Helsinki, and procedures were in line with established ethical standards in sports sciences (Winter & Maughan, 2009).

Study design

The methodology utilized a repeated measures approach, exposing players to various experimental conditions: normal situation (NOR) without visual occlusion, and visual occlusion with an eye patch covering the dominant foot's corresponding eye.

Small-sided games (SSG) were conducted on fields of different dimensions following the design outlined by Santos et al. (2022). The study employed a specialized training format called Gk+4vs4+Gk Small-Sided Game (SSG) to investigate the effects of different experimental scenarios on player performance. These scenarios included:

- Normal condition (NOR) in a small pitch size (40x30m): Players participated in SSG without visual occlusion, allowing uninhibited vision and movement within the smaller pitch dimensions.

- Visual occlusion (OCC) in a small pitch size (40x30m): Players wore eye patches covering the dominant foot's corresponding eye during SSG, simulating restricted vision to assess its impact within the smaller pitch area.
- Normal Condition in a larger pitch size (50x35m): Players engaged in SSG under normal conditions but within a larger pitch size, altering the spatial context compared to the smaller pitch.
- Visual Occlusion in a larger pitch size (50x35m): Players wore eye patches during SSG, similar to the previous condition, but in the context of the larger pitch size.

By implementing these conditions, the study aimed to examine the effects of increasing pitch size with and without visual occlusion, as well as the specific impacts of playing under visual occlusion in both small and large pitch sizes.

The testing procedures were carried out in six sessions on non-consecutive days. The first three sessions were devoted to familiarizing the players with the experimental scenarios. Subsequently, three evaluation sessions were conducted to assess the players' performance. After a warm-up period, players were introduced sequentially to a small and a large field. Within each field, players engaged in two 5-minute games interspersed with 2-minute rest periods, with a 10-minute break between field transitions. Therefore, each player participated in three 5-minute games per experimental scenario on both fields, for a total of 12 Small-Sided Games (SSG).

Data collection

The variables related to movement time were calculated using positional data (GPS), while the technical analysis was based on video recordings. A repeated measures analysis of variance was conducted to identify any differences between the conditions considered.

The data collection was conducted using highly precise instruments capable of recording both quantitative and qualitative data. In particular, the instruments deemed useful for the research included:

- GoPro HERO8: A high-frequency digital video camera (240 frames per second) used for image and video acquisition.
- K-50 Wearable Tech: A wearable GPS technology with a sampling frequency of 50 Hertz used for analysing workouts and matches.

Statistical analysis

Shapiro-Wilks tests were carried out to analyse if all variables were normally distributed within each group and evaluation moment. A repeated measures analysis of variance was conducted to identify differences in the considered variables between the conditions. Data were reported as Mean (SD) for all variables. Statistical significance was set at $p < .05$. Data analyses were performed using IMB SPSS Statistics (Version 27 for Windows; IBM, Armonk, NY, USA).

RESULTS

Table 1 presents the variations in variables measured across different game scenarios in soccer, divided by pitch size (small and large) and experimental condition (NOR: Normal situation without occlusion, OCC: Visual occlusion).

In terms of player movement, it was found that on larger pitches, players covered greater distances overall compared to smaller pitches ($p < .001$). Specifically, walking distances were significantly higher on smaller pitches ($p < .001$), while running distances were notably higher on larger pitches ($p < .001$). Sprinting distances also showed significant differences based on pitch size ($p < .002$).

Table 1. Variations in variables across different game scenarios.

Variables	Game Scenarios (mean ± SD)				F	p
	NOR small pitch	OCC small pitch	NOR large pitch	OCC large pitch		
Total distance covered (m)	499 ± 23.4	455 ± 41.8	525 ± 68.4	523 ± 63.7	12.6	<.001*
Walking (<7.0 km/h)	220.5 ± 22.3	228 ± 14.8	215.3 ± 25.7	244 ± 29.8	10.3	<.001*
Running (10.0 - 12.0 km/h)	37.2 ± 12.8	38.6 ± 14.2	65.4 ± 18.9	44.7 ± 26.8	8.7	<.001*
Sprinting (12.1 - 14.0 km/h)	18.1 ± 11.2	12.5 ± 10.1	21.6 ± 15.3	22.9 ± 13.6	5.92	<.002*
Shots						
Dominant foot	0.8 ± 0.6	1.0 ± 1.1	0.8 ± 0.8	1.0 ± 1.0	0.267	.779
Non-dominant foot	0.18 ± 0.3	0.30 ± 0.45	0.18 ± 0.3	0.12 ± 0.32	0.49	.697
On Target	0.5 ± 0.6	0.8 ± 0.8	0.6 ± 0.8	0.8 ± 0.8	0.611	.612
Off Target	0.4 ± 0.5	0.3 ± 0.4	0.3 ± 0.4	0.2 ± 0.5	0.29	.778
Dribbles						
Successful	1.2 ± 1.25	0.9 ± 1.07	1.5 ± 1.1	0.9 ± 1.2	0.954	.401
Unsuccessful	0.71 ± 0.91	0.59 ± 0.79	0.12 ± 0.8	0.3 ± 01.3	0.719	.524
Touches						
Dominant foot	14.1 ± 3.2	9.2 ± 6.1	13.8 ± 7.6	14.7 ± 7.3	2.67	.071
Non-dominant foot	4.8 ± 2.2	1.6 ± 1.7	2.6 ± 1.6	3.5 ± 2.0	1.48	.258
Passes						
Dominant foot	6.2 ± 2.7	5.1 ± 2.4	5.3 ± 2.5	4.9 ± 2.3	2.71	.071
Non-dominant foot	1.0 ± 0.9	0.9 ± 1.0	0.8 ± 0.8	0.4 ± 0.6	1.24	.312
Successful	6.1 ± 2.7	5.0 ± 2.4	4.6 ± 2.3	4.1 ± 2.0	4.03	.002*
Unsuccessful	1.2 ± 1.4	0.6 ± 0.8	1.0 ± 1.2	0.8 ± 0.9	0.724	.577

Interestingly, there were no significant differences observed in the number of shots taken with dominant and non-dominant feet across the different scenarios. Similarly, the success rate of dribbles did not vary significantly between experimental conditions.

When examining ball interactions, the number of touches with the dominant foot exhibited a trend towards significance between pitch sizes ($p = .071$), suggesting potential differences in ball control strategies. Notably, successful passes significantly differed between pitch sizes, with smaller pitches showing higher success rates ($p = .002$).

DISCUSSION

Despite no significant effects being observed on technical performance between the NOR and OCC conditions, suggesting that players adapt well to the constraints of visual occlusion, some trends emerged. Increasing the field size in the NOR condition resulted in greater physical demand and increased use of the dominant foot, while smaller fields led to an increase in the number of passes.

In larger fields with visual occlusion, higher physical demands were observed. Furthermore, players showed a greater propensity to use the non-dominant foot in smaller fields with visual occlusion. Visual occlusion in wider fields instead significantly slowed down the pace of play, movements, and dribbling frequency, making the decision-making process more influenced by environmental information. In larger fields, players covered greater distances and reached higher speeds during visual occlusion compared to the normal situation.

The results demonstrate how visual occlusion can influence players' behaviour and performance, leading to changes in the use of both dominant and non-dominant feet. Coaches might consider varying field dimensions to increase physical demands during training. Additionally, using smaller fields could be beneficial in emphasizing teamwork and encouraging players to effectively develop their non-dominant foot in visually occluded scenarios. It has been shown that performing under sub-optimal visual conditions can encourage individuals to use their limited viewing time more efficiently or to effectively utilize additional sensory information, such as auditory and/or proprioceptive cues (McGuckian et al., 2019). The reduction of visual information can potentially lead to a greater sense of attention, which in turn can focus attention externally to the task, rather than internally (Raiola, 2014; Wilkins & Appelbaum, 2019).

The use of spatial occlusion also allows for the improvement of basic visual perception, temporary attention, the ability to anticipate trajectories, and short-term memory. To date, two studies have been conducted using this particular form of visual occlusion, specifically in basketball and soccer (Dunton et al., 2019). Although research on spatial occlusion has provided a new paradigm for understanding how athletes utilize visual information to identify the outcomes of specific sports activities, there is currently a lack of studies examining the effectiveness of spatial occlusion as a training method. The analysis of laterality in football provides a clear understanding of the importance of this aspect on sports performance. It is a relevant aspect in football as it influences agility, precision, and speed of actions on the field. Aspects related to laterality, such as foot and eye dominance, can have a significant impact on motor coordination and, consequently, on the execution of technical movements.

Several studies have focused on analysing laterality in football players, primarily focusing on the use of the dominant foot during technical actions (Pietsch & Jansen, 2018; Stöckel & Carey, 2016; Verbeek et al., 2017). However, ocular dominance, despite its crucial role in visual perception and reaction abilities during gameplay, has often been overlooked. Ocular dominance appears to be correlated with the ability to quickly process information, providing an advantage to players in reading the field and making immediate decisions. Therefore, it is of paramount importance to carefully consider laterality, with particular attention to ocular dominance, in order to maximize individual performance in football.

The study's practical applications highlight the benefits of incorporating visual occlusion and varied field dimensions into football training sessions. By doing so, coaches can enhance players' adaptability, teamwork, decision-making skills, and overall performance on the field. This approach not only challenges players to excel under sub-optimal conditions but also fosters a deeper understanding of the role of laterality, particularly ocular dominance, in maximizing individual performance.

CONCLUSIONS

Playing with visual occlusion may impact players' behaviours and performance, leading to adjustments in the use of dominant and non-dominant feet. Coaches can consider adjusting pitch sizes to increase physical demands. Additionally, smaller pitches can be used to emphasize passing and encourage players to use their non-dominant foot effectively during OCC scenarios. Furthermore, implementing specific training drills that simulate visual occlusion scenarios can help players improve their decision-making and spatial awareness skills. Encouraging players to practice using both feet equally during regular training sessions can aid in developing ambidextrous skills, beneficial in various game situations. Providing feedback and reinforcement to players when they successfully use their non-dominant foot during matches or training exercises can reinforce the importance of this skill. Finally, incorporating video analysis sessions to review player performance during visual occlusion drills can identify areas for improvement or refinement in technique and decision-making.

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No potential conflict of interest were reported by the author.

REFERENCES

Alesi, M., Bianco, A., Padulo, J., Luppina, G., Petrucci, M., Paoli, A., Palma, A., & Pepi, A. (2015). Motor and cognitive growth following a Football Training Program. Frontiers in psychology, 6, 1627. https://doi.org/10.3389/fpsyg.2015.01627

Altavilla, G. (2020). Energetic cost in the different running conditions in team sport for the educational teaching method. Sport Science, 14(1), 17-20.

Araujo, D., Davids, K., & Hristovski, R. (2006). The ecological dynamics of decision making in sport. Psychology of sport and exercise, 7(6), 653-676. https://doi.org/10.1016/j.psychsport.2006.07.002

Bozkurt, S., & Kucuk, V. (2018). Comparing of technical skills of young football players according to preferred foot. International Journal of Human Movement and Sports Sciences, 6(1), 19-22. https://doi.org/10.13189/saj.2018.060103

Correia, V., Araújo, D., Vilar, L., & Davids, K. (2013). From recording discrete actions to studying continuous goal-directed behaviours in team sports. Journal of sports sciences, 31(5), 546-553. https://doi.org/10.1080/02640414.2012.738926

D'Elia, F., D'Isanto, T., Altavilla, G., Esposito, G., & Raiola, G. (2023). Does training with visual occlusion improve technical skills in Under-14 football players?. Acta Gymnica, 53, 1-5. https://doi.org/10.5507/ag.2023.004

D'Elia, F. (2023). External loading in football to discriminate the different performance model. Journal of Physical Education and Sport, 23(4), 1050-1055. https://doi.org/10.7752/jpes.2023.04131

De Waelle, S., Van Bostraeten, S., Lenoir, M., Deconinck, F. J., & Bennett, S. J. (2021). Visual cognition and experience mediate the relation between age and decision making in youth volleyball players. Optometry and Vision Science, 98(7), 802-808. https://doi.org/10.1097/OPX.0000000000001724

D'Isanto, T. (2019). Effectiveness and influence of some technical fundamentals on the game's quality in football. Journal of Human Sport and Exercise, 14(5), 2026-2030. https://doi.org/10.14198/jhse.2019.14.Proc5.24

Dunton, A., O'Neill, C., & Coughlan, E. K. (2019). The impact of a training intervention with spatial occlusion goggles on controlling and passing a football. Science and Medicine in Football, 3(4), 281-286. https://doi.org/10.1080/24733938.2019.1616106

Esposito, G., Ceruso, R., Valentini, M., & D'Isanto, T. (2019). The use of enabling tests to provide a qualitative measurement of the sport skill level of small soccer players. Journal of Human Sport and Exercise, 14(4proc), S592-S601. https://doi.org/10.14198/jhse.2019.14.Proc4.17

Esposito, G., D'Elia, F., & Raiola, G. (2020). A method to promote the Development of intelligence and game skills in youth football. Physical Education Theory and Methodology, 20(3), 142-148. https://doi.org/10.17309/tmfv.2020.3.03

Esposito, G., & Raiola, G. (2020). Monitoring the performance and technique consolidation in youth football players. Trends in Sport Sciences, 27(2). https://doi.org/10.23829/TSS.2020.27.2-6

Erickson, G. B. (2007). Sports vision: vision care for the enhancement of sports performance. Elsevier Health Sciences.

Fadde, P. J., & Zaichkowsky, L. (2018). Training perceptual-cognitive skills in sports using technology. Journal of Sport Psychology in Action, 9(4), 239-248. https://doi.org/10.1080/21520704.2018.1509162

Farrow, D., Abernethy, B., & Jackson, R. (2005). Probing Expert Anticipation with the Temporal Occlusion Paradigm: Experimental Investigations of some Methodological Issues. Motor Control, 9, 330-349. https://doi.org/10.1123/mcj.9.3.330

Frontani, F., Prenassi, M., Paolini, V., Formicola, G., Marceglia, S., & Policastro, F. (2022). Dominant and nondominant leg kinematics during kicking in young soccer players: a cross-sectional study. Motor Control, 27(2), 327-337. https://doi.org/10.1123/mc.2022-0017

González-Víllora, S., García-López, L. M., & Contreras-Jordán, O. R. (2015). Decision making and skill development in youth football players. Revista Internacional de Medicina y Ciencias de la Actividad Fisica y del Deporte, 15(59). https://doi.org/10.15366/rimcafd2015.59.005

Laby, D. M., & Kirschen, D. G. (2011). Thoughts on ocular dominance-is it actually a preference?. Eye & contact lens, 37(3), 140-144. https://doi.org/10.1097/ICL.0b013e31820e0bdf

Laksono, D. A., & Rachman, H. A. (2020). The Effect of Training Methods and Eye-Foot Coordination on Football Dribbling Ability. Journal of Physical Education, Sport, Health and Recreation, 9(1), 1-5.

Mann, D. L., Abernethy, B., & Farrow, D. (2010). Action specificity increases anticipatory performance and the expert advantage in natural interceptive tasks. Acta psychologica, 135(1), 17-23. https://doi.org/10.1016/j.actpsy.2010.04.006

McGuckian, T. B., Cole, M. H., Chalkley, D., Jordet, G., & Pepping, G.J. (2019). Visual exploration when surrounded by affordances: frequency of head movements is predictive of response speed. Ecological Psychology, 31(1), 30-48. https://doi.org/10.1080/10407413.2018.1495548

McGuckian, T. B., Cole, M. H., Jordet, G., Chalkley, D., & Pepping, G.J. (2018). Don't turn blind! The relationship between exploration before ball possession and on-ball performance in association football. Frontiers in psychology, 9, 2520. https://doi.org/10.3389/fpsyg.2018.02520

Müller, S., & Abernethy, B. (2014). An expertise approach to training anticipation using temporal occlusion in a natural skill setting. Technology, Instruction, Cognition and Learning, 9, 295-312.

