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ORIGINAL ARTICLE

Influence of compression garments on perceived exertion during maximal isometric exercises

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ABSTRACT

Compression garments have gained popularity in the sports world as a means to enhance athletic performance and accelerate recovery. This study investigates the effectiveness of upper-body compression garments and their impact on the rate of perceived exertion (RPE) during maximal isometric contractions. Eight adult males, students of a Master's degree program in Sports Sciences, participated in the study, conducting tests in controlled conditions at the University of Salerno. The subjects performed maximal isometric contractions in three separate sessions, wearing compression garments (CG), traditional sportswear (noCG), and a tight-fitting garment without compression effect, to minimize the placebo effect (Placebo), respectively. Perceived exertion was assessed using the modified CR-10 scale. Statistical analysis revealed a significant reduction in RPE when athletes wore compression garments compared to other conditions, suggesting a benefit in the use of such clothing. The findings indicate that compression garments can attenuate the perception of exertion during intense physical activities, with potential implications for performance, comfort, and recovery. This study contributes to the existing literature by expanding the understanding of the effects of compression clothing and highlighting the importance of further research to optimize the use of these garments in enhancing athletic performance.
Keywords: Performance analysis, Compression garment, Maximal isometric contraction, Rated Perceived Exertion (RPE), Sports performance.

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INTRODUCTION

Compression garments are identified as a non-invasive therapeutic strategy used to apply mechanical pressure to body tissues. This pressure is designed to compress the underlying tissues and provide stability to limbs or targeted anatomical areas (Partsch, 2005). Initially devised for treating conditions such as lymphedema and edemas (Moseley, Carati & Piller, 2007; Partsch, Winiger & Lun, 2004; Brennan & Miller, 1998; Földi, 1998; Rinehart-Ayres, 1998), they have also proven effective in other clinical contexts such as pulmonary embolism (Asano et al., 2001) and venous ulcers (O'Meara et al., 2012; Blair et al., 1988). Compression garments are widely used to treat clinical pathologies like deep vein thrombosis, chronic venous insufficiency, and other circulatory disorders by improving compromised hemodynamic functionality (Galanaud, Laroche & Righini, 2013; Qaseem et al., 2011; Ibegbuna et al., 2003; Scurr et al., 2001; Amaragiri & Lees, 2000; Agu, Hamilton & Baker, 1999; Krijnen et al., 1997; Mayberry et al., 1991). Despite the traditional use of graduated compression garments in the treatment of vascular conditions, the sports apparel industry has played a significant role in promoting their non-medical adoption, incorporating them into a wide array of items such as socks, tops, and garments for the lower and upper body (Cotter et al., 2022). This trend has led to an increased interest in scientific research in the sports domain, with a growing number of coaches and athletes from various disciplines and competitive levels integrating these garments into their training regimens (Stickford et al., 2015; Gupta, Bryers & Clothier, 2015; Fu, Liu & Fang, 2013; Sperlich et al., 2013; Troynikov et al., 2013; Ali, Creasy & Edge, 2011; Dascombe et al., 2011; Ali, Creasy & Edge, 2011; Doan et al., 2003). The exerted pressure depends on the mechanical properties of the fabric determined by its characteristics and fit (MacRae, Cotter & Laing, 2011).

The beneficial effects of wearing compression garments during exercise and recovery have been the subject of numerous scientific studies (Broatch, Bishop & Halson, 2018; Wannop et al., 2016; Driller & Halson, 2013). Meta-analyses by Brown et al. (2017), and Marqués-Jiménez et al. (2016), have highlighted that the use of such garments can facilitate recovery of strength and power performance after resistance training sessions, in addition to aiding recovery during cycling exercise. These findings are further supported by the meta-analyses of Machado et al. (2018), and Hill et al. (2014), which also identified a significant reduction in creatine kinase (CK) levels associated with the use of compression garments, suggesting an acceleration in muscle recovery process and a reduction in delayed onset muscle soreness (DOMS). It has been found that the use of compression garments enhances the economy of sports movements, promotes better management of soft tissues, reduces post-exercise limb swelling, and tends to lower blood lactate levels during physical activity (Leabeater, James & Driller, 2022; Engel, Holmberg & Sperlich, 2016). While not showing a significant impact on overall endurance performance, the use of compression garments has shown positive effects on specific sports variables, such as counter-movement jump height (Leabeater, James & Driller, 2022). Several studies on the use of compression garments have focused on perceived exertion, revealing, albeit modestly, a positive impact (Miyamoto & Kawakami, 2014; Rugg & Sternlicht, 2013), while others have shown no appreciable effect (Rider et al., 2014; Venckūnas et al., 2014). Despite evidence of positive effects in many studies, the use of compression garments presents a still inconsistent picture in the scientific literature, with some studies reporting conflicting results regarding certain benefits, highlighting the need for further research for a comprehensive evaluation (Cotter et al., 2022; Da Silva et al., 2018; Dascombe et al., 2013). A critical analysis of the literature on the subject has highlighted how discrepancies in the obtained results can be attributed to various variables, including the characteristics of the subjects involved in the studies, the exercise modalities adopted, the application of strategies to minimize the placebo effect, the types of compression garments used, and the duration of the treatment employed (Brophy-Williams et al., 2021; Wannop et al., 2016; Hill et al., 2015; MacRae, Cotter & Laing, 2011). In particular, discrepancies in results between studies could be attributed to a lack of standardization of the pressure exerted by compression garments, underscoring the need for further understanding of optimal parameters to achieve significant benefits in athletic performance (Brophy-Williams et al., 2021; Driller & Halson, 2013).

Given that research has mainly focused on the positive effects of wearing compression garments on the lower limbs, with particular emphasis on the analysis of perceived exertion, this study aims to observe the effects of using compression garments on the upper body during maximal isometric contractions. The goal is to analyse perceived exertion (RPE) in relation to the use of such garments, taking into account the subjects' intrinsic ability to perceive physiological load during physical activity. The hypothesis is that participants should indicate a lower RPE when using compression garments.

MATERIALS AND METHODS

Participants

The sample consists of eight adult males with an average age of 26.4 years (± 2.6 years), an average height of 172.88 cm (± 4.5 cm), a body mass of 72.03 kg (± 8.19 kg), and a brachial bicep diameter of 30.56 cm (± 0.90 cm), all enrolled in a Master's degree program in Sports Sciences (LM-68) at the University of Salerno (Unisa). The sample was selected based on the following inclusion criteria: students who engage in sports activities, with a similar brachial bicep diameter (≃30 cm). Exclusion criteria included a history or reported presence of any cardiovascular diseases, traumas that could influence the test, and current use of medications.

Procedures and measures

Participants were asked to refrain from alcohol consumption and intense workouts, and to maintain their normal dietary and hydration habits 24 hours before the experimental session. All participants were informed of potential risks and provided written informed consent for participation in this study, which was conducted in accordance with the Declaration of Helsinki. This study has been approved by the Ethical Committee of the Department at the University (Protocol Number: 0186309). The study was designed and coordinated by the research staff of the Laboratory for Innovative Teaching and Sports Performance Analysis at the University of Salerno (Unisa).

Evaluations were conducted in the gym of the University Sports Center (CUS) under controlled environmental conditions (room temperature, 22 ± 2°C; relative humidity, 60% ± 2%) and at a fixed time (from 9:00 to 14:00). Each participant performed the test 48 hours apart, under controlled environmental conditions and at a fixed time.

To analyse the differences in perceived exertion related to the use of garments, sessions were conducted with compression garments (CG), traditional sportswear (noCG), and tight-fitting non-compressive clothing (Placebo), used to minimize the placebo effect.

Before each experimental trial, all subjects underwent a standardized warm-up consisting of three sets of unilateral bicep curls, with six repetitions at 50% of their 1RM (Zhao, Nishioka & Okada, 2022). There was a 1-minute recovery period between sets. In each experimental session, subjects performed 3 trials of isometric curl with both arms, maintaining a 90° elbow flexion angle, at 100% of maximum voluntary contraction for a duration of 10 seconds (Muthalib et al., 2010). The recovery between trials consisted of a passive rest period lasting 180 seconds (Peixoto et al., 2010). In the first session, subjects performed the trials wearing traditional sportswear (noCG). In the second session, they performed the trials wearing a compression garment (CG) from LB9 (®LB9 BRAND S.R.L.).

The characteristics of the worn garment are: 60% Nylon, 40% Spandex, size M. The pressure at the wrist measurement point corresponds to ≃24 mmHg, from which the pressure decreases before increasing at the level of the brachial biceps with a pressure of ≃22.7 mmHg.

In the third session, subjects performed the trial wearing tight-fitting but non-compressive clothing (Placebo). At the end of each trial, subjects were asked to indicate the RPE value of the trial using the validated Italian translation of the modified CR-10 scale (Foster et al., 2001; Foster et al.,1996; Borg, 1998). This scale is a category-ratio scale ranging from 0 to 10, where each number has a verbal anchor indicating the level of perceived exertion, ranging from "*rest*" (0) to "*maximum*" (10) (Table 1).

Table 1. Modified CR-10 Scale (Foster et al., 1996).

Rating	Description
0	Rest
1	Very, very easy
2	Easy
3	Moderate
4	Somewhat hard
5	Hard
6	
7	Very hard
8	
9	
10	Maximal

Analysis

From the collected data, the mean RPE values for each of the three trials were calculated for each participant. Subsequently, the group average for each of the three conditions was determined. The statistical analysis was conducted in MATLAB (The MathWorks, Inc., 2024). The Shapiro-Wilk test for normality was performed for each condition to verify the distribution of the data. Depending on the nature of the data, the Friedman test was used, being the most suitable choice for analysing differences in RPE among the three conditions. To determine which specific pairs of conditions differed significantly, the Wilcoxon Signed-Rank test with Bonferroni correction for multiple comparisons was utilized.

RESULTS

The RPE data, including means and standard deviations for each condition, are presented in Table 2. The Placebo group shows the highest values, followed by the noCG group, and finally, the CG group ranks third with the lowest values.

Table 2. RPE Means and Standard Deviation for each tested condition.

Condition	RPE Means	Std. Dev.
noCG	5.7	1.3
CG	4.9	1.3
Placebo	6	1.6

The Friedman test revealed significant differences in RPE between at least two of the three conditions. Subsequently, the Wilcoxon Signed-Rank test with Bonferroni correction for multiple comparisons, the results of which are reported in Table 3, indicates a significant difference in RPE between the noCG and CG conditions and between the CG and Placebo conditions. No significant difference was found between the noCG and Placebo conditions after correction for multiple comparisons.

Table 3. Wilcoxon Signed-Rank Test results with Bonferroni correction.

Comparison	Raw *p*-Value	Bonferroni *p*-Value	Significance
noCG vs CG	.0014	.0043	Yes
noCG vs Placebo	.1006	.3019	No
CG vs Placebo	.0001	.0004	Yes

DISCUSSION

The results of this study indicate that the participants reported significantly lower levels of perceived exertion during the performance of maximal isometric contractions while wearing compression garments (CG) compared to the noCG and Placebo conditions. The comparison between noCG and Placebo conditions did not show significant differences, suggesting that, from the perspective of perceived exertion (RPE), wearing tight-fitting garments to eliminate the placebo effect does not result in a significant change compared to performing with traditional sportswear. The presence of significant differences in the comparisons between noCG vs. CG and CG vs. Placebo suggests the effectiveness of compression garments in mitigating the subjective perception of exertion during maximal isometric contractions, as assessed by the Rating of Perceived Exertion (RPE). This observation can be interpreted through a series of physiological and psychological mechanisms that presumably contribute to this improvement.