Newcombe, D. J., Roberts, W. M., Renshaw, I., & Davids, K. (2019). The effectiveness of constraint-led training on skill development in interceptive sports: a systematic review (Clark, McEwan and Christie)-a commentary. International Journal of Sports Science & Coaching, 14(2), 241-254. https://doi.org/10.1177/1747954119829918

Petro, B., & Szabo, A. (2016). The impact of laterality on soccer performance. Strength and Conditioning Journal, 38(5), 66-74. https://doi.org/10.1519/SSC.0000000000000246

Pietsch, S., & Jansen, P. (2018). Laterality-specific training improves mental rotation performance in young soccer players. Frontiers in Psychology, 9, 319309. https://doi.org/10.3389/fpsyg.2018.00220

Raiola, G. (2014). Motor control and learning skills according to cognitive and ecological dynamic approach in a vision on behaviorism, cognitive, Gestalt and phenomenology theories. Mediterranean Journal of Social Sciences, 5(15), 504-506. https://doi.org/10.5901/mjss.2014.v5n15p504
Raiola, G. (2017). Motor learning and teaching method. Journal of Physical Education and Sport, 17, 2239-2243. https://doi.org/10.7752/jpes.2017.s5236
Santos, S., Gonçalves, B., Coutinho, D., Vilas Boas, G., & Sampaio, J. (2022). Visual occlusion effects on youth football players' performance during small-sided games. Plos one, 17(7), e0268715. https://doi.org/10.1371/journal.pone.0268715
Stöckel, T., & Carey, D. P. (2016). Laterality effects on performance in team sports: Insights from soccer and basketball. Laterality in sports, 309-328. https://doi.org/10.1016/B978-0-12-801426-4.00014-6
Vaeyens, R., Lenoir, M., Williams, A. M., & Philippaerts, R. M. (2007). Mechanisms underpinning successful decision making in skilled youth soccer players: An analysis of visual search behaviors. Journal of motor behavior, 39(5), 395-408. https://doi.org/10.3200/JMBR.39.5.395-408
Verbeek, J., Elferink-Gemser, M. T., Jonker, L., Huijgen, B. C., & Visscher, C. (2017). Laterality related to the successive selection of Dutch national youth soccer players. Journal of sports sciences, 35(22), 2220-2224. https://doi.org/10.1080/02640414.2016.1262544
Wilkins, L., & Appelbaum, L. (2019). An early review of stroboscopic visual training: insights, challenges and accomplishments to guide future studies. International Review of Sport and Exercise Psychology, 1-16. https://doi.org/10.1080/1750984X.2019.1582081
Winter, E. M., & Maughan, R. J. (2009). Requirements for ethics approvals. Journal of sports sciences, 27(10), 985-985. https://doi.org/10.1080/02640410903178344
Zago, M., Motta, A. F., Mapelli, A., Annoni, I., Galvani, C., & Sforza, C. (2014). Effect of leg dominance on the center-of-mass kinematics during an inside-of-the-foot kick in amateur soccer players. Journal of Human Kinetics, 42, 51. https://doi.org/10.2478/hukin-2014-0060
Zouhal, H., Abderrahman, A. B., Dupont, G., Truptin, P., Le Bris, R., Le Postec, E., Coppalle, S., Ravé, G., Brughelli, M., & Bideau, B. (2018). Laterality influences agility performance in elite soccer players. Frontiers in physiology, 9, 807. https://doi.org/10.3389/fphys.2018.00807

ORIGINAL ARTICLE

The interpersonal coordination constraint on the volleyball setter's decision-making on setting direction

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ABSTRACT

This study investigated the setter's decision-making on setting direction based on interpersonal (interaction between players) and extra personal (interaction between players and some place or object) coordination. The sample consisted of 86 sequences of play involving settings performed by males (n = 43) and females (n = 43). Fifty-nine spatiotemporal measures of interpersonal and extra personal coordination were obtained from the x and y coordinates of volleyball players' displacements using the TACTO software. Settings to each court zone were compared in relation to each spatiotemporal measure. Results showed that when the final area between attacker in the zone 3 and block was greatest and emerged from highest velocity, setters decided to set to zone 2. On the other hand, when the foregoing area was smallest and emerged from lowest velocity, setters decided to set to zones 3 and 4. It was concluded that the final area between attacker in the zone 3 and block and its emerging velocity constrained the setters' decision-making on setting direction. This study provides useful insights into the design of practice tasks in volleyball, suggesting that setters should be advised to be attuned to the interpersonal coordination involving attacker in the zone 3 and block.

Keywords: Performance analysis, Tactical behaviour, Team sport, Spatiotemporal interactions, Game analysis, Motor skill.

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INTRODUCTION

Understanding how volleyball players make decisions has increasingly been the focus of research in the last few years (e.g., Castro et al., 2022; Degrenne et al., 2023; Link & Raab, 2022; Lola & Tzetzis, 2021; Ramos et al., 2022; Suárez et al., 2020). This is because the game dynamic that emerges from the players' simultaneous interactions of cooperation and opposition requires they frequently make decisions as a *sine qua non* for successful performances.

Recently, a set of studies has been developed to comprehend how such decisions are made from an ecological dynamic perspective (e.g., Denardi et al., 2017, 2018, 2023). This implies investigating the team sport of volleyball as a dynamic system functioning at an ecological level of analysis, that is, in the context in which decisions are made (Araújo et al., 2006). The main assumption here is that in such context players make decisions based on constraints (e.g. affordances) emerging from spatiotemporal interpersonal and extra personal coordination (Passos et al., 2014). These coordinations have been referred as dynamic interactions between players and between them and some place or object in game context, respectively (Millar et al., 2013). On this concern, findings have pointed out that setters make decisions on tipping based on the gap size (area) formed by defenders (Denardi et al., 2017b). In addition, they have showed that in attacking phases setters decide to tip based on greater defending area and passing velocity than in counterattacking phase (Denardi et al., 2023).

Notwithstanding the advances in knowledge about the setters' decision-making, where they pass the ball to attack conclusion has been considered their main and most frequent decision-making (Ramos et al., 2017; Silva et al., 2013). This is because such setter's decision-making may generate optimal condition for attacking, which enables uncertainty or perturbation on opponents' responses (Costa et al., 2016; Sotiropoulos et al., 2019). A recent study by Sotiropoulos et al. (2019) investigated the setting zone choices by elite setters by considering the quality of the dig in two game phases: until the second counterattack (complex II) and from the third counterattack (complex III). The dig quality was rated by coaches based in statistical analyses of volleyball team performance. They also categorized the setting choices by considering the consequent attacking zone. Results showed that in the complex II, most digs were evaluated as good and related to the ball distribution to the zone 4. Differently, in the complex III many digs were of moderate quality. However, they were also related to the choice of zone 4 for male and zones 4 and 2 for females.

The present study aimed to extend the current findings about setters' decision-making on setting direction based on the interpersonal and extra personal coordinations. It appeared reasonable to consider that, similarly to several team sports, physical variables representing information emerging from players interactions could constrain the setter's decision-making on setting direction to different court zones.

METHOD

Sample

The sample consisted of 86 sequences of play involving settings performed by males (n = 43) and females (n = 43). They were randomly selected from 20 volleyball games played during the 40th edition of the men and women's Paulista Championship 2013-Division I. This is one of the largest Brazilian professional championships of volleyball, held in the São Paulo state, from which participated about 6 male and 10 female teams, approximately 190 players and 30 setters. The research protocol was given ethical approval by the local Institutional Review Board.

Procedures

The sequences of the game were randomly selected from digital video footage of the aforementioned games. They were recorded by a digital camera (Casio HS EX-FH100) located above and behind the volleyball court. Images were captured in a frequency of 30 Hz and posteriorly adjusted to 25 Hz, using the Video Converter Factory software.

Specifically, the displacements of all players were edited through TACTO software (Duarte et al., 2010; Fernandes et al., 2010), from the moment the receiver touched the ball (initial moment "*I*") to the moment the setter touched the ball (final moment "*F*"). The receiver was defined as the player who touches the ball before the setter. This procedure consisted of following the players' working point (projection of the centre of gravity of each individual player on the floor) in a slow-motion video image (frequency = 2 Hz), using a computer mouse.

This procedure allows the acquisition of the virtual *x* and *y* coordinates of each displacement trajectory (i.e., in pixels). After that, these coordinates were transformed into real coordinates by direct linear transformation (DLT2D) software and filtered with a low-pass filter (6 Hz) (Winter, 2005). This method considers the *z*-coordinates to be equal to zero and directly correlates an object point located in the object space/plane with a corresponding image point on the image plane (Duarte et al., 2010; Fernandes et al., 2010).

The player's *x* and *y* coordinates of displacement trajectories and the calibration references were inserted into RStudio software (2022.02.3 version), from which the following spatiotemporal measures of interpersonal coordination (gaps) (Figure 1) were calculated. These measures were defined based on their importance to setters' decision-making on setting distribution (Denardi et al., 2017b; Gouvêa & Lopes, 2007).

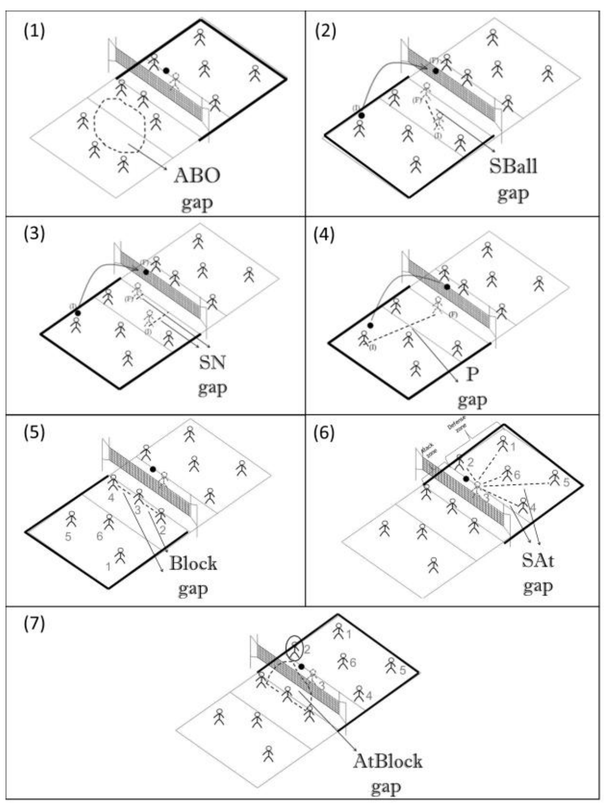

Figure 1. Illustration of spatiotemporal measures of interpersonal and extra personal coordination.

(1) *ABO gap* (Figure 1-1): *Area between opponents in the initial and final moments* [*(ABO) I, (ABO) F*]. This was calculated by the equation:

$$A = \left|(x_1 y_2 - y_1 x_2) + (x_2 y_3 - y_2 x_3) \ldots + (x_n y_1 - y_n x_1)/2\right|,$$

where x_1 refers to the coordinate *x* of player 1, y_n refers to the coordinate *y* of player *n*, and so on.

(2) *SBall* gap (Figure 1-2): *Displacement of the setter to reach the ball* [*d(SBall)*]. It was calculated by the equation:

$$d = \sqrt[2]{(SI_x - SF_x)^2 + (SI_y - SF_y)^2},$$

where *d* refers to the distance between setter position in the initial (SI) and final (SF) moments, according to *x* and *y* axes.

(3) *SN* gap (Figure 1-3): *Distance between setter and net in the initial and final moments* [*d(SN) I, d(SN) F*]. This was calculated by the equation:

$$d = \sqrt[2]{(S_x - N_x)^2 + (S_y - N_y)^2},$$

where *d* refers to the distance between setter (S) and net (N), according to *x* and *y* axes.

(4) *P* gap (Figure 1-4): *Passing distance – displacement of the ball from receiver to setter* [*d(P)*]. This was calculated by the equation:

$$d = \sqrt[2]{(R_x - S_x)^2 + (R_y - S_y)^2},$$

where *d* refers to the distance between receiver (R) to setter (S), according to *x* and *y* axes.

(5) *Block* gap (Figure 1-5): *Distance between blockers (zones 2, 3, and 4) in the initial and final moments* [*d(Block 2-3) I/F, d(Block 3-4) I/F*]. This was calculated by the equation:

$$d = \sqrt[2]{(B1_x - B2_x)^2 + (B1_y - B2_y)^2},$$

where *d* refers to the distance between a blocker (B1) and the next blocker (B2), according to *x* and *y* axes.

(6) *SAt* gap (Figure 1-6): *Distance between setter and attackers (zones 1, 3, 4, 5 and 6) in the initial and final moments* [*d(SAt 1) I/F, d(SAt 3) I/F, d(SAt 4) I/F, d(SAt 5) I/F, d(SAt 6) I/F*]. This was calculated by the equation:

$$d = \sqrt[2]{(S_x - At_x)^2 + (S_y - At_y)^2},$$

where *d* refers to the distance between setter (S) and attacker (At), according to *x* and *y* axes.

(7) *AtBlock* gap (Figure 1- 7): *Area between attackers in the zones 1, 3, 4, 5 and 6, (named attackers 1, 3, 4, 5, and 6, respectively) and block (zones 2, 3, and 4) in the initial and final moments* [*(At1Block) I/F, (At3Block) I/F, (At4Block) I/F, (At5Block) I/F and (At6Block) I/F*]. This was calculated by the equation:

$$A = \left|(x_1 y_2 - y_1 x_2) + (x_2 y_3 - y_2 x_3) \ldots + (x_n y_1 - y_n x_1)/2\right|,$$

where x_1 refers to the coordinate *x* of player 1, y_n refers to the coordinate *y* of player *n*, and so on.

These measures were also analysed in terms of their rates of changing from initial to final moments. For this purpose, the changing velocity was calculated through:

$v = [(mF – mI) / t]$,

where *v* was the velocity, *mF* was the final value of the measure, *mI* was the initial value of the measure, and *t* referred to time between both initial and final moments. And the *variability* was calculated by:

$CV = \sigma / \mu$

where *CV* is the ratio of variability, σ refers to the standard deviation, and μ is the arithmetic mean of the measure from initial to final moment. The foregoing measures are summarized in the Table 1.

Table 1. Summary of the spatiotemporal measures of interpersonal(*) and extra personal(**) coordination.

	Variables	Description
1	(ABO) I	Area between opponents in the initial moment(*)
2	(ABO) F	Area between opponents in the final moment(*)
3	v(ABO)	Changing velocity of the area(*)
4	CV(ABO)	Variability of the area(*)
5	d(SBall)	Displacement of the setter to reach the ball(**)
6	v(SBall)	Setter's velocity of displacement to reach the ball(**)
7	CV(SBall)	Variability of displacement of the setter to reach the ball(**)
8	d(SN) I	Distance between setter and net in the initial moment(**)
9	d(SN) F	Distance between setter and net in the final moment(**)
10	d(P)	Passing distance – displacement of the ball from receiver to setter(*)
11	v(P)	Passing velocity(*)
12	d(B 2-3) I	Distance between blockers 2 and 3 in the initial moment(*)
13	d(B 2-3) F	Distance between blockers 2 and 3 in the final moment(*)
14	d(B 3-4) I	Distance between blockers 3 and 4 in the initial moment(*)
15	d(B 3-4) F	Distance between blockers 3 and 4 in the final moment(*)
16	v(B 2-3)	Velocity of approaching/moving away of blockers 2 and 3(*)
17	v(B 3-4)	Velocity of approaching/moving away of blockers 3 and 4(*)
18	CV(B 2-3)	Variability of approaching/moving away of blockers 2 and 3(*)
19	CV(B 3-4)	Variability of approaching/moving away of blockers 3 and 4(*)
20	d(SAt1) I	Distance between setter and attacker 1 in the initial moment(*)
21	d(SAt1) F	Distance between setter and attacker 1 in the final moment(*)
22	d(SAt3) I	Distance between setter and attacker 3 in the initial moment(*)
23	d(SAt3) F	Distance between setter and attacker 3 in the final moment(*)

24	d(SAt4) I	Distance between setter and attacker 4 in the initial moment(*)
25	d(SAt4) F	Distance between setter and attacker 4 in the final moment(*)
26	d(SAt5) I	Distance between setter and attacker 5 in the initial moment(*)
27	d(SAt5) F	Distance between setter and attacker 5 in the final moment(*)
28	d(SAt6) I	Distance between setter and attacker 6 in the initial moment(*)
29	d(SAt6) F	Distance between setter and attacker 6 in the final moment(*)
30	v(SAt1)	Velocity of approaching/moving away of setter and attacker 1(*)
31	v(SAt3)	Velocity of approaching/moving away of setter and attacker 3(*)
32	v(SAt4)	Velocity of approaching/moving away of setter and attacker 4(*)
33	v(SAt5)	Velocity of approaching/moving away of setter and attacker 5(*)
34	v(SAt6)	Velocity of approaching/moving away of setter and attacker 6(*)
35	CV(SAt1)	Variability of approaching/moving away of setter and attacker 1(*)
36	CV (SAt3)	Variability of approaching/moving away of setter and attacker 3(*)
37	CV (SAt4)	Variability of approaching/moving away of setter and attacker 4(*)
38	CV (SAt5)	Variability of approaching/moving away of setter and attacker 5(*)
39	CV (SAt6)	Variability of approaching/moving away of setter and attacker 6(*)
40	(At1Block) I	Area between attacker 1 and block in the initial moment(*)
41	(At1Block) F	Area between attacker 1 and block in the final moment(*)
42	(At3 Block) I	Area between attacker 3 and block in the initial moment(*)
43	(At3 Block) F	Area between attacker 3 and block in the final moment(*)
44	(At4 Block) I	Area between attacker 4 and block in the initial moment(*)
45	(At4 Block) F	Area between attacker 4 and block in the final moment(*)
46	(At5 Block) I	Area between attacker 5 and block in the initial moment(*)
47	(At5 Block) F	Area between attacker 5 and block in the final moment(*)
48	(At6 Block) I	Area between attacker 6 and block in the initial moment(*)
49	(At6 Block) F	Area between attacker 6 and block in the final moment(*)
50	v(At1 Block)	Changing velocity of the area At1 Block(*)
51	v(At3 Block)	Changing velocity of the area At3 Block(*)
52	v(At4 Block)	Changing velocity of the area At4 Block(*)
53	v(At5 Block)	Changing velocity of the area At5 Block(*)
54	v(At6 Block)	Changing velocity of the area At6 Block(*)
55	CV(At1 Block)	Variability of the area At1 Block(*)
56	CV(At3 Block)	Variability of the area At3 Block(*)
57	CV(At4 Block)	Variability of the area At4 Block(*)
58	CV(At5 Block)	Variability of the area At5 Block(*)
59	CV(At6 Block)	Variability of the area At6 Block(*)

Statistical procedures

An ANOVA was run for each spatiotemporal measure to compare the settings to each zone. As the number of settings was different for each zone, in order to make inferential comparison possible, the *Fdr* method of the function *p.adjust* was used to adjust each ANOVA *p* value. Observed significant effects were followed up by use of Tukey-Kramer post-hoc. The settings of males and females were analysed together because separately there were some conditions which did not allow statistical comparison. For instance, female players performed only 2 settings to zone 1. In addition, there was no setting to zone 6. In sum, the number of settings to zones 1, 2, 3, 4, 5, and 6 were 7, 28, 11, 35, and 5, respectively. For all analyses, the level of significance was set at $p < .05$.