From a physiological perspective, compression garments may reduce muscle oscillations during exercise, promoting greater stability and control, reducing the sensation of fatigue, perceived exertion, and structural damage to the muscles (Valle et al., 2014; Duffield, Cannon & King, 2010; Kraemer et al., 2010; Bringard, Perrey & Belluye, 2006; Doan et al., 2003). Additionally, it is plausible to consider that the positive effect of compression garments on RPE could be mediated by improved lymphatic drainage, which reduces muscle swelling, and by improvements in blood flow to the limbs, leading to greater muscle oxygenation (Faulkner et al., 2013; Kraemer et al., 2010; Kraemer et al., 2001). These physiological aspects provide a solid foundation for understanding the relationship between the use of compression garments and the perception of exertion during physical exercise.

From a psychological viewpoint, it is reasonable to hypothesize that the comfort derived from the use of compression garments may have a significant impact on athletes' perception of exertion (Rugg & Sternlicht, 2013), contributing to performance improvement (Wannop et al., 2016). This aspect could be crucial in understanding the perceptual improvements observed in our study. The combination of these factors might contribute to reducing the perception of exertion during physical exercise, allowing athletes to maintain higher activity intensities or complete a greater volume of work during training (Loturco et al., 2016). It is important to consider that the results obtained in this study are consistent with other studies in the scientific literature that have reported improvements in muscle pain perception, RPE, and/or fatigue with the use of compression garments during physical exercise (Engel, Holmberg & Sperlich, 2016; Rugg & Sternlicht, 2013; MacRae, Cotter & Laing, 2011). However, there are also studies that report contrasting results (Mizuno et al., 2017; Venckūnas et al., 2014; Del Coso et al., 2014; Houghton, Dawson & Maloney, 2009; Bringard, Perrey & Belluye, 2006).

The potential role of the placebo effect in research on compression garments should also be considered, as knowledge of the purported benefits can influence individuals' expectations and thus the outcomes. The nature of compression garments, which involves a perceivable pressure on the body, makes them inherently difficult to test under blind experimental conditions (Driller & Halson, 2013; MacRae, Cotter & Laing, 2011). However, it is important to note that in the present study, a tight-fitting sports shirt was used as a control to minimize the placebo effect, which may have contributed to the robustness of the results obtained.

CONCLUSIONS

The perception of one's state of comfort and well-being during physical activity might play a significant role in determining athletic performance. Therefore, in addition to physiological aspects, the perception of exertion during exercise emerges as one of the factors that could impact sports performance (Duffield & Portus, 2007).

This study highlighted how the attire worn during the execution of a maximal isometric curl can significantly influence athletes' perception of exertion. Specifically, the use of a compression garment appears to reduce the RPE compared to other conditions, suggesting a potential beneficial effect on the perceived exertion experience during exercise. These findings provide important insights for athletes and coaches regarding the choice of clothing during training and competition, with potential implications for comfort, exertion perception, and performance.

As suggested by MacRae, Cotter & Laing (2011), the fundamental characterization of the garment and fabric provides useful information that allows for comparison between different studies.

In this study, it was possible to identify both the composition of the compression garment through the analysis of the materials used, and the pressure exerted by the garment on the affected body area, through specific measurements.

In conclusion, it is widely recognized in the scientific literature that any variation in the perception of exertion during physical activity can act as an ergogenic mechanism contributing to improved performance, regardless of the presence of direct physiological effects (Born, Sperlich & Holmberg, 2013). Therefore, the observed reduction in RPE with the use of compression garments could have significant implications for enhancing athletic performance.

AUTHOR CONTRIBUTIONS

The article is the result of collaborative work by all the authors. Rodolfo Vastola is the Scientific Coordinator of the entire contribution.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

ETHICAL APPROVAL

The present study has been approved by DISUFF Ethical Committee of University of Salerno (protocol N. 0186309).

DATA AVAILABILITY STATEMENT

Data available on request.

REFERENCES

Agu, O., Hamilton, G., & Baker, D. (1999). Graduated compression stockings in the prevention of venous thromboembolism. British Journal of Surgery, 86(8), 992-1004. https://doi.org/10.1046/j.1365-2168.1999.01195.x

Ali, A., Creasy, R. H., & Edge, J. A. (2011). The effect of graduated compression stockings on running performance. The Journal of Strength & Conditioning Research, 25(5), 1385-1392. https://doi.org/10.1519/JSC.0b013e3181d6848e

Amaragiri, S. V., & Lees, T. A. (2000). Elastic compression stockings for prevention of deep vein thrombosis. The Cochrane database of systematic reviews(3). https://doi.org/10.1002/14651858.CD001484

Asano, H., Matsubara, M., Suzuki, K., Morita, S., & Shinomiya, K. (2001). Prevention of pulmonary embolism by a foot sole pump. The Journal of Bone & Joint Surgery British Volume, 83(8), 1130-1132. https://doi.org/10.1302/0301-620X.83B8.0831130

Blair, S. D., Wright, D. D., Backhouse, C. M., Riddle, E., & McCollum, C. N. (1988). Sustained compression and healing of chronic venous ulcers. BMJ, 297(6657), 1159-1161. https://doi.org/10.1136/bmj.297.6657.1159

Borg, G. (1998). Borg's Perceived Exertion and Pain Scales. Human Kinetics.

Born, D., Sperlich, B., & Holmberg, H. (2013). Bringing Light into the Dark: Effects of Compression Clothing on Performance and Recovery. International Journal of Sports Physiology and Performance, 8(1), 4-18. https://doi.org/10.1123/ijspp.8.1.4

Brennan, M. J., & Miller, L. T. (1998). Overview of treatment options and review of the current role and use of compression garments, intermittent pumps, and exercise in the management of lymphedema. Cancer, 83(12 Suppl American), 2821-2827. https://doi.org/10.1002/(SICI)1097-0142(19981215)83:12B+<2821::AID-CNCR33>3.0.CO;2-G

Bringard, A., Perrey, S., & Belluye, N. (2006). Aerobic energy cost and sensation responses during submaximal running exercise--positive effects of wearing compression tights. International journal of sports medicine, 27(5), 373-378. https://doi.org/10.1055/s-2005-865718

Broatch, J. R., Bishop, D. J., & Halson, S. (2018). Lower Limb Sports Compression Garments Improve Muscle Blood Flow and Exercise Performance During Repeated-Sprint Cycling. International Journal of Sports Physiology and Performance, 19(7), 882-890. https://doi.org/10.1123/ijspp.2017-0638

Brophy-Williams, N., Fell, J., Halson, S., Kitic, C., & Driller, M. (2021). Pressure gradient differences between medical grade and sports compression socks. The Journal of The Textile Institute, 112(2), 187-191. https://doi.org/10.1080/00405000.2020.1730664

Brown, F., Gissane, C., Howatson, G., Van Someren, K., Pedlar, C., & Hill, J. (2017). Compression Garments and Recovery from Exercise: A Meta-Analysis. Compression Garments and Recovery from Exercise: A Meta-Analysis, 47(11), 2245-2267. https://doi.org/10.1007/s40279-017-0728-9

Cotter, J., Stade, M., Morse, B., & Schick, E. (2022). Graded Compression Garments Worn During Resistance Exercise: Impact on Muscle Damage, Fatigue, and Oxygenation in Untrained Individuals. International Journal of Kinesiology and Sports Science, 10(2), 51-59. https://doi.org/10.7575/aiac.ijkss.v.10n.2p.51

Da Silva, C. A., Helal, L., Da Silva, R. P., Belli, K. C., Umpierre, D., & Stein, R. (2018). Association of Lower Limb Compression Garments During High-Intensity Exercise with Performance and Physiological Responses: A Systematic Review and Meta-analysis. Sports medicine, 48(8), 1859-1873. https://doi.org/10.1007/s40279-018-0927-z

Dascombe, B. J., Hoare, T. K., Sear, J. A., Reaburn, P. R., & Scanlan, A. T. (2011). The effects of wearing undersized lower-body compression garments on endurance running performance. International journal of sports physiology and performance, 6(2), 160-173. https://doi.org/10.1123/ijspp.6.2.160

Dascombe, B., Laursen, P., Nosaka, K., & Polglaze, T. (2013). No effect of upper body compression garments in elite flat-water kayakers. European journal of sport science, 13(4), 341-349. https://doi.org/10.1080/17461391.2011.606842

Del Coso, J., Areces, F., Salinero, J., González-Millán, C., Abián-Vicén, J., Soriano, L., . . . Calleja-Gonzalez, J. (2014). Compression stockings do not improve muscular performance during a half-ironman triathlon race. European journal of applied physiology, 114(3), 587-595. https://doi.org/10.1007/s00421-013-2789-2

Doan, B. K., Kwon, Y. H., Newton, R. U., Shim, J., Popper, E. M., Rogers, R. A., . . . Kraemer, W. J. (2003). Evaluation of a lower-body compression garment. Journal of sports sciences, 21(8), 601-610. https://doi.org/10.1080/0264041031000101971

Driller, M. W., & Halson, S. L. (2013). The effects of wearing lower body compression garments during a cycling performance test. International journal of sports physiology and performance, 8(3), 300-306. https://doi.org/10.1123/ijspp.8.3.300

Duffield, R., Cannon, J., & King, M. (2010). The effects of compression garments on recovery of muscle performance following high-intensity sprint and plyometric exercise. Journal of science and medicine in sport, 1, 136-140. https://doi.org/10.1016/j.jsams.2008.10.006

Duffield, R., & Portus, M. (2007). Comparison of three types of full-body compression garments on throwing and repeat-sprint performance in cricket players. British journal of sports medicine, 41(7), 409-414. https://doi.org/10.1136/bjsm.2006.033753

Engel, F. A., Holmberg, H. C., & Sperlich, B. (2016). Is There Evidence that Runners can Benefit from Wearing Compression Clothing? Sports medicine, 46(12), 1939-1952. https://doi.org/10.1007/s40279-016-0546-5

Faulkner, J. A., Gleadon, D., McLaren, J., & Jakeman, J. R. (2013). Effect of lower-limb compression clothing on 400-m sprint performance. Journal of strength and conditioning research, 27(3), 669-976. https://doi.org/10.1519/JSC.0b013e31825c2f50

Foster, C., Daines, E., Hector, L., Snyder, A. C., & Welsh, R. (1996). Athletic performance in relation to training load. Wisconsin medical journal, 95(6), 370-374.

Foster, C., Florhaug, J. A., Franklin, J., Gottschall, L., Hrovatin, L. A., Parker, S., Doleshal, P., & Dodge, C. (2001). A new approach to monitoring exercise training. Journal of strength and conditioning research, 15(1), 109-115. https://doi.org/10.1519/00124278-200102000-00019

Földi, E. (1998). The treatment of lymphedema. Cancer, 83(12 Suppl American), 2833-2834. https://doi.org/10.1002/(SICI)1097-0142(19981215)83:12B+<2833::AID-CNCR35>3.0.CO;2-3

Fu, W., Liu, Y., & Fang, Y. (2013). Research Advancements in Humanoid Compression Garments in Sports. International Journal of Advanced Robotic Systems, 10(1). https://doi.org/10.5772/54560

Galanaud, J. P., Laroche, J. P., & Righini, M. (2013). The history and historical treatments of deep vein thrombosis. Journal of Thrombosis and Haemostasis, 11(3), 402-411. https://doi.org/10.1111/jth.12127

Gupta, A., Bryers, J. J., & Clothier, P. J. (2015). The effect of leg compression garments on the mechanical characteristics and performance of single-leg hopping in healthy male volunteers. BMC sports science, medicine & rehabilitation, 7, 10. https://doi.org/10.1186/s13102-015-0005-x

Hill, J., Howatson, G., van Someren, K., Davidson, S., & Pedlar, C. (2015). The variation in pressures exerted by commercially available compression garments. Sports Engineering, 18, 115-121. https://doi.org/10.1007/s12283-015-0170-x

Hill, J., Howatson, G., Van Someren, K., Leeder, J., & Pedlar, C. (2014). Compression garments and recovery from exercise-induced muscle damage: a meta-analysis. British journal of sports medicine, 48(18), 1340-1346. https://doi.org/10.1136/bjsports-2013-092456

Houghton, L. A., Dawson, B., & Maloney, S. K. (2009). Effects of wearing compression garments on thermoregulation during simulated team sport activity in temperate environmental conditions. Journal of science and medicine in sport, 12(2), 303-309. https://doi.org/10.1016/j.jsams.2007.09.004

Ibegbuna, V., Delis, K. T., Nicolaides, A. N., & Aina, O. (2003). Effect of elastic compression stockings on venous hemodynamics during walking. Journal of vascular surgery, 37(2), 420-425. https://doi.org/10.1067/mva.2003.104

Kraemer, W. J., Bush, J. A., Wickham, R. B., Denegar, C. R., Gomez, A. L., Gotshalk, L. A., . . . Sebastianelli, W. J. (2001). Continuous Compression as an Effective Therapeutic Intervention in Treating Eccentric-Exercise-Induced Muscle Soreness. Journal of Sport Rehabilitation, 10(1), 11-23. https://doi.org/10.1123/jsr.10.1.11

Kraemer, W. J., Flanagan, S. D., Comstock, B. A., Fragala, M. S., Earp, J. E., Dunn-Lewis, C. H., . . . Maresh, C. M. (2010). Effects of a whole body compression garment on markers of recovery after a heavy resistance workout in men and women. Journal of strength and conditioning research, 24(3), 804-814. https://doi.org/10.1519/JSC.0b013e3181d33025

Krijnen, R. M., De Boer, E. M., Adèr, H. J., Osinga, D. S., & Bruynzeel, D. P. (1997). Compression stockings and rubber floor mats: do they benefit workers with chronic venous insufficiency and a standing profession? Journal of occupational and environmental medicine, 39(9), 889-894. https://doi.org/10.1097/00043764-199709000-00013

Leabeater, A., James, L., & Driller, M. (2022). Tight Margins: Compression Garment Use during Exercise and Recovery-A Systematic Review. Textiles, 2, 395-421. https://doi.org/10.3390/textiles2030022

Loturco, I., Winckler, C., Lourenço, T., Veríssimo, A., Kobal, R., Kitamura, K., . . . Nakamura, F. (2016). Effects of compression clothing on speed-power performance of elite Paralympic sprinters: a pilot study. Springerplus, 5(1). https://doi.org/10.1186/s40064-016-2681-8

Machado, A., Kohn Cardoso, R., & Rombaldi, A. J. (2018). ost-exercise effectsof graduated compression garment use on skeletal muscle recovery and delayedonset muscle soreness: a systematic review. Motricidade, 14, 129-137. https://doi.org/10.6063/motricidade.13776

MacRae, B., Cotter, J., & Laing, R. (2011). Compression Garments and Exercise. ports Med, 815-843. https://doi.org/10.2165/11591420-000000000-00000

Mayberry, J. C., Moneta, G. L., De Frang, R. D., & Porter, J. M. (1991). The influence of elastic compression stockings on deep venous hemodynamics. Journal of vascular surgery, 13(1), 91-100. https://doi.org/10.1016/0741-5214(91)90016-N

Miyamoto, N., & Kawakami, Y. (2014). Effect of pressure intensity of compression short-tight on fatigue of thigh muscles. Medicine and science in sports and exercise, 46(11), 2168-2174. https://doi.org/10.1249/MSS.0000000000000330

Mizuno, S., Arai, M., Todoko, F., Yamada, E., & Goto, K. (2017). Wearing Compression Tights on the Thigh during Prolonged Running Attenuated Exercise-Induced Increase in Muscle Damage Marker in Blood. Frontiers in physiology, 8, 834. https://doi.org/10.3389/fphys.2017.00834

Moseley, A. L., Carati, C. J., & Piller, N. B. (2007). A systematic review of common conservative therapies for arm lymphoedema secondary to breast cancer treatment. Annals of oncology : official journal of the European Society for Medical Oncology, 18(4), 639-646. https://doi.org/10.1093/annonc/mdl182

Muthalib, M., Millet, G. Y., Quaresima, V., & Nosaka, K. (2010). Reliability of near-infrared spectroscopy for measuring biceps brachii oxygenation during sustained and repeated isometric contractions. Journal of biomedical optics, 15(1), 017008. https://doi.org/10.1117/1.3309746

O'Meara, S., Cullum, N. A., Nelson, E. A., & Dumvillle, J. C. (2012). Compression for venous leg ulcers (Cochrane review). Cochrane database of systematic reviews, 11, 1465-1858. https://doi.org/10.1002/14651858.CD000265.pub3

Partsch, H. M. (2005). The Static Stiffness Index: A Simple Method to Assess the Elastic Property of Compression Material In Vivo. Dermatologic Surgery, 31(6), 625-630. https://doi.org/10.1111/j.1524-4725.2005.31604

Partsch, H., Winiger, J., & Lun, B. (2004). Compression stockings reduce occupational leg swelling. Dermatologic surgery : official publication for American Society for Dermatologic Surgery, 30(5), 737-743. https://doi.org/10.1111/j.1524-4725.2004.30204.x

Peixoto, L. R., da Rocha, A. F., de Carvalho, J. L., & Goncalves, C. A. (2010). Electromyographic evaluation of muscle recovery after isometric fatigue. Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Annual International Conference, 2010, 4922-4925. https://doi.org/10.1109/IEMBS.2010.5627256

Qaseem, A., Chou, R., Humphrey, L. L., Starkey, M., Shekelle, P., & Physicians, C. G. (2011). Venous thromboembolism prophylaxis in hospitalized patients: a clinical practice guideline from the American College of Physicians. Annals of internal medicine, 155(9), 625-632. https://doi.org/10.7326/0003-4819-155-9-201111010-00011

Rider, B. C., Coughlin, A. M., Hew-Butler, T. D., & Goslin, B. R. (2014). Effect of compression stockings on physiological responses and running performance in division III collegiate cross-country runners during a maximal treadmill test. Journal of strength and conditioning research, 28(6), 1732-1738. https://doi.org/10.1519/JSC.0000000000000287

Rinehart-Ayres, M. E. (1998). Conservative approaches to lymphedema treatment. Cancer, 83(12 Suppl American), 2828-2832. https://doi.org/10.1002/(SICI)1097-0142(19981215)83:12B+<2828::AID-CNCR34>3.0.CO;2-T

Rugg, S., & Sternlicht, E. (2013). The effect of graduated compression tights, compared with running shorts, on counter movement jump performance before and after submaximal running. Journal of strength and conditioning research, 27(4), 1067-1073. https://doi.org/10.1519/JSC.0b013e3182610956

Scurr, J. H., Machin, S. J., Bailey-King, S., Mackie, I. J., McDonald, S., & Smith, P. D. (2001). Frequency and prevention of symptomless deep-vein thrombosis in long-haul flights: a randomised trial. Lancet, 357(9267), 1485-1489. https://doi.org/10.1016/S0140-6736(00)04645-6

Sperlich, B., Born, D. P., Swarén, M., Kilian, Y., Geesmann, B., Kohl-Bareis, M., & Holmberg, H. C. (2013). Is leg compression beneficial for alpine skiers? BMC sports science, medicine & rehabilitation, 5(1), 18. https://doi.org/10.1186/2052-1847-5-18

Stickford, A. S., Chapman, R. F., Johnston, J. D., & Stager, J. M. (2015). Lower-leg compression, running mechanics, and economy in trained distance runners. International journal of sports physiology and performance, 10(1), 76-83. https://doi.org/10.1123/ijspp.2014-0003

Troynikov, O., Wardiningsih, W., Koptug, A., Watson, C., & Oggiano, L. (2013). Influence of material properties and garment composition on pressure generated by sport compression garments. Procedia Engineering, 60, 157-162. https://doi.org/10.1016/j.proeng.2013.07.054
Valle, X., Til, L., Drobnic, F., Turmo, A., Montoro, J., Valero, O., & Artells, R. (2014). Compression garments to prevent delayed onset muscle soreness in soccer players. Muscles Ligaments Tendons J, 24;3(4), 295-302. https://doi.org/10.32098/mltj.04.2013.10
Venckūnas, T., Trinkūnas, E., Kamandulis, S., Poderys, J., Grūnovas, A., & Brazaitis, M. (2014). Effect of lower body compression garments on hemodynamics in response to running session. TheScientificWorldJournal. https://doi.org/10.1155/2014/353040
Wannop, J. W., Worobets, J. T., Madden, R., & Stefanyshyn, D. J. (2016). Influence of Compression and Stiffness Apparel on Vertical Jump Performance. Journal of strength and conditioning research, 30(4), 1093-1101. https://doi.org/10.1519/JSC.0000000000001195
Zhao, H., Nishioka, T., & Okada, J. (2022). Validity of using perceived exertion to assess muscle fatigue during resistance exercises. PeerJ, 10, e13019. https://doi.org/10.7717/peerj.13019

ORIGINAL ARTICLE

The effect of 10-week wholebody calisthenics training program on the muscular endurance of untrained collegiate students

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ABSTRACT

The study aimed to investigate the effects of calisthenics exercise on muscular endurance by implementing a 10-week whole-body calisthenic training program on 183 randomly selected untrained collegiate students (108 females, 75 males). A two-group pretest-posttest design was employed (Control group = 88; Experimental group = 95), accompanied by three muscular endurance field tests—the one-minute push-up test, planking test, and wall sit test—to thoroughly observe the probable effects of the training program on this fitness component. The pretest involved administering fitness tests, followed by the 10-week training program for the experimental group. The control group was instructed to engage in one hour of preferred physical activity three times a week for 10 weeks. Post-testing was completed by administering the same fitness tests. The normality of the data was assessed using the Shapiro-Wilk test. For intragroup comparison, the Wilcoxon signed-rank test was used, while for intergroup comparison, the Mann-Whitney U test was employed. Among females in the Controlled Group, the One Minute Push-up Test showed a significant improvement from a mean of 10.80 (±7.18) to 13.97 (±7.53) (p < .00001*), while the PT increased from 68.83 (±37.80) to 78.79 (±41.50) (p = .00036*), and the Wall Sit scores rose from 48.90 (±27.04) to 65.59 (±31.86) (p < .00001*). In males, the Wall Sit demonstrated a significant improvement from 58.15 (±26.47) to 83.88 (±50.28) (p = .00022*). Conversely, the Experimental Group exhibited significant improvements in all three tests for both females and males. Inter-group comparisons revealed the Experimental Group's significantly higher mean scores in the One Minute Push-up Test (24.50 vs. 18.17, p = .00494*), PT(107.87 vs. 79.85, p = .01044* for males), and Wall Sit (112.34 vs. 83.88, p = .01255*). Both female and male participants in the Experimental Group showed significant improvements in the One Minute Push-up Test, Planking Test, and Wall Sit compared to the Control Group, with consistently higher mean scores across all tests. The study recommends testing more muscle groups, like those involved in pulling and hip movements, to better understand calisthenics' impact on overall endurance and suggests additional field tests for a more complete evaluation.