RESULTS

The ANOVAs' results revealed effects only for two spatiotemporal measures: *At3 Block* ($F_{4,81}$ = 7.605, p = .0017, ηp^2 = 0.27) and *vAt3 Block* ($F_{4,81}$ = 5.427, p = .0187, ηp^2 = 0.21). It was verified that in settings to zone 2, the final area between attacker 3 and block *(At3 Block)* was larger (M = 9.58 m^2) than those areas of the zones 1 (M = 5.98 m^2), 3 (M = 5.17 m^2), and 4 (M = 6.85 m^2) (p < .01). It was also revealed that the changing velocity of this same area (*At3 Block*) was larger (M = 2.28 m/s) than those of the zones 3 (M = 0.90 m/s) and 4 (M = 0.24 m/s) *(p* < .01) (Figure 2).

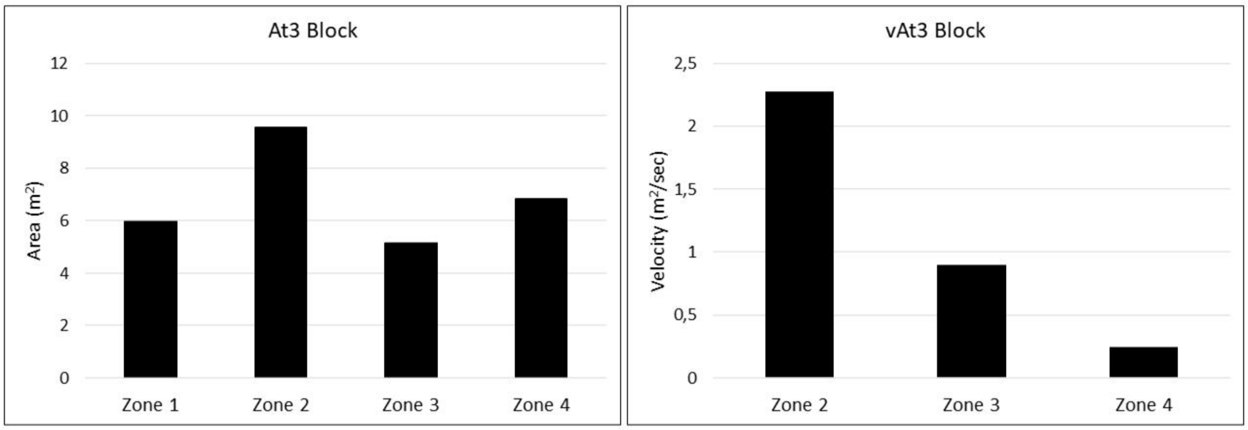

Figure 2. Illustration of difference revealed by the statistical analyses by considering the area (m^2) and area velocity (m^2/sec).

DISCUSSION

This study investigated the volleyball setters' decision-making on setting direction based on physical measures of interpersonal and extra personal coordination. Results showed effects for two interpersonal ones, that is, when the final areas between attacker 3 and block were greatest and they emerged from highest velocity, setters decided to set to zone 2. In an opposite vein, when the final areas between attacker 3 and block were smallest and they emerged from lowest velocity, setters made the decision to set to zones 3 and 4.

It is possible that, when setters decided to set to zone 2 (where opposite and middle hitters played), attacker 3 and block were further away each other in the moment of the setting. The fast velocity culminating in a greater area involving the block probably occurred because the middle hitters were preparing an attack in a fast tempo, which did not allow a double or triple block formation (Afonso et al., 2005; Costa et al., 2016; Marcelino et al., 2014; Tsavdaroglo et al., 2018). Conversely, when setters decided to set to zones 3 and 4, attacker 3 and block were closer each other in the moment of the setting, and this area, from receiver to setter, slowly changed, compared to zone 2.

It can also be thought that the slow velocities could be related to middle hitter and block, which were already positioned in their cover zones. And the fast velocities could mean that these players were organising themselves for an unusual play, with the middle hitter carrying out a one-leg attack, when the setter was in the front court (Palao et al., 2007). In this last scenario, the block formation is made difficult, being easier to be explored.

In addition, it is possible that the fast middle hitters' displacement resulting in a gap between them and block constrained setters to pass the ball to a zone where block would not be well-positioned (zone 2), compared to the other settings when they were in the front court (zones 3 and 4). Indeed, the setter aims to build favourable block situations to hitters (Matias & Greco, 2012). For instance, Castro and Mesquita (2008) suggest that the exploration of the zone 4 external offensive space allows the attacker to take advantage over opponent block, not only because of the most block displacement demand, but because in this zone is positioned the poor blocker, the setter.

These findings provide support for ecological dynamics perspective's propositions about physical variables of players interaction functioning as constraints on volleyball players' decision-making (e.g., Denardi et al., 2017, 2018, 2023). Specifically, the area and its emerging velocity represented a kind of collective behaviour involving attacker and defenders interactions that constrained setter's decision-making.

It is interesting to note that, unlike other team sports, the variability of interactions between volleyball players did not function as an informational variable constraining the setters' decision-making. For instance, studies have shown that in the team sport of futsal the variability of players' interpersonal coordination plays important role in the successful decision making (Corrêa eta al., 2016, 2020). Given the importance of variability in the performance of motor skills (Corrêa et al., 2015), its role in volleyball players' decision-making should be further investigated.

In summary, the results of this study allow us to conclude that the final area between attacker 3 and block and its velocity constrained the setters' decision-making on ball distribution to different court zones. This study provides useful insights into the design of practice tasks in volleyball, suggesting that setters should be advised to be attuned to the interpersonal coordination involving attacker 3 and block. Future studies should investigate such decision-making by considering the different game stages (throughout the sets) and status (when the team is winning and losing).

AUTHOR CONTRIBUTIONS

Renata Alvares Denardi: contributed to all stages of research development. Fabian Alberto Romero Clavijo: contributed mainly to the elaboration of the method and analysis of the results. Tatyane De Souza Santana: mainly contributed to data collection and text review. Thiago Augusto Costa De Oliveira: mainly contributed to the elaboration of the method and analysis of the results. Umberto Cesar Corrêa: contributed to analysing the results and writing the article.

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DISCLOSURE STATEMENT

No potential conflict of interest were reported by the authors.

REFERENCES

Afonso, J., Mesquita, I., & Palao, J.M. (2005). Relationship between the use of commit-block and the numbers of blockers and block effectiveness. International Journal of Performance Analysis in Sport, 5(2), 36-45. https://doi.org/10.1080/24748668.2005.11868326

Araújo, D., Davids, K., & Hristovski, R. (2006). The ecological dynamics of decision making in sport. Psychology of Sport and Exercise, 7, 653-676. https://doi.org/10.1016/j.psychsport.2006.07.002

Castro, J., & Mesquita, I. (2008). Estudo das implicações do espaço ofensivo nas características do ataque no Voleibol masculino de elite. [Study of the implications of offensive space on attack characteristics in elite men's volleyball.]. Revista Portuguesa de Ciências do Desporto, 8(1), 114-125. https://doi.org/10.5628/rpcd.08.01.114

Castro, H.O., Praça, G.M., Mesquita, I.M.R., Afonso, J., Costa, G.D.T., Moreno, M.P., Morales, J.C.P., & Greco, P.J. (2022). The impact of pendular model on decision-making and tactical-technical performance of U18 male volleyball players. International Journal of Sports Science and Coaching, 17(4), 792-803. https://doi.org/10.1177/17479541211048586

Corrêa, U.C., Benda, R.N., Oliveira, D.L., Ugrinowitsch, H., Freudenheim, A.M., Tani, G. Different faces of variability in the adaptive process of motor skill learning. (2015). Nonlinear Dynamics, Psychology and Life Sciences, 19, 465-487.

Corrêa, U.C.; Bastos, F.H., Silva, S.L., Clavijo, F.A.R., & Torriani-Pasin, C. (2020). Higher variability in dyadic interaction plays a positive role in the decision making of futsal passing. Kinesiology, 52, 290-298. https://doi.org/10.26582/k.52.2.17

Costa, G.C.T., Ceccato, J.S., Evangelista, B.F.B., Freire, A.B., Oliveira, A.S., Milistetd, M., Rodrigues, H.A., & Ugrinowitsch, H. (2016). Tactic determinants of game practiced by middle attacker in men's volleyball. Revista Brasileira de Cineantropometria e Desempenho Humano, 18(3), 371-379. https://doi.org/10.5007/1980-0037.2016v18n3p371

Degrenne, O., Langlois, V., Paulo, A., Éloi, S., & Mouchet, A. (2023). The role of performance analysis within the coaching process: Dealing with failure in volleyball side out attack. Movement and Sports Sciences - Science et Motricite, 119, 47-60. https://doi.org/10.1051/sm/2022025

Denardi, R.A., Clavijo, F.A.R., Oliveira, T.A.C., Silva, S.L., Travassos, B., & Corrêa, U.C. (2017). The influence of defender's positional gap on the aces in the sport of volleyball. Journal of Human Sport and Exercise, 12, 286-293. https://doi.org/10.14198/jhse.2017.122.05

Denardi, R.A., Clavijo, F.A.R., Oliveira, T.A.C., Ugrinowitsch, H., & Corrêa, U.C. (2023). The volleyball setter's decision-making on tipping in different game phases. Journal of Human Sport and Exercise, 18(3), 709-718. https://doi.org/10.14198/jhse.2023.183.17

Denardi, R.A., Farrow, D., & Corrêa, U.C. (2018). The influence of the first pass on the volleyball blocker's decision-making. Journal of Physical Education, 29, e-2951. https://doi.org/10.4025/jphyseduc.v29i1.2951

Duarte, R., Araújo, D., Fernandes, O., Fonseca, C., Correia, V., Gazimba, V., ... Lopes, J. (2010). Capturing complex human behaviours in representative sports contexts with a single camera. Medicina, 46, 408-414. https://doi.org/10.3390/medicina46060057

Fernandes, O., Folgado, H., Duarte, R., & Malta, P. (2010). Validation of the tool for applied and contextual time-series observation. International Journal of Sport Psychology, 41, 63-64.

Gouvêa, F. L., & Lopes, M. B. S. (2007). Analysis of offensive actions distribution (settings) in junior female volleyball. Revista do Instituto de Ciências da Saúde, 25(4), 337-44.

Link, D., & Raab, M. (2022). Experts use base rates in real-world sequential decisions. Psychonomic Bulletin and Review, 29 (2), 660-667. https://doi.org/10.3758/s13423-021-02024-6

Lola, A.C., & Tzetzis, G.C. (2021). The effect of explicit, implicit and analogy instruction on decision making skill for novices, under stress. International Journal of Sport and Exercise Psychology, 1-21. https://doi.org/10.1080/1612197X.2021.1877325

Marcelino, R., Afonso, J., Moraes, J.C., & Mesquita, I. (2014). Determinants of attack players in high-level men's volleyball. Kinesiology, 46(2), 234-41.

Matias, C.J.A.S., & Greco, P.J. (2012). A exploração tática efetuada pelo levantador de voleibol na organização do sistema ofensivo à luz das ações adversárias. [Tactical exploration of volleyball setters in the organization of the offensive system according to opponent actions] Revista Mineira de Educação Física, 1(Special Edition), 7, 297-306.

Millar, S. K., Oldham, A. R. & Renshaw, I. (2013). Interpersonal, intrapersonal, extrapersonal? Qualitatively investigating coordinative couplings between rowers in Olympic sculling. Nonlinear Dynamics Psychology, and Life Science, 17, 425-443.

Palao, J.M., Santos J.A., & Ureña A. (2007). Effect of the manner of spike execution on spike performance in volleyball. International Journal of Performance Analysis in Sport, 7(2), 126-138. https://doi.org/10.1080/24748668.2007.11868402

Passos, P., Araújo, D., Travassos, B., Vilar, L., & Duarte, R. (2014). Interpersonal coordination tendencies induce functional synergies through co-adaptation processes in team sports. In K. Davids, R. Hristovski, D. Araújo, N. B. Serre, C. Button, & P. Passos (Eds.), Complex systems in sport (104-124). Routledge.

Ramos, A., Coutinho, P., Silva, P., Davids, K., & Mesquita, I. (2017). How players exploit variability and regularity of game actions in female volleyball teams. European Journal of Sport Science, 17(4), 473-481. https://doi.org/10.1080/17461391.2016.1271459

Ramos, F.J.V., González, P.I.S., & de Pablos Pons, J. (2022). Decisional profile, gender and sports practice in sports at school age. Retos, 43, 379-387. https://doi.org/10.47197/retos.v43i0.88909

Silva, M., Lacerda, D., & João, P. (2013). Match analysis of discrimination skills according to the setter attack zone position in high level volleyball. International Journal of Performance Analysis in Sport, 13(2), 452-460. https://doi.org/10.1080/24748668.2013.11868661

Sotiropoulos, K., Barzouka, K., Tsavdaroglou, S., & Malousaris, G. (2019). Comparison and assessment of the setting zone choices by elite male and female volleyball setters in relation to the quality of defence. Facta Universitatis Series Physical Education and Sport, 17, 57-68. https://doi.org/10.22190/FUPES190222008S

Suárez, M.C., Serenini, A.L.P., González-Silva, J., & Arroyo, M.P.M. (2020). Factors used to make appropriate decisions in youth categories in volleyball. Sustainability, 12(14), 5633. https://doi.org/10.3390/su12145633

Tsavdaroglou, S., Sotiropoulos, K., & Barzouka, K. (2018). Comparison and assessment of the setting zone choices by elite male and female volleyball setters in relation to opposing block organization. Journal of Physical Education and Sport, 18(Sup. 5), 2147 - 2152. https://doi.org/10.7752/jpes.2018.s5325

Winter, D. A. (2005). Biomechanics and motor control of human movement (3rd ed.). New York: John Wiley & Sons. Inc.

ORIGINAL ARTICLE

Impact of game format and age group on technical performance in youth football: A comprehensive analysis

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ABSTRACT

This study aimed to analyse technical action variations among 5, 7, 9, and 11-a-side game formats and investigate the effects of age groups (U8, U10, U12, and U14) on these actions. A total of 197 soccer players aged between 6.94 ± 0.7 and 13.46 ± 0.5 years participated, with three matches conducted weekly, totalling 48 matches. Two-way ANOVA was employed to analyse age group and game format as independent factors. The study revealed the influence of age group on players' technical actions variability: front pass success $p < .001$; side pass success $p < .001$; back pass success $p < .001$; short pass success $p < .001$; reception success $p < .001$; goal $p < .002$; unsuccessful short pass $p < .001$; unsuccessful long pass $p < .001$; ball contacts $p < .001$. Additionally, the study highlighted the impact of game format on success rates: front pass success $p < .001$; side pass success $p < .001$; back pass success $p < .001$; short pass success $p < .001$; reception success $p < .001$; goal $p < .036$; shot on target $p < .001$; ball contacts $p < .001$; interception $p < .001$. These findings enhance understanding of how game format and age group affect technical performance in youth soccer, emphasizing the need for interventions that optimize players' development trajectories.
Keywords: Performance analysis, Youth football, Game formats, Technical actions, Age groups, Player development.

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INTRODUCTION

Football is a phenomenon with a widespread impact on society. Consequently, interest in developing the sport has increased over the years, seeking to improve collective and individual performance. One of the most significant axes of strategic growth in football is the development of young players. This is because it can lead to higher levels of sports performance and increase the profitability of player transactions.

However, during football matches, various constraints can influence sports performance, including environmental, structural, and functional constraints (Coutinho, Gonçalves, Travassos, Folgado, Figueira, & Sampaio, 2020; Heuvelmans, Di Paolo, Benjaminse, Bragonzoni, & Gokeler, 2024; Joode, 2023; Teune, Woods, Sweeting, Inness, & Robertson, 2022). In this context, it becomes crucial to provide appropriate match-play conditions for young players, ensuring that variables such as field size, number of players, and match durations are effectively adapted to the age and characteristics of the participants (Castellano, Puente, Echeazarra, Usabiaga, & Casamichana, 2016; Serra-Olivares, García-López & Gonçalves, 2019; García-Angulo, Palao, Giménez-Egido, García-Angulo, & Ortega-Toro, 2020). This is essential for contributing to the development of their physical, tactical, technical, and psychological demands (Brito, Roriz, Duarte, & Garganta, 2018).