Keywords: Physical education, Calisthenics, Untrained, Muscular endurance.

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INTRODUCTION

Muscular endurance denotes the ability of a muscle to repeatedly generate force, sustaining contraction over a defined duration (Hockey, 1973). This attribute is distinctive for each muscle group in the human body (Radovanović, 2013). Characterized by the capacity of a muscle group to endure repeated force application against resistance, muscular endurance is a crucial fitness component (Priya & Devi, 2023). Within the context of fatigue, it manifests as the performance of repetitive body actions (Kević et al., 2013). Beyond its role as a health-related fitness component, muscular endurance serves as a negative predictor for Body Mass Index (BMI) (Ding & Jiang, 2020; Garcia-Hermoso et al., 2019) and the risk of obesity (Garcia-Hermoso et al., 2019). Furthermore, elevated levels of this parameter are associated with reduced all-cause mortality and a decreased risk of cardiovascular diseases (Corder et al., 2019). As a vital health-related fitness component necessitating maintenance and enhancement, muscular endurance contributes significantly to weight management and disease prevention.

Despite its health-related significance, low muscular endurance may engender challenges in an individual's athletic, physiological, and psychological domains (Walker et al., 2017). Research indicates that diminished muscular endurance, even within the context of health-focused considerations, significantly impacts athletic performance and heightens the risk of injuries (Ambegaonkar et al., 2012). Moreover, it is associated with metabolic risk factors such as triglycerides, HOMA index, and inflammatory markers (Cohen et al., 2014). Cardiovascular diseases, including those of a metabolic nature, exhibit correlations with low muscular fitness (Artero et al., 2012). The ramifications extend beyond physical health, impacting psychological well-being. Individuals with lower muscular fitness are susceptible to anxiety (Kandola et al., 2020), while adolescents and middle-aged women with insufficient levels of this fitness component face an increased risk of psychiatric conditions such as schizophrenia and depression (Ortega et al., 2012; Ganasarajah et al., 2019). Premature mortality is a noteworthy concern, particularly in the context of an elevated risk of suicide before the age of 55 (Ortega et al., 2012). Thus, beyond serving as a health-related fitness component, low muscular endurance harbours alarming implications across athletic, cardiovascular, and mental health domains.

Body weight exercises and calisthenics

Bodyweight exercises involve utilizing the exerciser's body weight as resistance, performed without additional equipment such as free weights or machines (Chaves et al., 2020; Punia & Kulandaivelan, 2019; Ebert et al., 2018; Ebert et al., 2017). Positioned as an alternative to resistance training with equipment (Stephenson & Swank, 2004), bodyweight exercises are deemed joint-friendly and widely accessible, often considered a cornerstone in training regimens (Klisaric' et al., 2021). Functioning as closed-chain exercises, they engage multiple joints with resistance either distanced away from or toward the body part, connecting to a surface (Karp, 2008). Research affirms their positive impact on various fitness components, including cardiorespiratory endurance, muscle fitness, balance, flexibility, body composition, posture (Cigerci et al., 2020; Archila et al., 2021; Thomas et al., 2017), and exercise economy (McDaniel et al., 2020). Beyond serving as a training modality, bodyweight exercises find application in rehabilitative settings (Comfort et al., 2015; Ryan et al., 2021). Consequently, bodyweight exercises present themselves as a viable alternative to traditional resistance training, contributing to physical fitness enhancement and rehabilitation interventions.

Effectiveness of body weight training on muscular endurance

Body weight training, or calisthenics, emerges as a viable and effective approach to improving body composition (Thomas et al., 2017; Cigeri & Genc, 2020; Poti, K., & Upadhye, 2019), even in athletic populations (Bayrakdar et al., 2019). Its utility extends to physical education programs, where it enhances muscular endurance of the core and upper extremities (Guerra et al., 2019). Noteworthy gains in flexibility are observed among elderly individuals (Farinatti et al., 2014; Pinar et al., 2014), school-aged boys (Srivastava et al., 2013), and combative athletes, particularly in hip and trunk flexibility (Marwat et al., 2021; Esan & Okebiorun, 2015). The components of muscular fitness, encompassing both strength and endurance, are believed to be positively influenced by calisthenics (Faraley et al., 2020; Kotarsky et al., 2018; Pinar et al., 2014; Marwat et al., 2021). In addition to health-related fitness components, improvements in sports-related fitness components, such as balance (Genc, 2020) and coordination (Marwat et al., 2021), are documented outcomes of this training approach. Importantly, bodyweight training is found to positively influence exercise economy in conditions such as chronic obstructive pulmonary disease (Basso-Vanelli et al., 2016), demonstrating efficacy comparable to cycle exercise training and traditional resistance training (Duruturk et al., 2016; Greulich et al., 2014). The benefits extend to individuals with diabetes, where similar significant effects are noted (Nordin & Zainuddin, 2019; Kimura et al., 2020; Kong et al., 2022). While existing literature establishes the efficacy of bodyweight training across various fitness components and rehabilitative contexts, limited attention has been dedicated to investigating its specific impact on the muscular endurance of the upper extremities.

The outcomes of this study are anticipated to contribute valuable insights into the effects of calisthenics on human well-being. In the realm of fitness, the findings may propose a targeted program for enhancing the muscular endurance of the upper extremities among students. Additionally, the study promotes an alternative avenue for achieving muscular fitness, alleviating the constraints associated with equipment-dependent regimes.

METHODOLOGY

Research design

The investigation employed a true experimental design, specifically a two-group pre-test post-test design, to assess the impact of a 10-week whole-body calisthenic program on muscular endurance. The study encompassed an initial phase wherein selected muscular endurance tests were administered as pre-tests, followed by the implementation of a structured 10-week calisthenic training program. Subsequently, the study concluded with the administration of the same fitness tests to evaluate potential changes in muscular endurance.

Participants and sampling method

The study included 183 collegiate students selected through random sampling, with 95 assigned to the experimental group and 88 to the control group. Originally, the participants were 200 but five participants from the experimental group and 12 from the control group withdrew from the study.

Sex profile of the participants

Table 1 exhibits the random designation of the participants to either the Controlled Group or the Experimental Group, with a focus on sex distribution. The control group consisted of 24 male participants and 64 female participants, while the Experimental Group comprised 51 male participants and 44 female participants.

Table 1. Distribution of the sex profile of the participants.

	Controlled	Experimental
Male	24	51
Female	64	44

Demographic profile of the participants

Table 2 shows that participants were divided into a Controlled Group and an Experimental Group, each subjected to different conditions. The control group exhibited a mean age of 19.90 ± 1.29 years, while the Experimental Group had a slightly higher mean age of 20.08 ± 1.46 years. Notably, the Experimental Group also had a higher mean height of 1.79 ± 1.43 meters, compared to the Controlled Group's mean height of 1.64 ± 0.09 meters. Regarding weight, participants in the Controlled Group had a weight of 52.68 ± 10.90 kilograms, whereas those in the Experimental Group displayed a slightly greater mean weight of 58.61 ± 12.82 kilograms. Furthermore, the Body Mass Index (BMI) of the control group was calculated to be 19.63 ± 3.335, while the Experimental Group demonstrated a higher mean BMI of 21.36 ± 4.52.

Table 2. Demographic profile of the participants.

	Controlled group	**Experimental group**
Age (years)	19.90 ± 1.29	20.08 ± 1.46
Height (meters)	1.64 ± 0.09	1.79 ± 1.43
Weight (kg)	52.68 ± 10.90	58.61 ± 12.82
Body Mass Index	19.63 ± 3.335	21.36 ± 4.52

Instruments

Muscular endurance for the lower and upper body, as well as the core, was assessed using body part-specific tests. The wall sit test, designed for lower body endurance, particularly targeting the quadriceps group, was employed (Jyothi & Sujaya, 2018). For upper body endurance, focusing on the arms, upper back, and pectoral muscles, the one-minute push-up test was administered (Fischer et al., 2016). Additionally, the planking test, acknowledged as one of the best and practical methods for assessing core endurance, was utilized (Pardeshi et al., 2020). The selection of these instruments was based on their validity in measuring fitness components and their relevance to specific body parts.

Data gathering procedure

Prior to testing, participants were briefed on the study details, and they participated in active rest 24 hours before the test administration. A light warm-up and whole-body stretching were conducted before the fitness tests. The testing sequence comprised the plank test administered first, followed by the wall sit test, and concluded with the one-minute push-up test. To guarantee full recovery and optimize performance, participants were provided with 5-10 minutes of recovery time between each test.

The experimental group participated in a 10-week whole-body calisthenic program, involving three sessions per week. Each session comprised six exercises targeting the upper and lower body, as well as the core. The training program progressed by introducing progressively more kinetically demanding exercises. The specific details of the 10-week whole-body calisthenic program are outlined in the table below.

Table 3. 10-week whole-body calisthenic program.

	Upper body	**Core**	**Lower body**
Week 1 to 3	Wall push up	Dead bug position	Kneeling hip hinge
Training Program A	Chair push up	Straight leg Lift raise	Standing double leg hip hinge
Week 4 to 6	Negative Knee Push up	Dead bug with hip, knee, and shoulder extension (Same side)	Chair Squat
Training Program B	Knee push up	Leg raise	Squat with chair as assistance

Week 7 to 10	Negative Push ups	Dead bug with hip, knee, and shoulder extension (Contralateral)	Body weight squats
Training Program C	Push ups	Isometric hold leg raise	Hinge Squat

In contrast, the control group received instructions to partake in a minimum of three weekly p sessions, each lasting one hour, engaging in self-selected physical activities for the duration of 10 weeks. Following this period, all participants underwent identical fitness tests. The aforementioned procedure was replicated during the pretest phase.

Data analysis

The normality of the data was assessed using the Shapiro-Wilk test. For intragroup comparison, the Wilcoxon signed-rank test was used, while for intergroup comparison, the Mann-Whitney U test was employed.

Potential ethical issue

Participants received a comprehensive briefing on the study, inclusive of a discussion of their rights within the research framework. After this, informed consent was asked through the signing of a consent letter by the participants. Subsequently, a Physical Readiness Questionnaire was administered to ascertain the absence of any underlying medical conditions among participants. Ultimately, it is imperative to underscore that the data acquired will be handled with the utmost commitment to confidentiality and will be shared with the owner upon request.

RESULTS

Muscular endurance testing data of controlled group

Table 4 shows that the Controlled Group's muscular endurance was assessed through pre-test and post-test measurements, focusing on the One Minute Push-up Test, Planking Test, and Wall Sit. Among females, the One Minute Push-up Test exhibited a significant improvement from a mean of 10.80 (±7.18) in the pre-test to 13.97 (±7.53) in the post-test (p < .00001*), as indicated by a notable Z-value of -5.1922. Similarly, the PT displayed significant enhancement with mean scores of 68.83 (±37.80) in the pre-test and 78.79 (±41.50) in the post-test (p = .00036*), reflected by a Z-value of -3.3844. The Wall Sit scores also showed a substantial increase from a mean of 48.90 (±27.04) in the pre-test to 65.59 (±31.86) in the post-test (p < .00001*), supported by a Z-value of -5.8232. Among males, while the One Minute Push-up Test and PT did not exhibit significant changes (p = .24196 and .14457, respectively), the Wall Sit scores demonstrated a significant improvement from a mean of 58.15 (±26.47) in the pre-test to 83.88 (±50.28) in the post-test (p = .00022*), with a corresponding Z-value of -3.5225.