Previous studies suggest that the number of technical actions is greater in the 8-a-side game format compared to 11-a-side (Joo, Hwang-Bo, & Jee, 2016); the chance of a shot on goal is greater in 5-a-side game format compared to 7-a-side and 8-a-side game formats in U10 age-group (Lapresa, Arana, Amatria, Fernández, & Anguera, 2017); and there are more technical actions in the 4-a-side game format compared to 8-a-side (Fenoglio, 2004). In summary, comparisons between formats suggest that individual frequencies of technical actions tend to increase in formats with fewer players (Clemente, Chen, Bezerra, Guiomar, & Lima, 2018; Bergmann, Braksiek, & Meier, 2022; Clemente & Sarmento 2020).

Despite these pedagogical insights, uncertainties persist regarding the variability of young players' technical actions between different game formats (Bergmann et al., 2022) and the effects of different age-groups on their respective technical actions. Assessing the technical performance of young players in different game formats can be relevant for developing and optimizing match-play conditions, ultimately enhancing player involvement, enjoyment, and satisfaction, leading to continued participation (Machado, Ribeiro, Palheta, Alcântara, Barreira, Guilherme, Garganta, & Scaglia, 2019; Hill, & Green, 2008). To observe and analyse technical performance patterns, such as the predominant technical actions during soccer games, notational analysis (James, 2006; Clemente, Couceiro, Martins, & Mendes, 2012) and/or observational analysis (Martone, Giacobbe, Capobianco, Imperlini, Mancini, Capasso, Buono, & Orrù, 2017; Lemes, Luchesi, Diniz, Bredt, Chagas, & Praça, 2020) are considered valuable and widely used tools. Manipulating game variables such as pitch size and player numbers to align with specific age-groups becomes pivotal for optimizing player development trajectories (Brito et al., 2018).

Research in this area has primarily focused on older age groups and elite levels of performance, emphasizing physical or time-motion variables. Studying the impact of game format becomes even more significant when considering the long-term development plan for younger players, highlighting the importance of understanding the effects of game format on technical actions across different age-groups.

Regarding younger age-groups, participation in adult versions of the game can hinder player development due to individual participation limitations. Authors have shown that skill development was greater in adapted game conditions with smaller areas and fewer players (Amatria, Lapresa, Arana, Anguera, & Garzón, 2016;

García-Angulo, Ortega-Toro, Giménez-Egido, Olmedilla, García-Mas, & Manuel Palao, 2021). Furthermore, comparing different match formats within the same age-group revealed significant differences in attacking plays and chances created, emphasizing the need to tailor match formats to specific developmental needs. Bergmann et al. (2022) compared 5-a-side and 7-a-side formats and found that U9 players perform more tactical decisions and technical actions in the smaller match format, with greater levels of effectiveness. Such findings underscore the importance of adapting match formats to optimize player engagement and development.

Therefore, this study aimed (1) to analyse the variations of technical actions between 5-a-side, 7-a-side, 9-a-side, and 11-a-side game formats; and; (2) to investigate the effects of different age-groups (U8, U10, U12, and U14) in technical actions. It was hypothesized that the different game formats and age-groups would induce differences in the success rates of technical actions of the young football players. By exploring variations in technical performance patterns, we aim to inform practical decisions for coaches and administrators, ultimately fostering an environment conducive to player development and enjoyment. Specifically, we hypothesize that both game formats and age-groups will exert discernible effects on success rates in the technical performance of young soccer players.

METHODS

Participants

One hundred and ninety-seven Portuguese youth football players from the U8, U10, U12, and U14 age-groups, participated in this study (Table 1). Participant selection, both teams and individual players, adhered to the following criteria: (1) teams and players registered at the Porto Football Association championship and (2) teams and players with similar competitive level.

Participants and their tutors were fully informed about the study's objectives, design, procedures, requirements, implications, benefits, and risks prior to their involvement. Given that participants were minors, written consent was obtained from their respective tutors. The study protocol adhered to the guidelines outlined in the Declaration of Helsinki and received approval from the Ethics Committee of the Faculty of Sport at Porto University.

Table 1. Description of player subsamples.

	U8 (*n* = 53)	**U10 (*n* = 44)**	**U12 (*n* = 41)**	**U14 (*n* = 59)**	***F***	***p***	**Post hoc (Bonferroni)**
Age (Y)	6.94±0.72	8.52±0.66	11.24±0.44	13.46±0.50	1282.65	<.001	a,b,c,d
Height (cm)	125.36±6.04	134.57±6.85	146.80±6.49	159.16±7.78	250.13	<.001	a,b,c,d
Weight (Kg)	27.16±5.75	34.70±7.49	41.57±7.47	49.89±8.89	91.02	<.001	a,b,c,d
Body-mass (Kg/m^2)	17.37±3.92	18.93±2.87	19.11±1.78	19.51±1.68	6.33	<.001	a
Soccer practice (h/week)	2.18±0.28	2.38±0.31	3.09±0.38	3.38±0.12	26.17	<.001	a,b,c,d
Soccer experience (years)	2.06±0.86	3.04±0.91	3.58±1.46	3.68±1.19	23.01	<.001	a,e

Note. Significant differences are identified as (a) U8 vs U10; U8 vs U12; U8 vs U14, (b) U10 vs U8; U10 vs U12; U10 vs U14, (c) U12 vs U8; U12 vs U10; U12 vs U14, (d) U14 vs U8; U14 vs U10; U14 vs U12, (e) U10 vs U14.

Methodological procedures

This observational analytic study was conducted during sixteen consecutive weeks and aimed to analyse the variability of four game formats (5-a-side; 7-a-side; 9-a-side; and 11-a-side) to assess technical actions performed by young soccer players across four age-groups (U8, U10, U12, and U14). Three soccer matches were conducted weekly, consistently on Sundays, totalling 48 matches. Matches were organized in a triangular tournament setup (e.g., match 1: team A vs. team B; match 2: team A vs. team C; match 3: team B vs. team C), in accordance with the football rules, except match duration (30 minutes, without breaks) and player substitutions (not allowed). Each week, an age group was tested in a game format following a progressive sequence (e.g., 1st week U8 in 5-a-side format; 2nd week U8 in 7-a-side format; …).

All matches were conducted on the same artificial third-generation pitch surface with official dimensions (length: 100 m, width: 64 m). The field size was adjusted for each game format using the relative space per player, i.e., reducing the length and width proportionally to accommodate the number of players (Silva, 2014). A detailed description of match conditions is presented in Table 2. Matches commenced with a planned, standardized warm-up lasting fifteen minutes, comprising running activities, small-sided games, and stretching. Subsequently, players engaged in a simulated match comprising two periods of two minutes each, separated by one minute of passive recovery. Coaches utilized subjective skill assessments to distribute players into balanced teams. All football matches were conducted between 9 and 11 a.m. under an average temperature of 13°C, with a relative humidity of 56%, and no precipitation. To maintain consistency between repeated measures, the same players were assigned to balanced teams based on recommendations from the head coach and playing positions. Matches were recorded using a digital camera, and technical actions were compared across sessions, age-groups, and game formats. This protocol was disseminated to the teams one month prior to commencement to ensure players, coaches, and directors were familiar with the procedures to be adopted before, during, and after the matches.

Table 2. Match conditions.

Match configuration				
Game formats	5-a-side	7-a-side	9-a-side	11-a-side
Game duration (min)	30 min	30 min	30 min	30 min
Pitch size (length x width)	45.5 x 29 m	64 x 41 m	82 x 52 m	100 x 64 m
Pitch ratio per player (m^2)	1:132	1:187	1:237	1:291
Tactical structure	1-1-2-1	1-2-3-1	1-3-4-1	1-4-3-3
Playing positions	1GK+1DF+2MD+1FW	1GK+2DF+3MD+1FW	1GK+3DF+4MD+1FW	1GK+4DF+3MD+3FW
Goals size (height x width)	2 x 6 m	2 x 6 m	2 x 6 m	2.44 x 7.32 m

Note: Playing positions categories: GK = Goalkeeper; DF = Defender; MD = Midfielder; FW = Forward.

Data collection

Match recordings and corresponding technical actions were captured using a digital camera (Sony Handycam DCR-SR210). The camera was securely mounted on a tripod (Sony VCT-R6400) positioned at the centre of the pitch, elevated at distances of 6 and 20 meters from the pitch surface. Recorded footage was transferred to a computer via USB and analysed using Windows Media Player (Microsoft Corporation, USA). All data were recorded in Microsoft Office Excel (Microsoft Corporation, USA) and subsequently exported to SPSS Statistics, version 32.0 (SPSS Inc., Chicago, USA), for further analysis.

Data analysis

The technical actions analysed were categorized as follows:

Successful technical actions

Front pass: precise transfer of possession from one player to a teammate positioned forward on the field, effectively advancing the team's offensive play;

Side pass: accurate transfer of possession from one player to a teammate positioned to the side on the field, facilitating ball circulation and maintaining control of the game's tempo;
Back pass: precise transfer of possession from one player to a teammate positioned behind them on the field to maintain possession or relieve pressure;
Short pass: accurate transfer of possession to a nearby teammate to maintain ball control, build up play, or evade opponents in close quarters on the field;
Long pass: accurate transfer of possession to a teammate located at a considerable distance away on the field to bypass opponents or switch play;
Reception: skilful and controlled act of receiving the ball from a teammate to maintain possession and enable offensive play;
Dribble: proficient manoeuvring of the ball past opponents while maintaining control to advance up the field and potentially creating goal-scoring opportunities;
Goal: ultimate objective in football, where a player successfully propels the ball into the opposing team's net, resulting in a score for their own team.

Unsuccessful technical actions
Front pass: attempted transfer of possession forward on the field that does not result in successful completion;
Side pass: attempted transfer of possession to a teammate positioned laterally on the field that does not result in successful completion;
Back pass: attempted transfer of possession to a teammate positioned behind on the field that does not result in successful completion;
Short pass: attempted transfer of possession to a nearby teammate that does not result in successful completion;
Long pass: attempted transfer of possession to a teammate located at a considerable distance away on the field that does not result in successful completion;
Reception: inability to successfully control and gain possession of a passed ball from a teammate;
Dribble: attempt to manoeuvre the ball past opponents while maintaining control that does not result in successful execution.

Technical actions of variable impact
Shot: attempt to strike the ball towards the opponent's goal with the intention of scoring;
Shot on target: shot attempt accurately directed towards the goal and would result in a goal if not blocked or saved by the goalkeeper;
Goal assists: providing a pass or set-up play that directly leading to a goal being scored by a teammate;
Ball contacts: number of times a player touches or interacts with the ball during a game or a specific period of play;
Crossing: delivery of the ball from the flanks or wings into the opposition's penalty area;
Turnover: loss of possession of the ball by one team to the other team;
Interception: successful gain of possession after an opponent’s pass;
Clearance: Defensive action to remove the ball from a dangerous area in or around the team's penalty area;
Foul: Infringement of the rules as defined by the laws of the game.

The observations and notifications were executed by the same observer, who had more than 12 years of experience in match analysis. The observer was tested for his reliability level. 12.5 percent of the full data was analysed twice, interspaced by a period of 15 days. An intra-class correlation of .88 was achieved, what ensured good reliability of the analysis.

Statistical analysis

Results are presented as means ± standard deviations (SD). Normality of the data was assessed using the Kolmogorov-Smirnov test, along with coefficients of skewness and kurtosis, and through visual inspection of box plots, normal quantile-quantile (q-q) plots, and histograms.

Dependent variables, including game formats and age-groups, were analysed using a 2-factor repeated-measures analysis of variance (ANOVA). This approach was chosen for its effectiveness in evaluating the interaction effects of two categorical independent variables (game formats and age-groups) on the dependent variables, while also considering potential within-subject correlations.

Effect sizes (Cohen's d) were calculated to assess the magnitude of differences observed. Effect sizes were interpreted according to established guidelines: <0.20 = denoted trivial effect sizes; 0.20–0.59 = indicated small effects; 0.60–1.19 = suggested moderate effects; 1.20–1.99 = signified large effects; and ≥2.0 = represented very large effects (Hopkins, Marshall, Batterham, & Hanin, 2009). To ensure methodological rigor and reliability, all statistical analyses were performed using SPSS Statistical Analysis Software (SPSS Inc., Chicago, USA) version 32.0 for Windows. Significance was defined as $p \leq .05$, consistent with conventional thresholds for statistical significance.

RESULTS

The findings of this investigation reveal a influence of age-group on the variability of young players' technical actions. Age-group exerted a more significant impact on the variability of technical actions under specific conditions, including:

Successful technical actions

[front pass success $F(3.611) = 11.604$, $p < .001$, $\eta^2 = 4.511$]; [side pass success $F(3.610) = 8.181$, $p < .001$, $\eta^2 = 3.032$]; [back pass success $F(3.457) = 6.265$, $p < .001$, $\eta^2 = 3.176$]; [short pass success $F(3.731) = 18.547$, $p < .001$, $\eta^2 = 13.501$]; [Reception success $F(3.690) = 13.395$, $p < .001$, $\eta^2 = 9.785$]; [Goal $F(3.139) = 5.181$, $p < .002$, $\eta^2 = .498$].

Unsuccessful technical actions

[Unsuccessful front pass $F(3.549) = 4.721$, $p < .003$, $\eta^2 = 1.699$]; [Unsuccessful side pass $F(3.277) = 4.132$, $p < .007$, $\eta^2 = .384$]; [Unsuccessful short pass $F(3.831) = 17.374$, $p < .001$, $\eta^2 = 11.901$]; [Unsuccessful long pass $F(3.335) = 5.272$, $p < .001$, $\eta^2 = .948$].

Technical actions of variable impact

[Shot on target $F(3.227) = 3.505$, $p < .016$, $\eta^2 = 1.474$]; [Ball contacts $F(3.749) = 20.738$, $p < .001$, $\eta^2 = 74.485$]; [Turnover $F(3.465) = 4.722$, $p < .003$, $\eta^2 = 1.401$].

Moreover, as illustrated in Table 3, there was a trend for the success rate to be significantly higher in the U14 compared to the younger age-groups (U8; U10; and U12) across several actions, such as: front pass; side pass; back pass; short pass; and reception. Conversely, the rate of goals scored was significantly higher more in the U8 age-group.

Furthermore, the U14 exhibited elevated rates of unsuccessful technical actions, particularly in front pass; side pass; short pass; and long pass, as depicted in Table 4.

Finally, the technical actions of variable impact (Table 5) indicated that the U14 age-group achieved higher rates of shot on target; ball contacts; and turnovers compared to younger age-groups.

In summary, older players demonstrated increased involvement in technical actions of the game and exhibited greater proficiency in executing said actions.

Concomitantly, the outcomes of this study underscore the influence of game format on the success rates of young players' technical actions. The impact of game format on success rates was more pronounced in various conditions, including:

Table 3. Successful technical actions of young players of four age-group (U8; U10; U12; and U14) in different game formats (5-a-side; 7-a-side; 9-a-side; and 11-a-side).

Age Group	M ± SD	Between Age-Groups	Technical Actions	Game Format	M ± SD	Between Game Formats
U8	2.89±0.192			5-a-side	3.83±0.256	*5-a-side>7-a-side**
U10	2.15±0.121	*U8>U10**		7-a-side	2.98±0.195	*5-a-side>9-a-side***
U12	2.39±0.138	*U10<U14***	Successful front pass	9-a-side	2.18±0.131	*5-a-side>11-a-side***
U14	3.45±0.208	*U12<U14***		11-a-side	2.44±0.129	*7-a-side>9-a-side**
Total	2.74±0.088			Total	1.13±0.044	
U8	2.58±0.129			5-a-side	3.59±0.194	*5-a-side>7-a-side**
U10	2.15±0.113	*U8<U14**		7-a-side	2.89±0.169	*5-a-side>9-a-side***
U12	2.70±0.115	*U10<U12**	Successful side pass	9-a-side	2.22±0.084	*5-a-side>11-a-side***
U14	3.13±0.187	*U10<U14***		11-a-side	2.26±0.117	*7-a-side>9-a-side**
Total	2.65±0.071			Total	2.65±0.071	*7-a-side>11-a-side**
U8	2.80±0.219	*U8>U10**		5-a-side	3.26±0.246	
U10	2.15±0.116	*U8>U12**		7-a-side	2.96±0.203	*5-a-side>9-a-side**
U12	2.16±0.107	*U10<U14**	Successful back pass	9-a-side	2.40±0.152	*5-a-side>11-a-side***
U14	2.94±0.188	*U12<U14**		11-a-side	1.88±0.083	*7-a-side<11-a-side***
Total	2.52±0.084			Total	2.52±0.084	
U8	5.96±0.314	*U8>U10***		5-a-side	8.62±0.397	*5-a-side>7-a-side***
U10	4.32±0.206	*U8<U14**		7-a-side	6.96±0.329	*5-a-side>9-a-side***
U12	5.50±0.191	*U10<U12**	Successful short pass	9-a-side	4.82±0.197	*5-a-side>11-a-side***
U14	7.13±0.340	*U10<U14***		11-a-side	4.28±0179	*7-a-side>9-a-side***
Total	5.74±0.140	*U14>U12***		Total	5.74±0.140	*7-a-side>11-a-side***
U8	1.23±0.093			5-a-side	6.40±0.347	
U10	1.20±0.064			7-a-side	5.15±0.337	
U12	1.29±0.084		Successful long pass	9-a-side	3.63±0.157	
U14	1.39±0.081			11-a-side	3.54±0.155	
Total	1.29±0.041			Total	4.39±0.122	
U8	4.50±0.267			5-a-side	6.40±0.347	*5-a-side>7-a-side**
U10	3.55±0.173	*U8>U10**		7-a-side	5.15±0.337	*5-a-side>9-a-side***
U12	3.90±0.170	*U8<U14**	Successful reception	9-a-side	3.63±0.157	*5-a-side>11-a-side***
U14	5.52±0.305	*U10<U14***		11-a-side	3.54±0.155	*7-a-side>9-a-side***
Total	4.39±0.122	*U12<14***		Total	4.39±0.122	*7-a-side>11-a-side***
U8	1.86±0.182			5-a-side	1.77±0.096	
U10	1.68±0.110			7-a-side	1.93±0.163	
U12	1.71±0.100		Successful dribble	9-a-side	1.53±0.132	
U14	1.66±0.117			11-a-side	1.60±0.112	
Total	1.73±0.066			Total	1.73±0.066	
U8	1.82±0.177			5-a-side	1.62±0.110	
U10	1.23±0.078			7-a-side	1.46±0.121	
U12	1.26±0.088	*U8>U10**	Goals	9-a-side	1.17±0.084	*5-a-side>9-a-side**
U14	1.47±0.127	*U8>U12**		11-a-side	1.25±0.160	
Total	1.43±0.062			Total	1.43±0.062	

Note: Significant difference across successful technical of players ($p \leq .05$); and ($p \leq .001$)**.*

Table 4. Unsuccessful technical actions of young players of four age-group (U8; U10; U12; and U14) in different game formats (5-a-side; 7-a-side; 9-a-side; and 11-a-side).

Age Group	M ± SD	Between Age-Groups	Technical Actions	Game Format	M ± SD	Between Game Formats
U8	2.19±0.126		Unsuccessful front pass	5-a-side	2.58±0.141	
U10	2.15±0.096			7-a-side	2.30±0.127	
U12	1.82±0.082	*U12<U14**		9-a-side	2.01±0.098	*5-a-side>9-a-side**
U14	2.40±0.126			11-a-side	1.90±0.090	*5-a-side>11-a-side***
Total	2.15±0.056			Total	2.15±0.056	
U8	1.26±0.070		Unsuccessful side pass	5-a-side	1.45±0.087	
U10	1.25±0.053	*U14>U10**		7-a-side	1.48±0.101	*11-a-side<5-a-side**
U12	1.23±0.052	*U14>12**		9-a-side	1.25±0.065	*11-a-side<7-a-side**
U14	1.55±0.113			11-a-side	1.17±0.047	
Total	1.32±0.038			Total	1.32±0.038	
U8	1.10±0.069		Unsuccessful back pass	5-a-side	1.18±0.122	
U10	1.11±0.111			7-a-side	1.06±0.062	
U12	1.22±0.147			9-a-side	1.16±0.095	
U14	1.20±0.117			11-a-side	1.20±0.145	
Total	1.15±0.053			Total	1.15±0.053	
U8	4.76±0.214		Unsuccessful short pass	5-a-side	7.62±0.297	*5-a-side>7-a-side**
U10	3.12±0.218	*U8>U10**		7-a-side	5.96±0.229	*5-a-side>9-a-side***
U12	4.30±0.161	*U10<U14***		9-a-side	3.82±0.097	*5-a-side>11-a-side***
U14	6.11±0.240	*U12<U14***		11-a-side	3.28±079	*7-a-side>9-a-side***
Total	4.57±0.170			Total	5.17±0.040	*7-a-side>11-a-side***
U8	1.59±0.117		Unsuccessful long pass	5-a-side	1.94±0.140	
U10	1.63±0.074			7-a-side	1.62±0.099	
U12	1.29±0.072	*U14>U12***		9-a-side	1.60±0.116	*5-a-side>11-a-side**
U14	1.91±0.138			11-a-side	1.48±0.081	
Total	1.63±0.054			Total	1.63±0.054	
U8	1.39±0.087		Unsuccessful reception	5-a-side	1.39±0.073	
U10	1.30±0.066			7-a-side	1.31±0.081	
U12	1.18±0.066			9-a-side	1.39±0.094	
U14	1.44±0.073			11-a-side	1.30±0.060	
Total	1.34±0.038			Total	1.34±0.038	
U8	1.33±0.091		Unsuccessful dribble	5-a-side	1.33±0.71	
U10	1.38±0.086			7-a-side	1.44±0.086	
U12	1.29±0.063			9-a-side	1.131±0.083	
U14	1.38±0.085			11-a-side	1.30±0.086	
Total	1.34±0.041			Total	1.34±0.041	

Note: Significant difference across successful technical actions of players (p ≤ .05); and (p ≤ .001)**.*

Successful technical actions

[front pass success $F(3.611) = 15.957$, $p < .001$, $\eta^2 = 4.422$]; [side pass success $F(3.610) = 19.413$, $p < .001$, $\eta^2 = 2.879$]; [back pass success $F(3.457) = 14.016$, $p < .001$, $\eta^2 = 3.028$]; [short pass success $F(3.731) = 53.779$, $p < .001$, $\eta^2 = 11.902$]; [Reception success $F(3.690) = 30.714$, $p < .001$, $\eta^2 = 9.135$]; [Goal $F(3.139) = 2.917$, $p < .036$, $\eta^2 = .521$].

Unsuccessful technical actions

[Unsuccessful front pass $F(3.549) = 7.111$, $p < .001$, $\eta^2 = 1.677$]; [Unsuccessful side pass $F(3.277) = 4.296$, $p < .006$, $\eta^2 = .384$]; [Unsuccessful short pass $F(3.335) = 5.272$, $p < .001$, $\eta^2 = 10.886$]; [Unsuccessful long pass $F(3.335) = 3.157$, $p < .025$, $\eta^2 = .966$].

Technical actions of variable impact

[Shot $F(3.145) = 4.902$, $p < .003$, $\eta^2 = .378$]; [Shot on target $F(3.227) = 21.965$, $p < .001$, $\eta^2 = 1.195$]; Ball contacts $F(3.749) = 61.311$, $p < .001$, $\eta^2 = 64.767$]; [Crossing $F(3.171) = 2.916$, $p < .036$, $\eta^2 = .807$]; [Turnover $F(3.465) = 5.002$, $p < .002$, $\eta^2 = 1.399$]; [Interception $F(3.589) = 28.627$, $p < .001$, $\eta^2 = 3.611$].

Table5. Technical actions of variable impact of young players of four age-group (U8; U10; U12; and U14) in different game formats (5-a-side; 7-a-side; 9-a-side; and 11-a-side).

Age Group	*M ± SD*	*Between Age-Groups*	*Technical Actions*	*Game Format*	*M ± SD*	*Between Game Formats*
U8	1.35±0.123			5-a-side	1.65±0.137	
U10	1.27±0.092			7-a-side	1.32±0.078	
U12	1.32±0.085		Shot	9-a-side	1.24±0.076	*5-a-side>9-a-side**
U14	1.48±0.111			11-a-side	1.14±0.067	*5-a-side>11-a-side**
Total	1.36±0.052			Total	1.36±0.052	
U8	1.73±0.243			5-a-side	2.68±0.169	
U10	1.67±0.125			7-a-side	1.76±0.131	*5-a-side>7-a-side***
U12	1.84±0.145	*U14>U8**	Shot on target	9-a-side	1.31±0.098	*5-a-side>9-a-side***
U14	2.40±0.149	*U14>U10**		11-a-side	1.29±0.119	*5-a-side>11-a-side***
Total	1.87±0.081			Total	1.87±0.081	
U8	1.29±0.127			5-a-side	1.14±0.067	
U10	1.10±0.066			7-a-side	1.16±0.091	
U12	1.05±0.050		Goal assists	9-a-side	1.07±0.067	
U14	1.05±0.050			11-a-side	1.10±0.100	
Total	1.13±0.044			Total	1.13±0.044	
U8	15.92±0.784	*U8>U10***		5-a-side	22.25±0.883	*5-a-side>7-a-side***
U10	11.43±0.455	*U8<U14**		7-a-side	18.54±0.846	*5-a-side>9-a-side***
U12	14.46±0.494	*U10<U12**	Ball contacts	9-a-side	12.38±0.452	*5-a-side>11-a-side***
U14	18.35±0.701	*U10<U14***		11-a-side	12.11±0.402	*7-a-side>9-a-side***
Total	15.11±0.327	*U12<U14***		Total	15.11±0.327	*7-a-side>11-a-side***
U8	1.52±0.131			5-a-side	1.68±0.125	
U10	1.40±0.113			7-a-side	1.88±0.180	
U12	1.61±0.108		Crossing	9-a-side	1.59±0.116	*7-a-side>11-a-side**
U14	1.83±0.161			11-a-side	1.30±0.109	
Total	1.62±0.069			Total	1.62±0.069	
U8	2.10±0.150			5-a-side	2.38±0.150	
U10	1.87±0.085	*U8>U12**		7-a-side	2.06±0.127	*5-a-side>9-a-side**
U12	1.63±0.091	*U12<U14**	Turnover	9-a-side	1.81±0.085	*5-a-side>11-a-side**
U14	2.18±0.098			11-a-side	1.81±0.094	
Total	1.96±0.055			Total	1.96±0.055	
U8	3.20±0.168			5-a-side	4.65±0.271	
U10	3.11±0.154			7-a-side	3.01±0.180	*5-a-side>7-a-side***
U12	3.00±0.176		Intersection	9-a-side	2.55±0.105	*5-a-side>9-a-side***
U14	2.93±0.169			11-a-side	2.74±0.123	*5-a-side>11-a-side***
Total	3.06±0.083			Total	3.06±0.083	
U8	1.44±0.119			5-a-side	1.28±0.080	
U10	1.45±0.095			7-a-side	1.46±0.115	
U12	1.33±0.082		Clearance	9-a-side	1.46±0.102	
U14	1.54±0.101			11-a-side	1.53±0.095	
Total	1.45±0.050			Total	1.45±0.050	
U8	1.06±0.059			5-a-side	1.20±0.082	
U10	1.07±0.046			7-a-side	1.08±0.058	
U12	1.19±0.065		Foul	9-a-side	1.04±0.040	
U14	1.10±0.069			11-a-side	1.13±0.063	
Total	1.12±0.031			Total	1.12±0.031	

Note: Significant difference across successful technical actions of players ($p \leq .05$); and ($p \leq .001$)**.*

The study findings reveal a consistent pattern indicating higher success rates of technical actions in smaller game formats (5-a-side and 7-a-side) compared to larger formats (9-a-side and 11-a-side). Specifically, analysis of Table 3 underscores the significance of this trend, particularly in successful front pass, side pass, back pass, short pass, reception, and goal actions.

Furthermore, smaller game formats exhibit elevated rates of unsuccessful technical actions relative to larger formats, with the 5-a-side format demonstrating the highest rates. Table 4 illustrates this trend, highlighting increased occurrences of unsuccessful front pass, side pass, short pass, and long pass.

Examining technical actions of variable impact in Table 5, we can see that on average, actions such as shot, shot on target, ball contacts, crossings, turnovers, and interceptions decrease as game format increases. This implies that young players exhibit more technical actions of variable impact in smaller game formats (5-a-side and 7-a-side) compared to larger formats (9-a-side and 11-a-side).

DISCUSSION

The aim of this study was to analyse the variations of technical actions between different game formats, and to investigate the effects of different age-groups in technical actions.

The main findings of this study confirm the hypothesis that different game formats and age-groups would induce differences in the technical performance patterns of the young soccer players. Specifically, it was demonstrated a significant influence of age group on the technical performance of young soccer players. Older age groups, particularly U14, demonstrated higher success rates in various technical actions such as front pass, side pass, back pass, short pass, and reception, suggesting that as players mature, they tend to exhibit greater proficiency in executing fundamental technical actions. Our findings are consistent with previous research indicating the superiority of smaller-sided game formats in promoting skill development among youth soccer players (Hill-Haas, Rowsell, Coutts, & Dawson, 2008; Figueiredo, Coelho-e-Silva, Sarmento, Moya, & Malina, 2020). The observed higher success rates in technical actions among older players also align with studies by (Kelly, Wilson, Jackson, & Williams, 2020; Huijgen, Elferink-Gemser, Lemmink, & Visscher, 2014; Ford, Carling, Garces, Marques, Miguel, Farrant, Stenling, Moreno, Le Gall, Holmström, Salmela, & Williams, 2012), highlighting the developmental progression of technical abilities throughout adolescence. Additionally, Ford et al. (2012) suggests that skill acquisition follows a developmental trajectory, with older players showing more refined technical abilities compared to their younger counterparts. However, it's noteworthy that while older players showed increased involvement in technical actions, they also demonstrated higher rates of unsuccessful technical actions, indicating a need for continued skill development and refinement across all age groups.

The research also underscores the impact of game format on the success rates of technical actions among young players. Smaller game formats, such as 5-a-side and 7-a-side, consistently yielded higher success rates in technical actions compared to larger formats like 9-a-side and 11-a-side, contrasting with the data from (Clemente, Praça, Aquino, Castillo, Raya-González, Rico-González, Afonso, Sarmento, Ana Silva, Rui Silva, & Ramirez-Campillo, 2023). This finding can perhaps be explained by the conceptual approach of the studies, since the aforementioned study focuses on small-sided games while our study is contextualized in formal games. This suggests that smaller-sided games provide a more conducive environment for skill refinement and execution among youth players, which is also supported by your (Hintermann, Born, Fuchslocher, Kern, & Romann, 2021). Additionally, smaller formats exhibited elevated rates of unsuccessful technical actions, implying that players may face greater challenges or opportunities for error in tighter spaces. The superiority of smaller-sided game formats in facilitating skill development has been widely documented in the literature (Hill-Haas et al., 2008; Figueiredo et al., 2020; Bergmann et al., 2022). Hill-Haas et al. (2008) demonstrated that small-sided games enhance technical proficiency, decision-making, and physical conditioning among youth players. Similarly, Figueiredo et al. (2019) emphasized the benefits of smaller formats in promoting skill acquisition and tactical understanding, supporting our findings of higher success rates in technical actions in 5-a-side and 7-a-side games. However, it's important to note that smaller formats also resulted in higher rates of technical actions of variable impact, indicating increased player involvement and decision-making opportunities.

Finally, The interaction between age group and game format highlights the importance of context-specific interventions in youth soccer development. While older players generally exhibited higher success rates in technical actions, the influence of game format remained significant across all age groups. For instance, even within the U14 age group, smaller formats demonstrated advantages in terms of technical proficiency and player involvement. Research by Memmert and Roth (2007) suggests that the effectiveness of training interventions depends on the developmental stage of the players. Similarly, Williams and Hodges (2005) emphasize the need for tailored approaches to skill acquisition based on the cognitive and physical capabilities of the players. Our study's findings underscore the significance of aligning match formats with the developmental needs of players to optimize learning and performance outcomes. This suggests that tailoring match formats to specific developmental needs is crucial for optimizing player engagement and performance trajectories.

CONCLUSIONS

In summary, the present study underscores the significance of providing developmentally appropriate match formats for youth soccer players. It emphasizes the efficacy of smaller-sided games, such as 5-a-side and 7-a-side, in fostering skill refinement and player involvement across different age groups. Coaches and administrators are urged to tailor match formats based on player age and developmental stage to optimize learning and performance outcomes. Furthermore, the importance of continuous skill development is emphasized, irrespective of age group or game format. Strategic planning informed by developmental principles and empirical evidence is crucial for creating an environment conducive to player growth, enjoyment, and sustained participation in soccer. This study enriches our understanding of the influence of game format and age group on success rates of technical performance in youth soccer, highlighting the necessity of customized interventions to enhance player development trajectories. However, acknowledging limitations such as sample size and study design, future research incorporating diverse methodologies is advocated to further elucidate player development dynamics and foster innovation in youth soccer development.

AUTHOR CONTRIBUTIONS

Ângelo Brito is responsible for the conception and design of the study; he drafted and wrote the manuscript; participated in the literature review; operationalized data collection, as well as the respective processing and presentation of results. Luis Freitas participated in the conception and design of the study; writing the initial draft and reviewing the literature; as well as in the collection, processing and analysis of data. The authors contributed to the manuscript, approved the final version for submission and consent to its publication in JHSE.

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REFERENCES

Amatria, M., Lapresa, D., Arana, J., Anguera, M. T., & Garzón, B. (2016). Optimization of Game Formats in U-10 Soccer Using Logistic Regression Analysis. Journal of Human Kinetics, 54(1), 163-171. https://doi.org/10.1515/hukin-2016-0047

Ben Teune, Carl Woods, Alice Sweeting, Mathew Inness & Sam Robertson (2022) The influence of environmental and task constraint interaction on skilled behaviour in Australian Football, European Journal of Sport Science, 22:8, 1268-1275. https://doi.org/10.1080/17461391.2021.1958011

Bergmann, F., Braksiek, M., & Meier, C. (2022). The influence of different game formats on technical actions and playing time parameters - A study with under-7 and under-9 soccer players in a competitive context. International Journal of Sports Science & Coaching, 17(5) 1089-1100. https://doi.org/10.1177/17479541211051654

Brito, Â., Roriz, P., Duarte, R., & Garganta, J. (2018). Match-running performance of young soccer players in different game formats. International Journal of Performance Analysis in Sport, 18(3), 410-422. https://doi.org/10.1080/24748668.2018.1479924

Clemente, F., Couceiro, M., Martins, F., & Mendes, R. (2012). Team's performance on FIFA U17 World Cup 2011: Study based on notational analysis. Journal of Physical Education and Sport, 12(1), 13.