Table 4. Within group comparison of the controlled group.

	Pre-test	Post-test	*p*-Value	Z-Value
Female				
OMPUT(Repetitions)	10.80 ± 7.18	13.97 ± 7.53	< .00001*	-5.1922
PT(Seconds)	68.83 ± 37.80	78.79 ± 41.50	.00036 *	-3.3844
WT(Seconds)	48.90 ± 27.04	65.59 ± 31.86	< .00001.*	-5.8232
Male				
OMPUT(Repetitions)	17.59 ± 10.45	18.17 ± 10.66	.24196	-0.7042
PT(Seconds)	91.76 ± 45.62	79.85 ± 37.97	.14457	-1.0601
WT(Seconds)	58.15 ± 26.47	83.88 ± 50.28	.00022*	-3.5225

Muscular endurance testing data of experimental group

On the other hand, among the experimental group, significant improvements were observed in all three fitness tests. The One Minute Push-up Test scores increased from a mean of 11.45 (±7.63) in the pre-test to 18.41 (±9.74) in the post-test ($p < .00001$*), supported by a Z-value of -5.3099. Similarly, the PT demonstrated a substantial enhancement with mean scores of 58.86 (±28.31) in the pre-test and 81.40 (±32.99) in the post-test ($p < .00001$*), indicated by a Z-value of -5.3858. The Wall Sit scores also showed a significant increase from a mean of 54.92 (±33.84) in the pre-test to 78.15 (±35.93) in the post-test ($p < .00001$*), with a corresponding Z-value of -5.415. Among males, all three exercises exhibited highly significant improvements. The One Minute Push-up Test scores increased from a mean of 16.82 (±7.59) in the pre-test to 24.50 (±9.33) in the post-test ($p < .00001$*), accompanied by a Z-value of 10.23. The PT demonstrated substantial enhancement, with mean scores of 81.73 (±44.96) in the pre-test and 107.87 (±40.39) in the post-test ($p < .00001$*), reflected by a Z-value of -4.706. The Wall Sit scores also significantly increased from a mean of 67.22 (±34.72) in the pre-test to 112.34 (±55.76) in the post-test ($p < .00001$*), supported by a Z-value of -6.154.

Table 5. Within group comparison of the experimental group.

	Pre-test	**Post-test**	***p*-Value**	**Z-Value**
Female				
OMPUT(Repetitions)	11.45 ± 7.63	18.41 ± 9.74	< .00001*	-5.3099
PT(Seconds)	58.86 ± 28.31	81.40 ± 32.99	< .00001*	-5.3858
WT(Seconds)	54.92 ± 33.84	78.15 ± 35.93	< .00001*	-5.415
Male				
OMPUT(Repetitions)	16.82 ± 7.59	24.50 ± 9.33	< .00001*	10.23
PT(Seconds)	81.73 ± 44.96	107.87 ± 40.39	< .00001*	-4.706
WT(Seconds)	67.22 ± 34.72	112.34 ± 55.76	< .00001*	-6.154

Muscular endurance testing data of male controlled group and experimental group

Table 6 shows the male participants in both the Controlled and Experimental scores in the fitness tests administered. In the One Minute Push-up Test, the Experimental Group exhibited a significantly higher mean score of 24.50 (±9.33) compared to the Controlled Group's mean of 18.17 (±10.66), with a *p*-value of .00494* and a corresponding Z-value of 2.58389. Similarly, in the Planking Test, the Experimental Group demonstrated a significantly improved mean score of 107.87 (±40.39) compared to the Controlled Group's mean of 79.85 (±37.97), with a *p*-value of .01044* and a Z-value of 2.30563. The Wall Sit scores also showed a significant increase in the Experimental Group, with a mean of 112.34 (±55.76), compared to the Controlled Group's mean of 83.88 (±50.28), resulting in a *p*-value of .01255* and a Z-value of 2.23748.

Table 6. Male between-group comparison.

	Control	**Experimental**	***p*-Value**	**Z-Value**
OMPUT(Repetitions)	18.17 ± 10.66	24.50 ± 9.33	.00494*	2.58389
PT(Seconds)	79.85 ± 37.97	107.87 ± 40.39	.01044*	2.30563
WT(Seconds)	83.88 ± 50.28	112.34 ± 55.76	.01255*	2.23748

Muscular endurance testing data of female controlled group and experimental group

Table 7 shows that the female participants in the One Minute Push-up Test, the Experimental Group, demonstrated a significantly higher mean score of 18.41 (±9.74) compared to the Controlled Group's mean of 13.97 (±7.53), with a *p*-value of .01255* and a corresponding Z-value of 2.23748. However, in the Planking Test, no significant difference was observed between the two groups, with the Experimental Group having a mean score of 81.40 (±32.99) and the control group having a mean of 78.79 (±41.50), resulting in a *p*-value of .2327 and a Z-value of -0.73468. In the Wall Sit, the Experimental Group exhibited a significantly improved mean score of 78.15 (±35.93) compared to the Controlled Group's mean of 65.59 (±31.86), with a *p*-value of .00734* and a Z-value of -2.44477.

Table 7. Female between-group comparison.

	Control	**Experimental**	***p*-Value**	**Z-Value**
OMPUT(Repetitions)	13.97 ± 7.53	18.41 ± 9.74	.01255*	2.23748
PT(Seconds)	78.79 ± 41.50	81.40 ± 32.99	.2327	-0.73468
WT(Seconds)	65.59 ± 31.86	78.15 ± 35.93	.00734*	-2.44477

Muscular endurance testing data of controlled group

Table 8 represents that all of the participants in the Controlled Group, in the One Minute Push-up Test, demonstrated a significant improvement, with mean scores increasing from 12.65 (±8.69) in the pre-test to 15.11 (±8.64) in the post-test (p < .00001*), reflected by a Z-value of -4.7851. Similarly, the PT showed a notable enhancement, with mean scores changing from 75.15 (±41.14) in the pre-test to 79.08 (±40.36) in the post-test (p = .0116*), supported by a Z-value of -2.2709. The Wall Sit scores exhibited a substantial increase, with mean scores rising from 51.42 (±27.05) in the pre-test to 70.58 (±38.35) in the post-test (p < .00001*), indicated by a Z-value of -6.7733.

Table 8. Within-group comparison of the controlled group (All participants).

	Pre-test	**Post-test**	***p*-Value**	**Z-Value**
OMPUT(Repetitions)	12.65 ± 8.69	15.11 ± 8.64	< .00001*	-4.7851
PT(Seconds)	75.15 ± 41.14	79.08 ± 40.36	.0116*	-2.2709
WT(Seconds)	51.42 ± 27.05	70.58 ± 38.35	< .00001*	-6.7733

Muscular endurance testing data of experimental group

On the other hand, Table 9. Shows that the Experimental Group, in the One Minute Push-up Test, displayed a significant improvement, with mean scores increasing from 14.62 (±8.68) in the pre-test to 21.83 (±10.45) in the post-test (p < .00001*), evidenced by a Z-value of -8.0455. Similarly, the PT showed a substantial enhancement, with mean scores changing from 69.89 (±37.89) in the pre-test to 92.40 (±38.45) in the post-test (p < .00001*), supported by a Z-value of -7.0837. The Wall Sit scores exhibited a remarkable increase, with mean scores rising from 60.51 (±33.78) in the pre-test to 94.07 (±48.40) in the post-test (p < .00001*), indicated by a Z-value of -8.2074.

Table 9. Within-group comparison of the experimental group (All participants).

	Pre-test	**Post-test**	***p*-Value**	**Z-Value**
OMPUT(Repetitions)	14.62 ± 8.68	21.83 ± 10.45	< .00001*	-8.0455
PT(Seconds)	69.89 ± 37.89	92.40 ± 38.45	< .00001*	-7.0837
WT(Seconds)	60.51 ± 33.78	94.07 ± 48.40	< .00001*	-8.2074

Muscular endurance testing data of controlled group and experimental group

Lastly, in Table 10, all of the participants in the Experimental Group, in the One Minute Push-up Test, exhibited a significantly higher mean score of 21.83 (±10.45) compared to the Controlled Group's mean of 15.11 (±8.64), with a *p*-value of < .00001* and a corresponding Z-value of 4.32364. In the Planking Test, the Experimental Group also showed a significantly improved mean score of 92.40 (±38.45) compared to the Controlled Group's mean of 79.08 (±40.36), resulting in a *p*-value of .00427* and a Z-value of 2.62966.

Likewise, in the Wall Sit, the Experimental Group demonstrated a significantly higher mean score of 94.07 (±48.40) compared to the Controlled Group's mean of 70.58 (±38.35), with a *p*-value of < .00001* and a Z-value of 4.2203.

Table 10. Between-group comparison between the controlled and experimental group.

	Control	**Experimental**	***p*-Value**	**Z-Value**
OMPUT(Repetitions)	15.11 ± 8.64	21.83 ± 10.45	< .00001*	4.32364
PT(Seconds)	79.08 ± 40.36	92.40 ± 38.45	.00427*	2.62966
WT(Seconds)	70.58 ± 38.35	94.07 ± 48.40	< .00001*	4.2203

DISCUSSION

Muscular endurance of the upper and lower extremities, as well as the abdomen, improved after 10 weeks of 3 hours per week of physical activity among female participants. However, among males, only the lower extremities' muscular endurance was positively affected. Some studies support the effect of regular physical activity on other physical fitness components. It was studied that it is a way to improve musculoskeletal fitness (Warburton et al., 2001). Additionally, it was investigated to have a positive correlation among anthropometric measurements such as waist-to-hip ratio and muscle mass, and other fitness components which consist of cardiorespiratory fitness and grip strength (Irēna et al., 2012). Physical activity and cardiovascular fitness were investigated to have a small to moderate correlation, suggesting their positive correlation (Piccinno et al., 2017). In a study about graduate and undergraduate female students, it was shown that the low physical inactivity identified through the International Physical Activity Questionnaire has been the reason for both groups having an insufficient level of physical fitness (Osipov et al., 2021). All participants in the control group exhibited an improvement in all muscular endurance pertaining to specific body parts after 10 weeks of 3 hours per week of physical activity. The results of the study among the control group strengthen the literature about the causal and correlational relationship between physical activity and physical fitness.

Regardless of the sex of the participants, the 10-week whole-body calisthenics training program improved the upper and lower extremities and abdomen of the participants. Not only muscular endurance but also body composition as one of the health-related components was established to be improved by calisthenics in non-athletic populations, as investigated by previous studies (Thomas et al., 2017; Cigeri & Genc, 2020; Poti, K., & Upadhye, 2019). This is the same case for athletic populations (Bayrakdar et al., 2019). Flexibility of elderly populations (Farinatti et al., 2014; Pinar et al., 2014) and school-aged boys (Srivastava et al., 2013) was also improved by incorporating calisthenics exercises. All participants in the experimental group exhibited an improvement in all muscular endurance pertaining to specific body parts after the 10-week whole-body calisthenics training program. The effectiveness of the calisthenics training program, regardless of sex, was not only seen in muscular endurance as the present study suggests but also in other aspects of physical fitness as the previous studies investigated.