Clemente F. M., Chen Y-S, Bezerra J. P., Guiomar J., & Lima R. (2018). between-format differences and variability of technical actions during small-sided soccer games played by young players. Human Movement, 19(5)special/issue:114-120. https://doi.org/10.5114/hm.2018.83103

Clemente, F., & Sarmento, H. (2020). The effects of small-sided soccer games on technical actions and skills: A systematic review. Human Movement, 21(3), 100-119. https://doi.org/10.5114/hm.2020.93014

Clemente, F. M., Praça, G. M., Aquino, R., Castillo, D., Raya-González, J., Rico-González, M., Afonso, J., Sarmento, H., Silva, A. F., Silva, R., & Ramirez-Campillo, R. (2023). Effects of pitch size on soccer players' physiological, physical, technical, and tactical responses during small-sided games: a meta-analytical comparison. Biology of Sport, 40(1), 111-147. https://doi.org/10.5114/biolsport.2023.110748

Coutinho, D., Gonçalves, B., Travassos, B., Folgado, H., Figueira, B., & Sampaio, J. (2020). Different Marks in the Pitch Constraint Youth Players' Performances during Football Small-Sided Games. Research Quarterly for Exercise and Sport, 91(1), 15-23. https://doi.org/10.1080/02701367.2019.1645938

Fenoglio, R. (2004). The Manchester United 4 v 4 pilot scheme for U9's-Part II. The analysis. Insight: The FA Coaches Association Journal, 6, 21-24.

Figueiredo, A. J., Coelho-e-Silva, M. J., Cumming, S. P., & Malina, R. M. (2019). Relative age effect: Characteristics of youth soccer players by birth quarter and subsequent playing status. Journal of Sports Sciences, 37(6), 677-684. https://doi.org/10.1080/02640414.2018.1522703

Figueiredo, A. J., Coelho-e-Silva, M. J., Sarmento, H., Moya, J., & Malina, R. M. (2020). Adolescent characteristics of youth soccer players: do they vary with playing status in young adulthood? Research in Sports Medicine (Print), 28(1), 72-83. https://doi.org/10.1080/15438627.2019.1586704

Ford, P., Carling, C., Garces, M., Marques, M., Miguel, C., Farrant, A., Stenling, A., Moreno, J., Le Gall, F., Holmström, S., Salmela, J., & Williams, M. (2012). The developmental activities of elite soccer players aged under-16 years from Brazil, England, France, Ghana, Mexico, Portugal and Sweden. Journal of Sports Sciences, 30(15), 1653-1663. https://doi.org/10.1080/02640414.2012.701762

García-Angulo, A., Palao, J. M., Giménez-Egido, J. M., García-Angulo, F. J., & Ortega-Toro, E. (2020). Effect of the Modification of the Number of Players, the Size of the Goal, and the Size of the Field in Competition on the Play Actions in U-12 Male Football. International Journal of Environmental Research and Public Health, 17(2). https://doi.org/10.3390/ijerph17020518

García-Angulo, A., Ortega-Toro, E., Giménez-Egido, J. M., Olmedilla, A., García-Mas, A., & Manuel Palao, J. (2021). Does Youth Soccer Players' Group Cooperation Improve when Pitch, Goal, and Team Size Are Reduced? Journal of Human Kinetics, 78(1), 151-160. https://doi.org/10.2478/hukin-2021-0035

Heuvelmans, P., Di Paolo, S., Benjaminse, A., Bragonzoni, L., & Gokeler, A. (2024). Relationships Between Task Constraints, Visual Constraints, Joint Coordination and Football-Specific Performance in Talented Youth Athletes: An Ecological Dynamics Approach. Perceptual & Motor Skills, 131(1), 161-176. https://doi.org/10.1177/00315125231213124

Hill, B., & Green, B. C. (2008). Give the Bench the Boot! Using Manning Theory to Design Youth-Sport Programs. Journal of Sport Management, 22(2), 184-204. https://doi.org/10.1123/jsm.22.2.184

Hill-Haas, S., Rowsell, G., Coutts, A., & Dawson, B. (2008). The Reproducibility of Physiological Responses and Performance Profiles of Youth Soccer Players in Small-Sided Games. International Journal of Sports Physiology & Performance, 3(3), 393-396. https://doi.org/10.1123/ijspp.3.3.393

Hintermann, M., Born, D.-P., Fuchslocher, J., Kern, R., & Romann, M. (2021). How to improve technical and tactical actions of dominant and non-dominant players in children's football? PLoS ONE, 16(7), 1-13. https://doi.org/10.1371/journal.pone.0254900

Hopkins, W., Marshall, S., Batterham, A., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. Medicine & Science in Sports & Exercise, 41(1):3-13. https://doi.org/10.1249/MSS.0b013e31818cb278

Huijgen, B. C. H., Elferink-Gemser, M. T., Lemmink, K. A. P. M., & Visscher, C. (2014). Multidimensional performance characteristics in selected and deselected talented soccer players. European Journal of Sport Science, 14(1), 2-10. https://doi.org/10.1080/17461391.2012.725102

James, N. (2006). Notational analysis in soccer: Past, present and future. International Journal of Performance Analysis in Sport, 6(2), 67-81. https://doi.org/10.1080/24748668.2006.11868373

Joo, C. H., Hwang-Bo, K., & Jee, H. (2016). Technical and Physical Activities of Small-Sided Games in Young Korean Soccer Players. Journal of Strength and Conditioning Research, 30(8), 2164-2173. https://doi.org/10.1519/JSC.0000000000001319

Julen Castellano, Asier Puente, Ibon Echeazarra, Oidui Usabiaga, & David Casamichana. (2016). Number of Players and Relative Pitch Area per Player: Comparing Their Influence on Heart Rate and Physical Demands in Under-12 and Under-13 Football Players. PLoS ONE, 11(1), e0127505. https://doi.org/10.1371/journal.pone.0127505

Kelly, A., Wilson, M. R., Jackson, D. T., & Williams, C. A. (2020). Technical testing and match analysis statistics as part of the talent development process in an English football academy. International Journal of Performance Analysis in Sport, 20(6), 1035-1051. https://doi.org/10.1080/24748668.2020.1824865

Lapresa Ajamil, D., Arana Idiakez, J., Amatria Jiménez, M., Fernández Alejandro, F. J., & Teresa Anguera, M. (2017). Fútbol: efectos de una unidad didáctica en la iniciación temprana. Apunts: Educación Física y Deportes, 127, 59-67. https://doi.org/10.5672/apunts.2014-0983.es.(2017/1).127.06

Lemes, J., Luchesi, M., Diniz, L., Bredt, S., Chagas, M., & Praça, G. (2020). Influence of pitch size and age category on the physical and physiological responses of young football players during small-sided games using GPS devices. Research in Sports Medicine (Print), 28(2), 206-216. https://doi.org/10.1080/15438627.2019.1643349

Machado, J. C., Ribeiro, J., Palheta, C. E., Alcântara, C., Barreira, D., Guilherme, J., Garganta, J., & Scaglia, A. J. (2019). Changing Rules and Configurations During Soccer Small-Sided and Conditioned Games. How Does It Impact Teams' Tactical Behavior? Frontiers in Psychology, 10, 1554. https://doi.org/10.3389/fpsyg.2019.01554

Martone, D., Giacobbe, M., Capobianco, A., Imperlini, E., Mancini, A., Capasso, M., Buono, P., & Orrù, S. (2017). Exercise Intensity and Technical Demands of Small-Sided Soccer Games for Under-12 and Under-14 Players: Effect of Area per Player. Journal of Strength & Conditioning Research, 31(6), 1486-1492. https://doi.org/10.1519/JSC.0000000000001615

Memmert, D., & Roth, K. (2007). The effects of non-specific and specific concepts on tactical creativity in team ball sports. Journal of Sports Sciences, 25(12), 1423-1432. https://doi.org/10.1080/02640410601129755

Serra-Olivares, J., García López, L. M., & Gonçalves, B. (2019). Effects of the players' level and age group category on positional tactical behaviour during 7- and 8-a-side football youth games. International Journal of Performance Analysis in Sport, 19(2), 236-247. https://doi.org/10.1080/24748668.2019.1593095

Silva, P., Aguiar. P., Duarte. R., Davids. K., Araújo. D., Garganta. J. (2014). Effects of pitch size and skill level on tactical behaviours of association football players during small-sided and conditioned games. International Journal of Sports Science & Coaching, 9(5): 993-1006. https://doi.org/10.1260/1747-9541.9.5.993

Tom De Joode. (2023). The manipulation of task constraints and the effect on creative performance of youth soccer players. Current Issues in Sport Science, 8(2). https://doi.org/10.36950/2023.2ciss043

Williams, A. M., & Hodges, N. J. (2005). Practice, instruction and skill acquisition in soccer: Challenging tradition. Journal of Sports Sciences, 23(6), 637-650. https://doi.org/10.1080/02640410400021328

ORIGINAL ARTICLE

Innovation in physical education: Proprioception, periferical vision, self-awareness, and sustainability

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ABSTRACT

In an era that increasingly emphasizes the importance of sustainable lifestyles, this study aims to explore the potential role of physical education in improving, through the training of proprioception and peripheral vision, self-awareness and attention, and to verify their possible correlation with virtuous behaviours. Utilizing applications of the Synchrony methodology within the context of embodied cognition, it is hypothesized that a greater sense of bodily awareness, achieved through targeted physical training, may promote behaviours oriented towards sustainability. This hypothesis is based on the idea that enhanced self-awareness and/or attention could lead to a better understanding of one's living space, personal choices, and their consequences, thereby increasing responsibility towards the shared living environment. A pilot observational study and a subsequent experimental study involving 84 high school students were conducted to outline these potential aspects of indirect connection between specific physical training and more responsible behaviours, with the aim of helping, in the future, young people to develop such qualities also through specially designed physical education methodologies.
Keywords: Physical education, Self-awareness, Pre-adolescents, Sustainable choices, Innovative teaching.

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INTRODUCTION

Physical education, traditionally focused on physical well-being, has gained new relevance in recent years due to an increasingly digitalized global context, early decreases in physical activity, and radical changes in diet, especially in industrialized countries. Such socio-cultural changes have induced a growing interest in physical education as a possible tool for overall well-being, not just physical. Recent studies indicate physical activity as necessary for the physical well-being of young people and also crucial for their cognitive development, especially where environmental changes have been fastest for younger populations (Spengler, 2018; Jassen, 2010; Tomporowski, 2008).

From this perspective, Bailey et al., as early as 2009, emphasized how regular physical activity contributed both to maintaining good health and to healthy mental and emotional growth in children (Bailey, 2009; Draper et al., 2010). The increasing awareness of the multidimensional benefits of physical education has led several countries to reassess the importance of this discipline in their educational systems. In Europe, for example, the HELENA project (Healthy Lifestyle in Europe by Nutrition in Adolescence) highlighted the importance of regular physical activity for young people, influencing educational policies in various countries and exploring the concept of healthy sustainable eating (Moreno et al., 2010). In Canada, the ParticipACTION strategy aimed to increase physical activity in the child population, emphasizing the need to expand the hours dedicated to physical education in schools as a tool for healthy cognitive-motor growth (Tremblay et al., 2011). In the United States, the "*Physical Activity Guidelines for Americans*" by the Department of Health and Human Services encouraged an increase in physical activity by proposing, in addition to increasing the hours of physical education at school, also extracurricular motor programs aimed at stimulating social skills (U.S. Department of Health and Human Services, 2018). Physical-motor education has thus broadened its scope of reference, beginning to position itself as a possible tool for broader improvement (Hillman, Erickson, & Kramer, 2008). Also in Italy, through the PNRR (National Recovery and Resilience Plan), an additional step forward is being sought by introducing strategic investments in education to promote innovative and inclusive physical education, to support sustainable development and the well-being of young people.

In this international context, the theory of embodied cognition emerges as an important tool for understanding the interconnection between mind and body in learning across disciplines. This approach emphasizes how physical experience directly and fundamentally influences the cognitive process, highlighting an indissoluble link between physical action and thought (Wilson, 2002; Barsalou, 2008; Niedenthal, 2007; Shapiro, 2011; Gallese & Sinigaglia, 2011; Lakoff & Johnson, 1999). Structured physical activity can thus be used as a possible vehicle for improvement for both generic and specific cognitive abilities, such as self-awareness, with results especially in young people (Pérez-Romero et al., 2023; Di Giacomo et al., 2017). This observation becomes particularly relevant in a historical period characterized by intense use of digital technologies by children and adolescents (Benzing & Schmidt, 2019; First, 2017), which often leads to a reduction in physical activity and social interactions. Faced with such changes, concerns arise regarding their cognitive development and their ability to critically judge (Nurhafid & Nursasi, 2019). Hence, the link between physical activity and cognitive well-being becomes even more critical. Therefore, it might be important to study physical education programs that are not limited to generic exercise but include activities specifically designed to stimulate positive behaviours in young people, for the possible strengthening of cognitive and social skills. Such a multidisciplinary approach to physical education could therefore meet the complex development needs of young people, offering them an additional opportunity to assimilate skills, fundamental for their overall well-being (Hillman, Erickson, & Kramer, 2008; Tomporowski, Davis, Miller, & Naglieri, 2008; Ratey & Hagerman, 2008; Best, 2010).

In light of the above, the authors have chosen to use the Sincrony movement education methodology, considered an innovative approach in this field. In line with the principles of embodied cognition, this methodology indeed aims to develop mechanical movement abilities in conjunction with cognitive ones, intervening with targeted and specifically validated tools in the key phases of development. Sincrony, through specific exercises, consolidates or increases body perception capacity, and visual skills, with possible results implied in a broader plan of health and development of social skills. (Routen et al., 2018; Nyberg & Larsson, 2017; O'Hagan et al., 2022) Franzini et al. (2009) also provided further perspectives on the interconnection between the physical and social environment in children in their study, highlighting how these two aspects are closely linked. This research has emphasized the existence of a profound relationship between different dimensions of child experience, reporting a further point of intersection between elements that might seem distant at first glance (Franzini et al., 2009).

In the context of physical education aimed at different juvenile ages, recent studies have highlighted the importance of integrating exercises aimed at enhancing self-awareness as a means to promote comprehensive development and a greater understanding of the social consequences of behaviours. These exercises have been recognized for their potential in increasing not only the physical competencies of students but also their cognitive and relational abilities. For example, a 10-week physical education intervention showed a positive impact on primary school students' self-concept regarding their endurance and strength, improving both perceived self-efficacy levels and confidence in their physical abilities, suggesting a beneficial effect of functional self-concepts in education for motor tasks (Schmidt, 2013). Furthermore, physical education has been identified as an effective means to improve self-esteem and promote social development, with a positive attitude towards other students being observed in secondary schools, highlighting the significant role of physical activity in the social and cognitive development of students (Kim & Shin, 2021).

In this multifactorial context, with growing attention to sustainable lifestyles and the need to develop personal and social awareness in young people, the present study aims to explore the role of physical education in promoting comprehensive development that embraces both the physical and cognitive-social aspects. As already expressed, the focus will be on the Sincrony methodology, situating it in the context of embodied cognition, to investigate how an enhanced bodily awareness, obtained through proprioceptive physical training and peripheral vision, in a group of preadolescents, and how it may potentially encourage sustainable behaviours. The authors hypothesize that an increase in proprioception reflects on self-awareness and may facilitate a deeper understanding of personal decisions and their repercussions, while work on peripheral vision may predispose to better space management, thus potentially enhancing responsibility towards others and the shared environment (Survey on Students et al., 2015; Werdermann, 2020; Ojedokun & Balogun, 2010; Koike, 1994; Strömbäck et al., 2023). The Sincrony method was chosen because, by its nature, it uses and combines the stimulation of proprioception and vision as necessary tools in training, integrating them into motor actions and their execution.

Through an observational pilot study, parameters were assessed to conduct an experiment in secondary schools, attempting to outline how, and if, physical training, studied ad hoc with the Sincrony methodology, can indirectly influence more responsible behaviours, providing insights for future physical educational methodologies specifically designed. The main goal was to examine how this innovative approach to physical education could influence the development of self-awareness and, potentially, promote sustainable behaviours among preadolescents through neuropsychological tests, field tests, and evaluative questionnaires. The choice of the Sincrony methodology is rooted in a multidisciplinary conception of physical education that sees movement not only as a tool for improving performance capabilities but also as a vehicle for strengthening cognitive and relational capacities, including self-awareness as a possible bridge to sustainable attitudes (Castelli, 2007; Hagger, 2002; Singh, 2012; Stodden, 2008). In this context, it could therefore be important to evaluate the effects of protocols from innovative methodologies, which highlight how mind and body are interconnected, or at least not divisible, and by exploiting physical works on specific variables have a possible impact on behaviour (Castelli, 2007; Hagger, 2002; Singh, 2012; Stodden, 2008).

MATERIALS AND METHODS

First experiment: evaluative pilot

A pilot study was conducted to identify any issues that might arise in a multifactorial study, allowing for the testing and refining of data collection methodologies, questionnaires, and instruments for the experiment. It involved a carefully selected group of 14 eleven-year-old girls, chosen from the students of a secondary school based on specific extracurricular needs. Students without interests in the ecological field were selected to evaluate the baseline effectiveness of the educational intervention (Stanley, 2011).