Male participants of the experimental group had higher muscular endurance of the upper and lower extremities, and abdomen in comparison with the control group counterpart. The same improvement was seen in literature about the effect of calisthenics as a training program in terms of body composition. Male footballers who underwent an 8-week calisthenic training program were observed to have better body weight, body mass index, fat percentage, and fat mass in comparison with athletes who focused on football training alone (Cigerci & Geno, 2020). In posture and strength of horizontal and vertical pulling, it was observed that untrained males who were administered the calisthenic training protocol had better performance in the said parameters compared to another group (Thomas et al., 2017). Male tennis players who underwent the same training program experienced an improvement in their static and dynamic balance (Genç, 2020). Literature about the positive effect of the calisthenic training program on the male population was supported by the present study. Among the male population, the training program is deemed effective in improving other fitness components. Female participants of the experimental group had higher muscular endurance of the upper and lower extremities in comparison with the control group counterpart. However, there is a lack of evidence on the difference between the groups in abdominal muscular endurance. Some studies about the effect of calisthenic training programs among females supported the results of the present study. Against Pilates, it was investigated that 6 months of calisthenics exercise is better in improving coordination of the lower extremities (Kaya et al., 2012). The present study adds up to a few studies investigating the effect of the calisthenics training program on the female population. This will not only lead to additional knowledge about the topic but also in the representation of females in exercise. The participants of the experimental group had higher muscular endurance of the upper and lower extremities, and abdomen in comparison with the control group counterpart.

In a 10-week study involving 3 hours of weekly physical activity, sex-specific outcomes were observed. Females exhibited improved muscular endurance in the upper and lower extremities and abdomen, while males experienced enhancement primarily in the lower extremities. The study supported the positive relationship between regular physical activity and musculoskeletal fitness, correlating anthropometric measurements with fitness components. All of the Control group participants demonstrated improved muscular endurance across body parts, reinforcing the connection between physical activity and fitness. On the other hand, the 10-week calisthenics program, regardless of sex, positively impacted upper and lower extremity muscular endurance, body composition, and flexibility. Males in the experimental group showed superior muscular endurance compared to controls, aligning with literature on calisthenics' benefits for body composition and strength in male athletes. Among females, calisthenics improved upper and lower extremity muscular endurance, contributing to the understanding of its effects on female populations and emphasizing its overall effectiveness in enhancing fitness components for both sexes.

CONCLUSION

The study investigated the effect of a 10-week whole-body Calisthenics training program on muscular endurance in Controlled and Experimental Groups, examining One Minute Push-up Test, Planking Test, and Wall Sit scores. In the Controlled Group, females displayed significant improvements in all fitness testing, while males showed a notable enhancement in Wall Sit scores. Conversely, the Experimental Group, both among females and males, exhibited highly significant improvements in all three tests. Inter-group analyses revealed that the Experimental Group outperformed the control group significantly in the one-minute push-up Test, PT(males only), and Wall Sit. Intra-group comparisons demonstrated consistent improvements in the Controlled Group, and highly significant changes in the Experimental Group, particularly in the One Minute Push-up Test. Overall, the 10-week whole-body Calisthenics training program yielded positive outcomes, with the Experimental Group consistently surpassing the Controlled Group in muscular endurance across three tests, emphasizing the effectiveness of the training program.

The study employs three specific muscular endurance tests, focusing on horizontal pushing, lumbar flexion, and squat movements. To comprehensively evaluate the effectiveness of calisthenics in enhancing overall muscular endurance, it is crucial to investigate other muscle groups involved in horizontal pulling, lumbar extension, and hip-dominant movements. This broader examination will provide a more comprehensive understanding of the impact of calisthenics on fundamental movements. To address the limitations of the study, additional field tests should be incorporated as instruments, offering a more holistic perspective on muscular endurance and contributing to a well-rounded evaluation of the effectiveness of the intervention.

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No potential conflict of interest was reported by the author.

REFERENCES

Ambegaonkar, J. P., Caswell, S. V., Winchester, J. B., Caswell, A. A., & Andre, M. J. (2012). Upper-body muscular endurance in female university-level modern dancers: a pilot study. Journal of Dance Medicine & Science, 16(1), 3-7. https://doi.org/10.1177/1089313X1201600101

Archila, L. R., Bostad, W., Joyner, M. J., & Gibala, M. J. (2021). Simple bodyweight training improves cardiorespiratory fitness with minimal time commitment: a contemporary application of the 5BX approach. International Journal of Exercise Science, 14(3), 93.

Artero, E. G., Lee, D. C., Lavie, C. J., España-Romero, V., Sui, X., Church, T. S., & Blair, S. N. (2012). Effects of muscular strength on cardiovascular risk factors and prognosis. Journal of cardiopulmonary rehabilitation and prevention, 32(6), 351. https://doi.org/10.1097/HCR.0b013e3182642688

Basso-Vanelli, R. P., Di Lorenzo, V. A. P., Labadessa, I. G., Regueiro, E. M., Jamami, M., Gomes, E. L., & Costa, D. (2016). Effects of inspiratory muscle training and calisthenics-and-breathing exercises in COPD with and without respiratory muscle weakness. Respiratory care, 61(1), 50-60. https://doi.org/10.4187/respcare.03947

Bayrakdar, A., Demirhan, B., & Zorba, E. (2019). The effect of calisthenics exercises of performed on stable and unstable ground on body fat percentage and performance in swimmers. MANAS Sosyal Araştırmalar Dergisi, 8(3), 2979-2992. https://doi.org/10.33206/mjss.541847

Chaves, L. M. D. S., Santos, G. V., Teixeira, C. L. S., & Da Silva-Grigoletto, M. E. (2020). Calisthenics and bodyweight exercises: different concepts or scientific synonyms. Rev Bras Fisiol Exerc, 19(1), 13-15. https://doi.org/10.33233/rbfe.v19i1.3985

Cigerci, A. E., & Genc, H. (2020). The effect of calisthenics exercises on body composition in soccer players. Prog. Nutr, 22(1), 94-102.

Cohen, D. D., Gómez-Arbeláez, D., Camacho, P. A., Pinzon, S., Hormiga, C., Trejos-Suarez, J., ... & Lopez-Jaramillo, P. (2014). Low muscle strength is associated with metabolic risk factors in Colombian children: the ACFIES study. PloS one, 9(4), e93150. https://doi.org/10.1371/journal.pone.0093150

Comfort, P., Jones, P. A., Smith, L. C., & Herrington, L. (2015). Joint kinetics and kinematics during common lower limb rehabilitation exercises. Journal of Athletic Training, 50(10), 1011-1018. https://doi.org/10.4085/1062-6050-50.9.05

Corder, K., Winpenny, E., Love, R., Brown, H. E., White, M., & van Sluijs, E. (2019). Change in physical activity from adolescence to early adulthood: a systematic review and meta-analysis of longitudinal cohort studies. British journal of sports medicine, 53(8), 496-503. https://doi.org/10.1136/bjsports-2016-097330

Diehl, C. L., Johnson, Q. R., Moses, J., Hicks, J., Lindsay, K. G., Dawes, J. J., & Trevino, M. (2019). Interrater reliability of assessing the 1-minute push-up test. In International Journal of Exercise Science: Conference Proceedings (Vol. 11, No. 7, p. 39). https://doi.org/10.1249/01.mss.0000670464.20031.f1

Ding, C., & Jiang, Y. (2020, December). The relationship between body mass index and physical fitness among chinese university students: Results of a longitudinal study. In Healthcare (Vol. 8, No. 4, p. 570). MDPI. https://doi.org/10.3390/healthcare8040570

Duruturk, N., Arıkan, H., Ulubay, G., & Tekindal, M. A. (2016). A comparison of calisthenic and cycle exercise training in chronic obstructive pulmonary disease patients: a randomized controlled trial. Expert review of respiratory medicine, 10(1), 99-108. https://doi.org/10.1586/17476348.2015.1126419

Ebert, A., Kiermeier, M., Marouane, C., & Linnhoff-Popien, C. (2017, May). Sensx: About sensing and assessment of complex human motion. In 2017 IEEE 14th International Conference on Networking, Sensing and Control (ICNSC) (pp. 327-332). IEEE. https://doi.org/10.1109/ICNSC.2017.8000113

Ebert, A., Marouane, C., Ungnadner, C., & Klein, A. (2018). An open, labeled dataset for analysis and assessment of human motion. In Wireless Mobile Communication and Healthcare: 7th International Conference, MobiHealth 2017, Vienna, Austria, November 14-15, 2017, Proceedings 7 (pp. 99-106). Springer International Publishing. https://doi.org/10.1007/978-3-319-98551-0_12

Esan, J. A., & Okebiorun, J. O. (2015). Effect of calisthenics exercises on HIP flexibility in male and female adults.

Farinatti, P., Rubini, E., Silva, E., & Vanfraechem, J. (2014). Flexibility of the elderly after one-year practice of yoga and calisthenics. International journal of yoga therapy, 24(1), 71-77. https://doi.org/10.17761/ijyt.24.1.5003007856u32q52

Farley, J. B., Stein, J., Keogh, J. W., Woods, C. T., & Milne, N. (2020). The relationship between physical fitness qualities and sport-specific technical skills in female, team-based ball players: A systematic review. Sports medicine-open, 6(1), 1-20. https://doi.org/10.1186/s40798-020-00245-y

Ganasarajah, S., Sundström Poromaa, I., Thu, W. P., Kramer, M. S., Logan, S., Cauley, J. A., & Yong, E. L. (2019). Objective measures of physical performance associated with depression and/or anxiety in midlife Singaporean women. Menopause (New York, N.Y.), 26(9), 1045-1051. https://doi.org/10.1097/GME.0000000000001355

García-Hermoso, A., Correa-Bautista, J. E., Olloquequi, J., & Ramírez-Vélez, R. (2019). Health-related physical fitness and weight status in 13-to 15-year-old Latino adolescents. A pooled analysis. Jornal de pediatria, 95, 435-442. https://doi.org/10.1016/j.jped.2018.04.002

García-Hermoso, A., Ramírez-Campillo, R., & Izquierdo, M. (2019). Is muscular fitness associated with future health benefits in children and adolescents? A systematic review and meta-analysis of longitudinal studies. Sports Medicine, 49, 1079-1094. https://doi.org/10.1007/s40279-019-01098-6

Genç, H. (2020). Effect Of The Calisthenics Exercises on Static and Dynamic Balance in Tennis Players. International Journal of Applied Exercise Physiology,(9), 3.

Greulich, T., Kehr, K., Nell, C., Koepke, J., Haid, D., Koehler, U., ... & Koczulla, A. R. (2014). A randomized clinical trial to assess the influence of a three months training program (gym-based individualized vs. calisthenics-based non-invidualized) in COPD-patients. Respiratory research, 15(1), 1-8. Diabetes. https://doi.org/10.1186/1465-9921-15-36

Guerra, L. A., Dos Santos, L. R. A., Pereira, P. E., Lauria, V. T., De Lima, C., Evangelista, A. L., ... & Teixeira, C. V. L. S. (2019). A low-cost and time-efficient calisthenics strength training program improves fitness performance of children. Journal of Physical Education and Sport, 19, 58-62.

Irēna, K., Anna, M., & Anda, B. (2012). Physical activity and its relation to health-related physical fitness in students. Ovidius University Annals, Series Physical Education & Sport/Science, Movement & Health, 12(2), 256-263.