The decision to focus exclusively on a female sample was driven by evidence emerging from previous research, which demonstrated better responsiveness to personalized physical education programs in females. Specifically, research like that conducted by Gordienko (2015) or Tüdös et al. (2020) has suggested that girls can benefit more markedly and verifiably from motor educational programs that take into account specific needs or learning modalities (Gordienko, 2015; Tüdös et al., 2020). All the girls had a medical certificate for physical-sports practice. Before conducting the tests with recording, a specific familiarization session was held. No test was trained during the 5 weeks of training, and no specific training on the qualities tested was directly carried out. The sample was chosen to be only female to reduce possible interfering variables.

Table 1. Types of exercises performed in the pilot study divided between the experimental group and the control group.

Week	Experimental group (Sincrony methodology)	Control group (Unspecific physical activity)
1	Warm-up with proprioceptive focus, peripheral games, and static centring exercises.	General warm-up, free play, relays, cooldown
2	Body warm-up with proprioception, peripheral coordination Static centring.	General warm-up, ball games, team activities
3	Warm-up with peripheral focus, movement-breath synchronization, dynamic centring.	Dynamic warm-up, obstacles, speed, running games
4	Movement awareness during warm-up, agility games in peripheral, centring.	Movement games, group activities, stretching
5	Proprioception, respiratory work, games with centring and peripheral.	Warm-up exercises, obstacle courses, cooldown

The pilot sample was divided into two groups: 7 participants in the control group and 7 in the experimental group. Participants were assigned to groups through simple randomization. The experimental group participated in an integrative physical education program based on the Sincrony methodology. The control group, on the other hand, carried out unspecific physical integrative activity. Both groups participated in two 30-minute sessions per week for a total of 5 weeks.

In the experimental group, the exercises included improving peripheral vision, proprioception, and diaphragmatic breathing techniques. In the control group, general physical exercises were conducted without a specific focus.

Evaluations for both groups were conducted across three different dimensions:

- Attention: Both groups were assessed using the Trail Making Test A, a standardized tool for evaluating executive functions and attention (Tombaugh, 2004). The Trail Making Test Part A is a standardized neuropsychological procedure used to assess cognitive processing speed and attention. During this test, the girls had to connect a series of numbers randomly distributed on a sheet of paper as quickly as possible without lifting the pen. The primary objective was to complete the test as quickly as possible, with the time taken being the main performance indicator (Bowie, 2006; Lezak, 2012).
- Self-awareness: The Stork Stand Test for balance was used to assess bodily self-awareness expressed in the ability to maintain the correct level of muscle tension in a balance task. Previous studies have indeed correlated the ability to maintain balance with greater body awareness (Prosperi et al., 2019). The Stork Stand Test was performed with the following procedure:

The participant removed their shoes and stood on a flat surface. Then, they had to lift one foot by bending the knee and resting the sole of the foot on the inner side of the opposite knee, mimicking the stance of a stork. Arms were placed at the sides, bent with hands resting on the hips. The goal was to remain in this position for as long as possible without losing balance, tilting the torso, or hopping. The evaluation was represented by the sum of the durations, measured with two stopwatches by a double experimenter (Johnson, 1979; Schell 1994).

- Behavioural Observations: Qualitative evaluations, Sustainable behaviours, were made on the use of changing rooms, a shared common space, to assess possible changes towards sustainability in behaviour. The teacher conducting these evaluations was unaware of the children's group affiliations to maintain objectivity; the dedicated teacher had followed a blind procedure and had never attended the lessons. The children were not made aware of these evaluations. The responsible teacher had to assign a score in the established macro-areas.

Table 2. Observational macro-areas.

Evaluation criterion	Description	Assigned score (1 or 0)
Responsible Water Use	Turning off the taps after use.	1 = Always closed 0 = Left open
Waste Management	Disposing of waste, tissues, etc., in the appropriate recycling bins.	1 = Correct use of bins 0 = Incorrect use or litter on the ground
Order and Cleanliness of Space	Keeping order and cleanliness in the common space, not leaving clothes around.	1 = Orderly and clean 0 = Disorderly or dirty
Energy Saving	Turning off the lights when not needed.	1 = Lights off when not needed 0 = Lights left on
Shared and Respectful Use of Resources	Sharing space and resources (benches, lockers, hangers) fairly.	1 = Fair sharing 0 = Excessive occupation or exclusive use

Experiment

In light of the encouraging results obtained from the pilot experiment, a second, more extensive experiment was undertaken with the aim of exploring the impact of the Sincrony methodology on a larger sample, diversified in terms of age. Given the feasibility of fieldwork, the experimentation weeks were increased to 12. (Kim, 2020) Additionally, 40 students for the experimental (work) group and 30 for the control sample aged between 10 and 13 years (average age 12) were selected from various secondary schools. The choice to include students of this age range is based on evidence suggesting a significant variation in responses to physical education during these ages are crucial for development (Eime et al., 2013; Smith et al., 2019). Moreover, based on the results of the pilot experiment, the same initial extracurricular screening was performed, with the addition of excluding girls who already participated in similar motor programs in their sports. Furthermore, the training protocol for the experiment was structured to last 10 weeks, with bi-weekly sessions of 45 minutes each, to better adapt to the evolutionary needs of the participants and to allow a deeper assimilation of the principles of the Sincrony methodology. This decision was made based on both the observations collected in the pilot experiment and the literature that emphasizes the importance of the duration and frequency of the intervention to maximize the potential impact on self-awareness and sustainable behaviours (Durlak et al., 2011; Beets et al., 2016).

In this case, too, the sample was divided into two groups through a process of stratified randomization, taking into account age and gender, to ensure a fair distribution of participant characteristics between the experimental group (40 students) and the control group (30 students). This approach was designed to reduce potential confounding variables and to ensure the reliability of the results (Kraemer et al., 2002).

For the experimental group, the exercises were designed to include a greater variety of activities to increase proprioception and spatial awareness, as per the pilot protocol, integrating them with a greater part of explanation and correction (Best, 2010; Pesce, 2012).

As in the pilot, the evaluation of performance and behaviours was conducted using validated tools and observational measures, such as the Trail Making Test for attention assessment and the Stork Stand Test for self-awareness, in line with previous evaluation protocols (Tomporowski, 2003; Haga, 2008).

RESULTS

The data were analysed using SPSS software. No subjects were excluded from the sample. No outlier values were found.

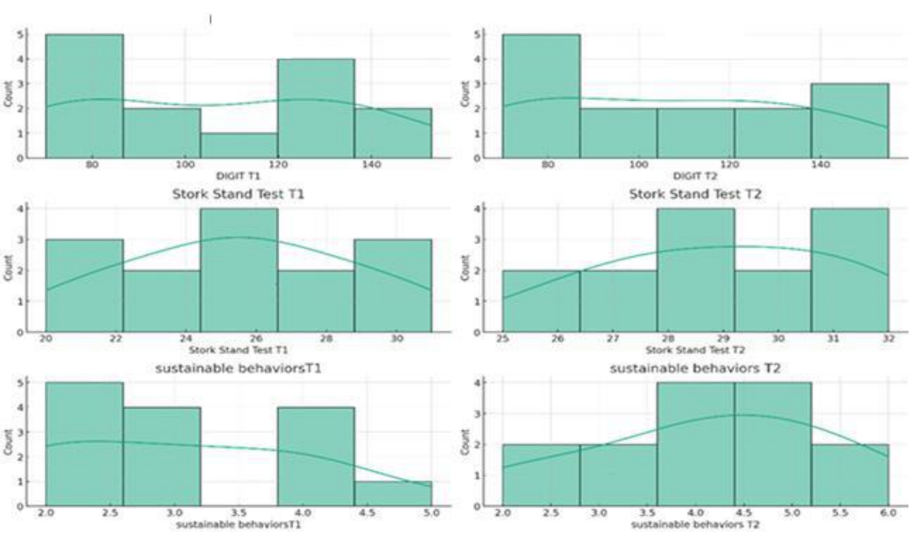

Figure 1. Distribution of pilot data.

Pilot analysis

The sample size was small, therefore the normality tests conducted are considered less reliable compared to a larger sample size. Nonetheless, they were necessary to verify the distribution of the sample.

Analysis of distributions through the visual reproduction of histograms (Figure 1).

The observed distributions highlight differences in distribution for the various study variables. The presence of peaks, asymmetries, or irregular distributions suggests that some of the variables do not follow a normal distribution, while others do. Therefore, specific tests will be conducted based on the distribution of the variable under examination.

Analysis of distributions through the Shapiro-Wilk Test
TMT T1: Shapiro-Wilk Statistic = 0.914, *p*-value = .182.
TMT T2: Shapiro-Wilk Statistic = 0.928, *p*-value = .284.
Stork Stand Test T1: Shapiro-Wilk Statistic = 0.979, *p*-value = .969.
Stork Stand Test T2: Shapiro-Wilk Statistic = 0.958, *p*-value = .692.
Sustainable Behaviours T1: Shapiro-Wilk Statistic = 0.862, *p*-value = .033.
Sustainable Behaviours T2: Shapiro-Wilk Statistic = 0.923, *p*-value = .243.

ANOVA for Variables with a Normal Distribution
ANOVA for TMT (T1 vs T2): F-statistic = 0.0106, *p*-value = .919. The high *p*-value (.919) suggests there are no significant differences between TMT T1 and TMT T2.
ANOVA for Stork Stand Test (T1 vs T2): F-statistic = 8.533, *p*-value = .0071. The *p*-value of .0071 indicates a significant difference between Stork Stand Test T1 and T2.

Kruskal-Wallis Test for Variables with Non-Normal Distribution
Kruskal-Wallis Test for Sustainable Behaviours: Kruskal-Wallis Statistic = 5.397, *p*-value = .0202. The *p*-value of .0202 indicates a significant difference between Sustainable Behaviours T1 and T2.

The results showed significance in variance for the parametric variable Stork Stand Test and the non-parametric variable Sustainable Behaviours; therefore, further analyses of these variables will be conducted.

- Stork Stand Test (Parametric Analysis): We will compare the means between the control group and the experimental group for both T1 and T2 using a t-test.

Control Group: t-test Statistic = -2.83, *p*-value = .03.
Experimental Group: t-test Statistic = -41.0, *p*-value = .002.

- Sustainable Behaviours (Non-Parametric Analysis): We will compare the means for the control and experimental groups for both T1 and T2 using the Mann-Whitney Test.

Control Group: Mann-Whitney U Statistic = 30.0, *p*-value = .504.
Experimental Group: Mann-Whitney U Statistic = 5.5, *p*-value = .0153.

Pilot discussion
The analysis of the pilot data highlighted significant differences in sustainable behaviours and the balance test (Stork Stand Test) between pre-tests and post-tests, indicating potential positive effects of the intervention. These results suggest that the program could indeed have effects and that the chosen protocols should therefore be further investigated.

Experiment

Descriptive Statistics

- Experimental Group (Group 1)

TMT T1: Mean = 120.98, Standard Deviation (SD) = 20.68.
TMT T2: Mean = 117.95, SD = 20.39.
Stork Stand Test T1: Mean = 27.88, SD = 1.90.
Stork Stand Test T2: Mean = 27.45, SD = 2.12.
Sustainable behaviours T1: Mean = 3.83, SD = 1.08.
Sustainable behaviours T2: Mean = 3.75, SD = 1.15.
Age: Mean = 11.93, SD = 0.86.

- Control Group (Group 0)

TMT T1: Mean = 117.37, SD = 16.43.
TMT T2: Mean = 117.47, SD = 16.30.
Stork Stand Test T1: Mean = 28.23, SD = 2.21.
Stork Stand Test T2: Mean = 28.27, SD = 2.26.
Sustainable behaviours T1: Mean = 3.37, SD = 1.00.
Sustainable behaviours T2: Mean = 3.33, SD = 0.92.
Age: Mean = 11.80, SD = 0.81.

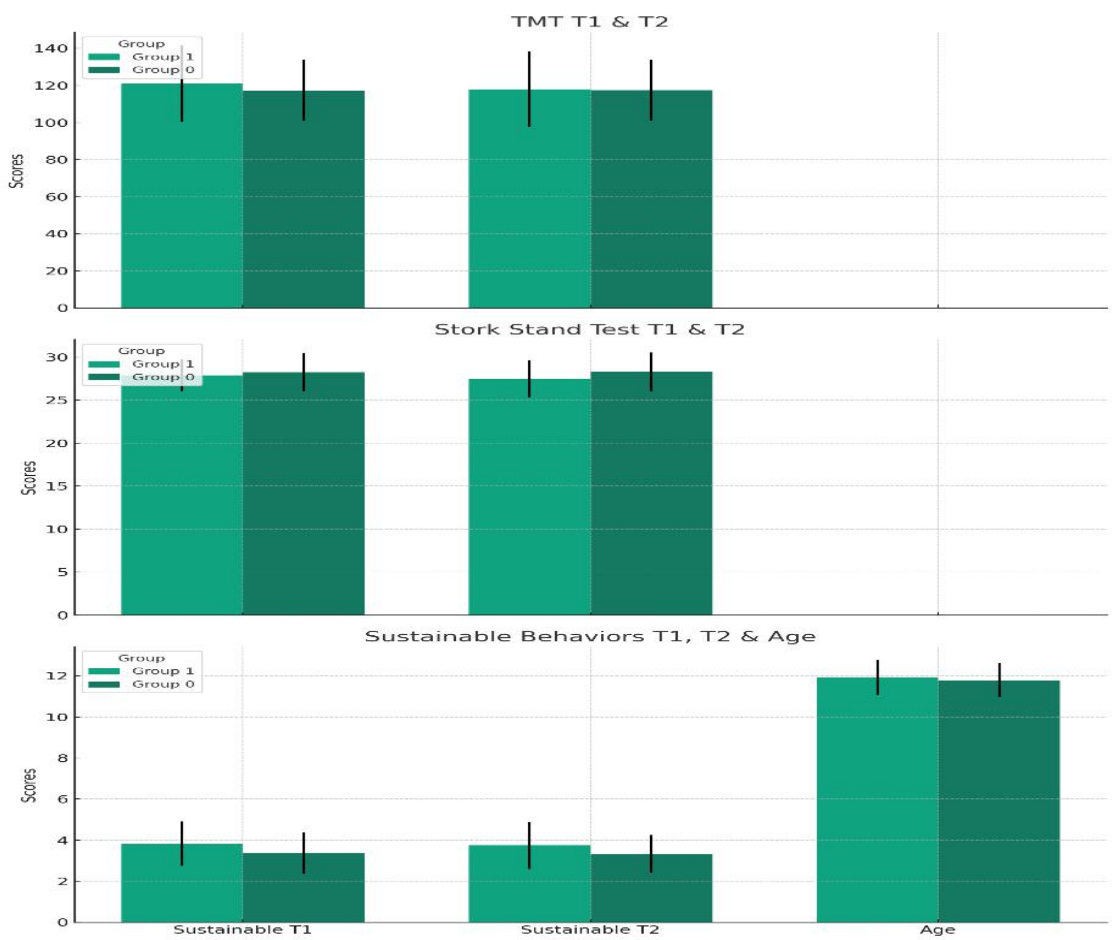

Figure 2. Descriptive distribution of the experiment.

Normality Testing Results
The results of the Shapiro-Wilk test indicate that none of the analysed variables follow a normal distribution:
TMT T1: *p*-value = .0043.
TMT T2: *p*-value = .0111.
Stork Stand Test T1: *p*-value = .000176.
Stork Stand Test T2: *p*-value = 9.56 (This *p*-value seems incorrect as it exceeds the range [0,1]. It might be a typographical error).
Sustainable Behaviours T1: *p*-value = 2.04 (This p-value also seems incorrect for the same reason).
Sustainable Behaviours T2: *p*-value = 2.08 (This p-value again seems incorrect for the same reason).

These results suggest that the data do not satisfy the assumption of normality.

Wilcoxon Test
The Wilcoxon Test was applied to compare medians between pre- and post-intervention measurements (T1 and T2) for each variable, in both control and experimental groups.

- Experimental Group (Work Group)

In the Experimental Group, the Wilcoxon Test revealed significant differences for some variables:
TMT T1 vs TMT T2: *p*-value = .048.
Stork Stand Test T1 vs T2: *p*-value = .033.
Sustainable Behaviours T1 vs T2: *p*-value = .017.

The significant differences found in the Experimental Group for these variables suggest that the intervention had a positive impact, leading to significant changes in sustainable behaviour and balance abilities.

- Control Group

For the Control Group, the Wilcoxon Test did not show statistically significant differences for any of the considered variables, as indicated by the following p-values:
TMT T1 vs TMT T2: *p*-value = .310.
Stork Stand Test T1 vs T2: *p*-value = .215.
Sustainable Behaviours T1 vs T2: *p*-value = .462.

These results suggest that there were no significant changes in the control group between the two measurement times.

Correlation analysis
Correlation analyses between the variables "*Delta T1-T2 for Stork Stand Test*" and "*Delta T1-T2 Sustainable Behaviours*" were conducted to examine if there was a significant relationship between these variables. Both the Kendall's Tau-b coefficient and the Spearman's Rho coefficient were utilized, and the results indicated a positive correlation between the two variables.

Specifically, the Kendall's Tau-b coefficient was found to be 0.275, with a *p*-value of .005, indicating that the correlation is statistically significant at the 1% level (two-tailed). This suggests that, generally, an increase in performance in the "*Stork Stand Test T2*" is associated with an increase in "*Sustainable Behaviours T2*".

Concurrently, the analysis using Spearman's Rho coefficient highlighted a slightly stronger correlation, with a coefficient of .299 and a *p*-value of .011, confirming statistical significance at the 5% level (two-tailed). This reinforces the evidence of a positive correlation between performance in the balance test and sustainable behaviours.

Both results, derived from 71 observations, support the existence of a significant relationship. However, it is important to emphasize that although there is a statistically significant correlation, this does not necessarily imply a causal relationship between the two variables. Further research might be necessary to explore the nature of this association.

Experiment results discussion

The statistical analysis conducted with the Wilcoxon Test on the experiment data revealed different outcomes for the control group and the experimental group. In the Control Group, the results do not show significant differences between T1 and T2 times for any of the variables considered. This implies that, without the intervention, there have been no appreciable changes in the subjects' performances in the variables of interest, such as balance and sustainable behaviours.

Conversely, the Experimental Group shows significant improvements. The differences in p-values in the Wilcoxon Test indicate that there has been a significant variation in performances measured by the TMT and the Stork Stand Test, as well as a change in sustainable behaviours. These findings suggest that the intervention could be the direct cause of these improvements.

DISCUSSION

The data from the Trail Making Test (TMT) Part A showed no significant differences pre- and post-intervention neither in the pilot experimental group nor in the control, suggesting that the initial intervention did not have a direct measurable impact on attention or visual and motor processing speed. In the main experiment, only the experimental group showed a slight improvement in TMT Part A completion times from pre to post-test, indicating a potential positive influence of the more prolonged and structured intervention on attention and processing capabilities, though not significant. Transitioning from the pilot study data analysis to the main experiment highlights how the intensification and longer duration of the intervention might have contributed to a slight improvement in performance in the Trail Making Test (TMT) Part A.

Data related to the Stork Stand Test showed a significant improvement from pre to post-test in the experimental group but not in the control in the pilot experiment, indicating an increase in balance and body self-awareness. The main experiment confirmed the pilot study results, with further improvements recorded in the experimental group, suggesting that the prolonged and more structured intervention had a possible greater impact.

The data on sustainable behaviours, based on behavioural observations recorded by personnel in a blind manner, showed a significant change in the representative values of sustainable behaviour, especially those related to spatial variables, for the experimental group in the pilot study. In the main experiment, this data was strengthened, showing that participants in the experimental group maintained and improved their sustainable behaviours, even on other considered variables.

The progression from the pilot study data to the main experiment shows consistency in the improvement of the assessed metrics: both for self-awareness measured through the Stork Stand Test and for observed sustainable behaviours.

CONCLUSIONS

This study aimed to explore the impact of innovative physical education that combined proprioceptive work with movement, using the Sincrony methodology. Quantifiable physical parameters were sought to measure self-awareness, attention, and sustainable behaviours in a sample of youth.

Self-awareness and Balance: The results demonstrated significant improvements in self-awareness and balance abilities, measured through the Stork Stand Test, for participants subjected to the intervention. This suggests that the Sincrony methodology could effectively increase body awareness in youth, a fundamental aspect for physical and mental well-being.

Sustainable Behaviours: The intervention led to significant changes in participants' sustainable behaviours, as observed in behavioural evaluations. This indicates that physical education, when properly structured, can play a crucial role in promoting environmental responsibility and eco-friendly behaviours among the youth.

Attention: Although the results of the Trail Making Test Part A did not show significant immediate improvements, the main experiment displayed a trend towards improvement in attention and processing speed performances, suggesting that more prolonged and intensive interventions might be necessary to observe significant effects in this area.

The potential efficacy of innovative physical education underscores the importance of studying teaching methodologies and new approaches to stimulate sustainable behaviours. Physical education, by promoting movement, allows for promoting healthy physical, social, and cognitive growth in youth. It would be interesting if, through new methodologies, it could also contribute to the formation of individuals who are more responsible and attentive to others and the environment around them. To further consolidate these results and explore the potential of innovative physical education, future research on larger and more diverse samples is advisable, evaluating the efficacy of longer-duration interventions. Additionally, investigating the integration of such educational programs with other school subjects would promote cross-disciplinary and holistic learning that encourages not just academic excellence but also the development of essential personal and social skills.

AUTHOR CONTRIBUTIONS

The paper is the result of coordinated and collaborative work by the Authors. In particular: Antinea Ambretti wrote "*Introduction*" and "*Materials and methods*"; Arianna Fogliata wrote "Data analysis"; Davide Di Palma wrote "*Discussion*" and "Conclusion".

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

The authors declare that there are no conflicts of interest that could have influenced the course or outcomes of this study. All funding and resources used for the research were employed solely for scientific purposes and are not influenced by external obligations that could compromise the integrity of the research.

ETHICAL STATEMENT

This study was conducted with utmost respect for international ethical principles concerning non-clinical research with human subjects, paying particular attention to the protection of minors involved. The authors adopted a rigorous approach to ensure that all procedures respected the rights and well-being of the participants, in line with the Declaration of Helsinki guidelines. Before data collection began, we obtained written informed consent from the legal guardians of every minor involved in the study.

We ensured that participation was entirely voluntary and that guardians and minors could withdraw from the study at any time without any penalty. The information collected during the study is treated with the utmost confidentiality and has been anonymized to protect the participants' identities.

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REFERENCES

Bailey, R., Hillman, C., Arent, S., & Petitpas, A. (2009). Physical activity: An underestimated investment in human capital? Journal of Physical Activity and Health, 6(3), 347-355.

Barsalou, L. W. (2008). Grounded cognition. Annual Review of Psychology, 59, 617-645. https://doi.org/10.1146/annurev.psych.59.103006.093639

Beets, M. W., Beighle, A., Erwin, H. E., & Huberty, J. L. (2016). After-school program impact on physical activity and fitness: A meta-analysis. American Journal of Preventive Medicine, 40(6), 207-219. https://doi.org/10.1016/j.ypmed.2016.07.002

Benzing, V., & Schmidt, M. (2019). Exergaming to enhance cognitive functions in children and adolescents. Journal of Sport and Health Science.

Best, J. R. (2010). Effects of physical activity on children's executive function: Contributions of experimental research on aerobic exercise. Developmental Review, 30(4), 331-351. https://doi.org/10.1016/j.dr.2010.08.001

Bowie, C., Harvey, P. (2006). Administration and interpretation of the Trail Making Test. Nat Protoc 1, 2277–2281.https://doi.org/10.1038/nprot.2006.390

Castelli, D. M., & Hillman, C. H. (2007) Physical activity improves cognition and brain function. Journal of Sport and Health Science, 6(3), 149-157.

Darlius, & J.P. Sitanggang. (2015). Hubungan antara kemampuan kognitif tentang etika lingkungan, persepsi tentang lingkungan dan tanggung jawab dalam pelestarian lingkungan dengan perilaku berwawasan lingkungan. Jurnal Satya Mandiri Manajemen Dan Bisnis, 1(1), 15–29. https://doi.org/10.54964/satyamandiri.v1i1.279

Di Giacomo, D., Ranieri, J., & Lacasa, P. (2017). Digital Learning As Enhanced Learning Processing? Cognitive Evidence for New insight of Smart Learning. Frontiers in Psychology, 8, 1329. https://doi.org/10.3389/fpsyg.2017.01329

Durlak, J. A., Weissberg, R. P., Dymnicki, A. B., Taylor, R. D., & Schellinger, K. B. (2011). The impact of enhancing students' social and emotional learning: A meta-analysis of school-based universal interventions. Child Development, 82(1), 405-432. https://doi.org/10.1111/j.1467-8624.2010.01564.x

Eime, R. M., Young, J. A., Harvey, J. T., Charity, M. J., & Payne, W. R. (2013). A systematic review of the psychological and social benefits of participation in sport for children and adolescents: Informing development of a conceptual model of health through sport. International Journal of Behavioral Nutrition and Physical Activity, 10, 98. https://doi.org/10.1186/1479-5868-10-98

First, L. (2017). How does physical activity improve cognitive and mental health in children and teens? Journal of Physical Activity and Health.

Franzini, L., Elliott, M. N., Cuccaro, P., Schuster, M., Gilliland, M. J., Grunbaum, J. A., Franklin, F., & Tortolero, S. R. (2009). Influences of physical and social neighborhood environments on children's physical activity and obesity. American Journal of Public Health, 99(2), 271-278. https://doi.org/10.2105/AJPH.2007.128702

Gallese, V., & Sinigaglia, C. (2011). What is so special about embodied simulation? Trends in Cognitive Sciences, 15(11), 512-519. https://doi.org/10.1016/j.tics.2011.09.003

Gordienko, N. (2015). Theoretical and methodical training of female students in physical education classes. Physical Education of Students, 19(4), 17-23. https://doi.org/10.15561/20755279.2015.0401

Haga, M. (2008). The relation between physical activity, health and psychological well-being from physical activity. Norwegian School of Sport Sciences.

Hagger, M. S., Chatzisarantis, N. L., & Biddle, S. J. (2002). A meta-analytic review of the theories of reasoned action and planned behavior in physical activity: Predictive validity and the contribution of additional variables. Journal of Sport and Exercise Psychology, 24(1), 3-32. https://doi.org/10.1123/jsep.24.1.3

Hillman, C. H., Erickson, K. I., & Kramer, A. F. (2008). Be smart, exercise your heart: Exercise effects on brain and cognition. Nature Reviews Neuroscience, 9(1), 58-65. https://doi.org/10.1038/nrn2298

Johnson, B.L. and Nelson, J.K. (1979) Practical measurements for evaluation in physical education. 4th Edit. Minneapolis: Burgess

Kim, J., & Shin, J. (2021). The Effect of Physical Activity on Social Development, Self-Esteem and Learning Attitude of Middle School Students. Research in Dance and Physical Education, 5(1), 41-52. https://doi.org/10.26584/RDPE.2021.04.5.1.41

Kim, J., Son, W. M., Headid Iii, R. J., Pekas, E. J., Noble, J. M., & Park, S. Y. (2020). The effects of a 12-week jump rope exercise program on body composition, insulin sensitivity, and academic self-efficacy in obese adolescent girls. Journal of pediatric endocrinology & metabolism : JPEM, 33(1), 129-137. https://doi.org/10.1515/jpem-2019-0327

Koike, y. (1994). Psychological evaluation of effects brought about by environmental measures and casual model of environmentally conscious behavior. https://doi.org/10.2208/proer1988.22.50

Kraemer, H. C., Yesavage, J. A., Taylor, J. L., & Kupfer, D. (2002). How can we learn about developmental processes from cross-sectional studies, or can we? American Journal of Psychiatry, 157(2), 163-171. https://doi.org/10.1176/appi.ajp.157.2.163

Lakoff, G., & Johnson, M. (1999). Philosophy in the flesh: The embodied mind and its challenge to Western thought. Basic Books.

Lezak, Muriel Deutsch (2012). Neuropsychological assessment. Diane B. Howieson, Erin D. Bigler, Daniel Tranel (5 ed.). Oxford.

Moreno, L. A., González-Gross, M., Kersting, M., Molnár, D., De Henauw, S., Beghin, L. & HELENA Study Group. (2010). Assessing, understanding and modifying nutritional status, eating habits and physical activity in European adolescents: The HELENA (Healthy Lifestyle in Europe by Nutrition in Adolescence) Study. Public Health Nutrition, 13(3), 511-521.

Niedenthal, P. M. (2007). Embodying emotion. Science, 316(5827), 1002-1005. https://doi.org/10.1126/science.1136930

Nurhafid, S. A., & Nursasi, A. Y. (2019). Teknik Intervensi Meningkatkan Efikasi Diri sebagai Upaya Promotif Aktivitas Fisik pada Remaja. Forikes Journal of Research, 10(3). https://doi.org/10.33846/sf10304

Nyberg, G., & Larsson, H. (2017). Physical Education Teachers' Content Knowledge of Movement Capability. Journal of Teaching in Physical Education, 36(1), 37-48. https://doi.org/10.1123/jtpe.2015-0180

O'Hagan, A. D., Behan, S., Peers, C., Belton, S., O'Connor, N. E., & Issartel, J. (2022). Do our movement skills impact our cognitive skills? Exploring the relationship between cognitive function and fundamental movement skills in primary school children. Journal of Science and Medicine in Sport, 25(8), 625-630. https://doi.org/10.1016/j.jsams.2022.08.001

Ojedokun, a., & balogun, s. (2010). environmental attitude as a mediator of the relationship between self-concept, environmental self-efficacy and responsible environmental behaviour among residents of high density areas in ibadan metropolis, nigeria. https://doi.org/10.4314/ejesm.v3i2.59834

Pérez-Romero, N., Sánchez-García, C., Sabarit-Peñalosa, A., Morillo-Baro, J. P., Vázquez-Diz, J. A., Ruiz-Junco, A., Franquelo-Egea, M. A., Reigal Garrido, R. E., Morales-Sánchez, V., & Hernández-Mendo, A. (2023). Revisión sistemática sobre la incidencia de los programas de actividad física en la mejora cognitiva en la infancia y adolescencia. Apuntes de Psicología, 41(1). https://doi.org/10.55414/ap.v41i1.1526

Pesce, C. (2012). Shifting the focus from quantitative to qualitative exercise characteristics in exercise and cognition research. Journal of Sport and Exercise Psychology, 34(6), 766-786. https://doi.org/10.1123/jsep.34.6.766

Prosperi, M., et al. (2019). The Relationship Between Body Awareness and Equilibrium in Children. Journal of Pediatric Health, 33(5), 567-574.

Ratey, J. J., & Hagerman, E. (2008). Spark: The revolutionary new science of exercise and the brain. Little, Brown and Company.

Routen, A., Johnston, J. P., Glazebrook, C., & Sherar, L. (2018). Teacher perceptions on the delivery and implementation of movement integration strategies: the CLASS PAL (Physically Active Learning) Programme. International Journal of Educational Research, 88, 48-59. https://doi.org/10.1016/j.ijer.2018.01.003

Schell, J. and Leelaethaepin, B (1994) Physical Fitness Assessment in Exercise and Sports Science. 2nd Ed, Leelar Biomedisience Services, Matraville, NSW. p. 327.

Schmidt, M., Valkanover, S., Roebers, C. M., & Conzelmann, A. (2013). Promoting a functional physical self-concept in physical education: Evaluation of a 10-week intervention. European Physical Education Review, 19(2), 232-255. https://doi.org/10.1177/1356336X13486057

Singh, A., Uijtdewilligen, L., Twisk, J. W., van Mechelen, W., & Chinapaw, M. J. (2012). Physical activity and performance at school: A systematic review of the literature including a methodological quality assessment. Archives of Pediatrics & Adolescent Medicine, 166(1), 49-55. https://doi.org/10.1001/archpediatrics.2011.716

Spengler, S., Mess, F., Schmocker, E., & Woll, A. (2018). Effects of a physical education-based intervention on motor competence and BMI in adolescents: A controlled trial. International Journal of Environmental Research and Public Health, 15(6), 1109. https://doi.org/10.3390/ijerph15061109

Stanley, D. (2011). Developing workable research methods: lessons from a pilot study with vulnerable participants and complex assessments. Journal of Research in Nursing, 16(4), 307-318. https://doi.org/10.1177/1744987110380336

Stodden, D., Goodway, J. D., Langendorfer, S., Roberton, M. A., Rudisill, M. E., Garcia, C., & Garcia, L. E. (2008). A developmental perspective on the role of motor skill competence in physical activity: An emergent relationship. Quest, 60(2), 290-306. https://doi.org/10.1080/00336297.2008.10483582

Strömbäck, c., lindkvist, e., & västfjäll, d. (2023). individual differences in environmental wellbeing and pro-environmental behaviors explained by self-control. https://doi.org/10.3389/fpsyg.2023.1088682
Tombaugh, T. N. (2004). Trail Making Test A and B: normative data stratified by age and education. Archives of Clinical Neuropsychology, 19(2), 203-214. https://doi.org/10.1016/S0887-6177(03)00039-8
Tomporowski, P. D. (2003). Effects of acute bouts of exercise on cognition. Acta Psychologica, 112(3), 297-324. https://doi.org/10.1016/S0001-6918(02)00134-8
Tomporowski, P. D., Davis, C. L., Miller, P. H., & Naglieri, J. A. (2008). Exercise and children's intelligence, cognition, and academic achievement. Educational Psychology Review, 20(2), 111-131. https://doi.org/10.1007/s10648-007-9057-0
Tüdös, Z., Kudláčová, B., & Pukanská, K. (2020). Impact of fitness themes introduction on bio-psychomotor abilities development and maintenance of psychophysical well-being by means of motor programs including fitness means in adolescent girls. Journal of Physical Education and Sport, 20(3), 1458-1466. https://doi.org/10.35189/dpeskj.2020.59.3.5
U.S. Department of Health and Human Services. (2018). Physical Activity Guidelines for Americans, 2nd edition. Washington, DC: U.S. Department of Health and Human Services.
Werdermann, j. (2020). Einfach mal etwas verändern.
Wilson, M. (2002). Six views of embodied cognition. Psychonomic Bulletin & Review, 9(4), 625-636. https://doi.org/10.3758/BF03196322