Kandola, A.A., Osborn, D.P.J., Stubbs, B. et al. Individual and combined associations between cardiorespiratory fitness and grip strength with common mental disorders: a prospective cohort study in the UK Biobank. BMC Med 18, 303 (2020). https://doi.org/10.1186/s12916-020-01782-9

Karp, J. R. (2008). High-school PE class revisited: using vintage body-weight exercises never goes out of style. IDEA Fitness Journal, 5(2), 32-36.

Kaya, D. O., Duzgun, I., Baltaci, G., Karacan, S., & Colakoglu, F. (2012). Effects of calisthenics and pilates exercises on coordination and proprioception in adult women: a randomized controlled trial. Journal of sport rehabilitation, 21(3), 235-243. https://doi.org/10.1123/jsr.21.3.235

Kević, G., Šiljeg, K., Mrgan, J., & Sporiš, G. (2013). How to measure muscular endurance in children: a new approach. Collegium antropologicum, 37(2), 385-390.

Kimura, T., Okamura, T., Iwai, K., Hashimoto, Y., Senmaru, T., Ushigome, E., ... & Fukui, M. (2020). Japanese radio calisthenics prevents the reduction of skeletal muscle mass volume in people with type 2 diabetes. BMJ Open Diabetes Research and Care, 8(1), e001027. https://doi.org/10.1136/bmjdrc-2019-001027

Klisarić, D., Ranisavljev, I., Matić, M., & Lakićević, M. (2021). Analytical classification of body weight exercises according to the topological criterion. Journal of Physical Education and Sport, 21, 2097-2104.

Kong, N., Yang, G., Wang, L., & Li, Y. (2022). Calisthenics exercises to intervene in obesity and diabetes in middle-aged people. Revista Brasileira de Medicina do Esporte, 28, 85-88. https://doi.org/10.1590/1517-8692202228022021_0457

Kotarsky, C. J., Christensen, B. K., Miller, J. S., & Hackney, K. J. (2018). Effect of progressive calisthenic push-up training on muscle strength and thickness. The Journal of Strength & Conditioning Research, 32(3), 651-659. https://doi.org/10.1519/JSC.0000000000002345

Marwat, N. M., Aslam, H., Hussain, A., Hassan, H., Asghar, E., Zafar, A., & Ullah, H. (2021). Calisthenics training: effects on physical fitness (coordination, flexibility and endurance) of kabaddi players. PalArch's Journal of Archaeology of Egypt/Egyptology, 18(1), 5212-5220.

McDaniel, B. B., Naquin, M. R., Sirikul, B., & Kraemer, R. R. (2020). Five weeks of aquatic-calisthenic high intensity interval training improves cardiorespiratory fitness and body composition in sedentary young adults. Journal of Sports Science & Medicine, 19(1), 187.

Nordin, N., & Zainuddin, Z. A. (2019). Calisthenics and passive stretching exercises for patients with type 2 diabetes mellitus: a study protocol. In Proceedings of the 3rd International Colloquium on Sports Science, Exercise, Engineering and Technology: ICoSSEET 2016, 20-22 November 2016, Kota Kinabalu, Malaysia 3 (pp. 51-58). Springer Singapore. https://doi.org/10.1007/978-981-10-6772-3_7

Ortega, F. B., Silventoinen, K., Tynelius, P., & Rasmussen, F. (2012). Muscular strength in male adolescents and premature death: cohort study of one million participants. Bmj, 345, e7279. https://doi.org/10.1136/bmj.e7279

Osipov, A. Y., Nagovitsyn, R. S., Vaganova, O. I., Kutepov, M. M., Chelnokova, E. A., Ratmanskaya, T. I., & Vapaeva, A. V. (2021). Analysis of physical fitness and physical activity results of female undergraduate and graduate students. Sport Mont, 19(1), 83-87. https://doi.org/10.26773/smj.210218

Piccinno, A., Colella, D. Differences in cardiovascular fitness of Italian high-school adolescents according to different physical activity levels assessed by IPAQ-A: a cross-sectional study. Sport Sci Health 13, 149-155 (2017). https://doi.org/10.1007/s11332-016-0326-5

Pinar, L., Kara, B., & Kozan, Ö. M. E. R. (2014). Effects of long-term calisthenics on physical fitness and quality of life in older women. Türk Fizyoterapi ve Rehabilitasyon Dergisi/Turkish Journal of Physiotherapy and Rehabilitation, 25, 1-9. https://doi.org/10.7603/s40680-014-0007-8

Poti, K., & Upadhye, J. A. (2019). Effect of calisthenics workouts for weight loss and flexibility. International Journal of Physiology, Nutrition and Physical Education, 5, 13-15.

Priya, J., & Devi, G. (2019). Evaluation of Muscular Endurance among Dentists. Indian Journal of Public Health Research & Development, 10(10). https://doi.org/10.5958/0976-5506.2019.02808.0

Punia, S., & Kulandaivelan, S. (2019). Effect of 8 weeks body-weight resistance training on high-normal blood pressure and stage 1 hypertension subjects-pilot study to validate the protocol. Executive editor, 10(2), 175. https://doi.org/10.5958/0976-5506.2019.00281.X

Radovanović, D. (2013). Towards endurance in sport. Serbian Journal of Experimental and Clinical Research, 14(1), 3-8. https://doi.org/10.5937/sjecr14-3890

Robert, V., & Hockey, E. D. (1973). Physical fitness: the pathway to healthful living. St. Louis: CV Mosby Company, 21.

Ryan, G. A., Cook, J., & Adams, K. (2021). Strength and Conditioning for Patients Recovering From Guillain-Barre Syndrome. Strength & Conditioning Journal, 43(1), 107-115. https://doi.org/10.1519/SSC.0000000000000529

Srivastava, R., Sakthignanavel, D., & Singh, V. (2013). Effect of Pilates exercise, calisthenics exercise and combination of Pilates and Calisthenics exercise on flexibility & strength of school boys. Int J Manag, Econ Soc Sci, 2(2), 75-7.

Stephenson, J., & Swank, A. M. (2004). Core training: designing a program for anyone. Strength & Conditioning Journal, 26(6), 34-37. https://doi.org/10.1519/00126548-200412000-00006

Strand, S. L., Hjelm, J., Shoepe, T. C., & Fajardo, M. A. (2014). Norms for an isometric muscle endurance test. Journal of human kinetics, 40, 93. https://doi.org/10.2478/hukin-2014-0011

Thomas, E., Bianco, A., Mancuso, E. P., Patti, A., Tabacchi, G., Paoli, A., ... & Palma, A. (2017). The effects of a calisthenics training intervention on posture, strength and body composition. Isokinetics and exercise science, 25(3), 215-222. https://doi.org/10.3233/IES-170001

Tomchuk, D. (2010). Companion guide to measurement and evaluation for kinesiology. Jones & Bartlett Publishers.

Vuolo, S. Offers. Retrieved from [Accessed 2024, june 26]: https://thepaleodiet.com/

Walker, S., Haff, G. G., Häkkinen, K., & Newton, R. U. (2017). Moderate-load muscular endurance strength training did not improve peak power or functional capacity in older men and women. Frontiers in physiology, 8, 743. https://doi.org/10.3389/fphys.2017.00743

Warburton DE, Gledhill N, Quinney A. (2001). Musculoskeletal fitness and health. Can J Appl Physiol; 26:217-37. https://doi.org/10.1139/h01-013

Warburton DE, Gledhill N, Quinney A. (2001). The effects of changes in musculoskeletal fitness on health. Can J Appl Physiol;26:161-216. https://doi.org/10.1139/h01-012

ORIGINAL ARTICLE

Ergogenic response to caffeine in resistance performance, perceived pain, and female sex hormones following muscular endurance in strength-trained eumenorrheic females during early follicular phase

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ABSTRACT

This study investigates the ergogenic response to caffeine, in terms of repetitions to failure, time under tension, perceived pain, and female sex hormones (oestradiol and progesterone), following muscular endurance during the early follicular phase. Eleven strength-trained eumenorrheic females performed two consecutive trials (48 h apart). Using a double-blind crossover design, participants were randomly assigned to receive either caffeine (4 mg/kg) 1 h before exercise or a placebo. In each trial, participants performed as many repetitions of leg extension and hip adduction as possible at 65% of 1-RM. Two minutes of recovery were allocated between each exercise. Each repetition was performed at maximal velocity. Perceived pain was rated on an 11-point scale immediately after each exercise, and blood samples were drawn from each participant 30 min after completing the test. Data revealed a significant ergogenic response to caffeine in repetitions to failure for leg extension and hip adduction (p = .003 and p = .043, respectively); meanwhile, caffeine led to a significantly longer time under tension in leg extension (p = .001), with no differences in hip adduction (p = .053). In terms of perceived pain, no differences between trials were found for hip adduction (p = .724), but it was rated higher after leg extension in the caffeine trial, when compared to the placebo (p = .011). No differences were observed between trials regarding oestradiol and progesterone levels (p = .138 and p = .350, respectively). In conclusion, ingestion of 4 mg/kg of caffeine increased leg extension and hip adduction repetitions to failure, without main effects on perceived pain and sex hormones, in strength-trained eumenorrheic females during the early follicular phase.

Keywords: Sport medicine, Muscular endurance, CYP1A2, Menstrual cycle, Ergogenic, Theobromine.

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INTRODUCTION

Caffeine (1,3,7-Trimethyxanthine) is one of the most widely used legal psychoactive substances in the world, consumed by both general and athletic populations (Norum et al., 2020; Del Coso et al., 2011; Mitchell et al., 2014; Sampaio-Jorge et al., 2021). It has been well-documented that caffeine improves endurance and anaerobic-based exercise (Grgic et al., 2021; Grgic et al., 2020; Aguiar et al., 2020; Graham & Spriet, 1995; Davis & Green, 2009; Mohr et al., 2011). In recent years, the consumption of anhydrous caffeine has been popularized as an ergogenic resource by athletes before resistance training (Polito et al., 2019; Grgic et al., 2021), in order to increase muscle strength and endurance (Grgic et al., 2020; Richardson & Clarke, 2016; Diaz-Lara et al., 2016; Aguiar et al., 2020; Grgic & Mikulic, 2017). The primary purpose of caffeine ingestion before muscular endurance training has been suggested not to increase muscle mass, but actually to tolerate more repetitions before reaching momentary muscle failure.

It is well-known that elevation of adenosine in the central nervous system (CNS) and peripheral tissues can induce drowsiness, tiredness, and mood swings (Adan et al., 2008). Caffeine can pass through the cerebral capillary endothelial cells, which make up blood–brain barrier (BBB), due to its high degree of lipophilicity and hydrophilicity (McCall et al., 1982; Bowtell et al., 2018; Davis & Green, 2009; Grgic & Mikulic, 2017; Polito et al., 2019; Duncan et al., 2013). The ingestion of caffeine before resistance exercise has been reported to reduce the sensation of pain and rating of perceived exertion (RPE) (Filip-Stanchik et al., 2021; Goldstein et al., 2010; Norum et al., 2020) through blocking selective adenosine A_1 and A_2a receptors in the CNS (Sampaio-Jorge et al., 2021; Norum et al., 2020; Sabblah et al., 2015; Adan et al., 2008; Ferré, 2016), thus delaying the onset of fatigue and improving performance.

Several prior studies have investigated the ergogenic effect of caffeine in the context of resistance exercise (Bowtell et al., 2018; Davis et al., 2012; Grgic & Mikulic, 2017; Polito et al., 2019; Raastad et al., 2000; Smilios et al., 2014; Wilk et al., 2019). Despite their findings, most of these studies have been primarily conducted only in men. A review by Salinero et al. (2019) revealed that only 13% of the experimental participants in research focused on ergogenic caffeine between 1978 and 2018 were women and, so, the number of females participating voluntarily in investigations examining caffeine ergogenicity on muscle strength and endurance remains very scarce (Filip-Stanchnik et al., 2021; Davis et al., 2012; Ferré, 2016; Salinero et al., 2019). The exclusion of females from caffeine-based research refers to changes in female sex hormones between phases of the menstrual cycle and the use of oral contraceptive pills (OCPs). Variations in female sex hormones can affect neuromuscular function (Norum et al., 2020), attenuating the ergogenic effect of caffeine. A few prior studies have been carried out only in women; however, improvement in resistance performance after caffeine ingestion was only demonstrated during the early follicular phase (Romero-Moraleda et al., 2019; Lara et al., 2020), or without determining the phase of the menstrual cycle (Goldstein et al., 2010; Filip-Stachnik et al., 2021). The effects of caffeine on resistance performance throughout the menstrual cycle remain unclear (Romero-Moraleda et al., 2019; Wilk et al., 2019). To the best of our knowledge, no prior study has investigated the ergogenic effect of caffeine on female sex hormones during any phase of the menstrual cycle. Therefore, it seems important to conduct research related to the effects of caffeine on muscular endurance in females during the early follicular phase.

During the early follicular phase of the menstrual cycle, oestradiol and progesterone are at low levels, but they gradually increase during the late follicular phase and reach a peak in the ovulation and luteal phases (Norum et al., 2020; Notbohm et al., 2023; Elliott et al., 2004). As the early follicular phase is characterized by the lowest concentration of catabolic progesterone (Elliott et al., 2004; Norum et al., 2020), it has been speculated that resistance training could be more comfortable in eumenorrheic athletes (Romero-Moraleda et al., 2019; Lara et al., 2020; Norum et al., 2020). The intake of ethinylestradiol, a substance included in OCPs, inhibits cytochrome P450 1A2 (CYP1A2) (Banks et al., 2019; Lara et al., 2020; Arnaud, 2014), an enzyme responsible for caffeine metabolism (Grgic et al., 2021; Martins et al., 2020), thus altering the ergogenic effect of caffeine. However, the remaining caffeine metabolites—namely, theobromine—can still induce ergogenic benefits. In addition, numerous eumenorrheic female athletes practice resistance training during menses. This discrepancy warrants further investigation to unveil the ergogenic effect of caffeine on strength in eumenorrheic females during the early follicular phase.

Consequently, the aim of the present study is to investigate the ergogenic response to caffeine on performance outcomes, perceived pain, and female sex hormone levels following muscular endurance exercise in strength eumenorrheic females during the early follicular phase for the first time. We hypothesized that caffeine could be helpful to eumenorrheic female athletes when the use of OCPs is excluded.

MATERIAL AND METHODS

Participants

Healthy strength-trained eumenorrheic females volunteered to participate in this investigation. The study sample included 11 females (age: 26.22 ± 4.27 years, height: 165.87 ± 4.11 cm, body mass: 53.33 ± 4.26 kg, BMI: 20.98 ± 2.44 kg/m^2, training experience: 5.41 ± 2.66 years). All participants were over 18 years old and familiar with the resistance exercises. The inclusion criteria of the participants were as follows: a) to be aged between 20–30 years; b) to have been engaged in resistance training for ≥ 1 h/day, at least 3 days/week, for the previous four years; c) to have had a low daily caffeine intake (i.e., ≤ 100 mg/day); and d) to have steady duration of menstrual cycle for the previous six months (i.e., 21–35 days in length). Females taking oral contraceptive pills in the previous month; having a menstrual disorder such as amenorrhea, dysmenorrhea, or acute symptoms linked to premenstrual syndrome; having musculoskeletal injures in the previous 3 months; or who smoked were excluded from the investigation. Before the beginning of the experimental protocol, participants were fully informed of the study procedures, especially the potential side effects of caffeine consumption (e.g., temporary tachycardia and numbness), and then signed an informed written consent to participate in the study. Participants were allowed to withdraw from the study at any time. The study was approved by the Ethics Committee of Al-Ahliyya Amman University (FES-18G-31/2023). All of the study protocols were in accordance with the latest version of the Declaration of Helsinki.

Experimental design

To investigate the ergogenic response to caffeine in terms of resistance performance, perceived pain, and sex hormones in eumenorrheic females during the early follicular phase, a randomized, double-blind, placebo-controlled crossover design was used. After enrolment, participants completed two trials. They ingested opaque and unidentifiable capsules containing either caffeine or a placebo. The experimental trials were separated by 48 h, in order to ensure that they occurred during the early follicular phase. The study trials were performed in a laboratory with controlled temperature (22–24 °C) and a relative humidity of 41–47%.

Pre-experimental standardization

Participants attended four laboratory visits. The first visit involved defining and approving the procedure and then signing the informed consent. The second visit focused on collecting demographic data and determining the one-repetition maximum (1-RM). Baseline measurements (oestradiol: 63.45 ± 8.76 pg/ml; progesterone: 2.14 ± 1.24 nmol/L) were conducted during the third visit (3 days prior to commencement of the main trials). On the day of each trial, participants arrived at the laboratory between 8.00 and 11.00 a.m. in a fasting state.

The day before each experimental trial, participants were asked to avoid strenuous exercise and/or physical stress and were encouraged to refrain from the ingestion of caffeine or ergogenic aids. All participants routinely consumed three main meals during the days between trials. Additionally, they were instructed not to consume breakfast or morning coffee on the days of the trials. Participants were asked to drink 500 ml of water 2 h before each trial, in order to avoid the sensation of thirst.

One repetition maximum

One week before the commencement of the trials, each participant underwent a 1-RM test for each exercise. First, participants performed their routine 10-minute warm-up on a treadmill (Technogym, Smart Code Program, A01, Italy) at 6.5 km/h, followed by 10 repetitions of the selected exercises using 40% loads of their estimated 1-RM, with a 60 s recovery interval. After 3 minutes of passive recovery, the 1-RM test commenced, following the method described by Filip-Stachnik et al. (2021). The 1-RM test constituted the maximum weight lifted once, encompassing concentric and eccentric phases, with a 5 minute passive recovery allowed between successful attempts. A pilot test indicated no significant difference in the 1-RM values for leg extension ($t = 1.11$, $p = .62$) or hip adduction ($t = 0.82$, $p = .58$).

Intervention intake

Two trials were performed under two consecutive conditions: one involving caffeine and the other a placebo. In the experimental trial, participants received 4 mg/kg of caffeine in a capsule form (Florida Supplement Caffeine Capsule, Nutrix Research, USA) and swallowed it with 250 ml of water (18 °C) 1 h before the trial began. In the placebo trial, participants ingested an empty capsule (dextrose, CapsuleB13, China) of similar shape using the same procedure. The capsules were coded and provided by an independent nutritionist, and neither the participants nor the assistants were aware of their content.

Experimental protocol

Upon arrival at the laboratory, participants were provided with the capsule to be ingested and then rested for 60 minutes. During this time, participants were seated in the Gym room (talking or reviewing social media). They subsequently performed an adapted warm-up, which consisted of 10 minutes on the treadmill at 7 km/h and a single set of 10 repetitions for each exercise at 50% 1-RM, with a 60 s recovery interval. After a 3-minute break, participants performed as many repetitions as possible for leg extension and hip adduction at 65% of 1-RM. Two minutes of recovery were allocated between each exercise. During the test, each repetition was performed at maximal velocity, and the examiner observed and counted the number of repetitions in each exercise during both trials. Failure was defined as an inability to tolerate full repetition. All exercises were performed according to the American College of Sports Medicine guidelines (ACSM, 2010). Both experimental trials were recorded using a camera (Sony, FDR, AX43), and total repetitions were confirmed according to the footage obtained with the camera. Time under tension was obtained manually from the recorded data through the camera (using slow-speed playback). To ensure the reliability of manual data collection, three independent persons conducted the analysis from the camera footage. There were no differences between the analysis data of these three reviewers. Perceived pain was rated on the 11-point numerical received pain (NRS) scale (0—no pain to 10—worst imaginable pain) immediately after the muscular endurance test for each exercise in each trial. Blood samples (4 ml) were drawn from the left antecubital vein of each participant 30 min after the completion of each trial. Serum samples were used for all parameter analyses of oestradiol and progesterone, and they were centrifuged at 3500 rpm for 10 minutes. These hormones were analysed through immunochromatography (lateral flow assay, Japan). The reference ranges of hormones during the early follicular phase were as follows: 19.0–140 pg/ml for oestradiol and 0.181–2.84 nmol/L for progesterone.

Statistical analysis

The normal distribution of the data was verified using the Shapiro–Wilk test, and both analysed variables (female sex hormones) adhered to normal distributions ($p > .05$). Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS) software (version 18.0). Between-group differences in performance outcomes and female sex hormone responses were determined using paired-sample *t*-tests. Cohen's effect size (d) was calculated for all statistically significant pairwise comparisons, with the magnitude of effect size interpreted as follows: ≤0.2 (trivial), >0.2–0.6 (small), >0.6–1.2 (moderate), >1.2–2.0 (large), >2.0 (very large) (Lara et al., 2020). Descriptive statistics are presented as the mean ± standard deviation. Statistical significance was set at $p < .05$.

RESULTS

Table 1 presents information about the effect of caffeine on repetitions until momentary muscle failure, time under tension, and perceived pain. Briefly, main effects of caffeine on repetitions to failure in leg extension ($p = .003$) and hip adduction ($p = .043$) were observed; furthermore, caffeine led to a significantly longer time under tension for leg extension ($p = .001$), with no differences between trials for hip adduction ($p = .053$). No differences between trials were observed in the NRS pain scale results obtained immediately after hip adduction repetitions to failure ($p = .724$), while the perceived pain was rated higher immediately after leg extension in the caffeine trial, when compared to the placebo ($p = .011$).

Table 1. Effect of caffeine and placebo on performance outcomes.

Performance outcomes	Caffeine	Placebo	Mean of Δ ± SD	95% CI	Effect size
RTF Leg extension (n)	31.7 ± 2.1	26.9 ± 1.8	2.8 ± 1.9	1.5, 4.1	0.36
TUT Leg extension (s)	32.5 ± 2.0	29.5 ±2.3	3.1 ± 1.8	1.9, 4.3	0.37
PP Leg extension	7.5 ± 0.8	6.8 ± 0.8	0.6 ± 0.7	0.2, 1.1	0.15
RTF Hip adduction (n)	34.3 ± 3.5	32.8 ± 3.7	1.5 ± 1.5	0.4, 2.5	0.04
TUT Hip adduction (s)	35.5 ± 4.1	35.0 ± 3.8	0.5 ± 0.7	0, 0.9	0.04
PP Hip adduction	6.1 ± 0.8	6.0 ± 0.8	0.1 ± 0.8	-0.5, 0.6	0.05

Note: Values are presented as mean ± SD, median, and 95% confidence intervals. Abbreviations: CI, confidence interval; RTF, repetition to failure; TUT, time under tension; PP, perceived pain.

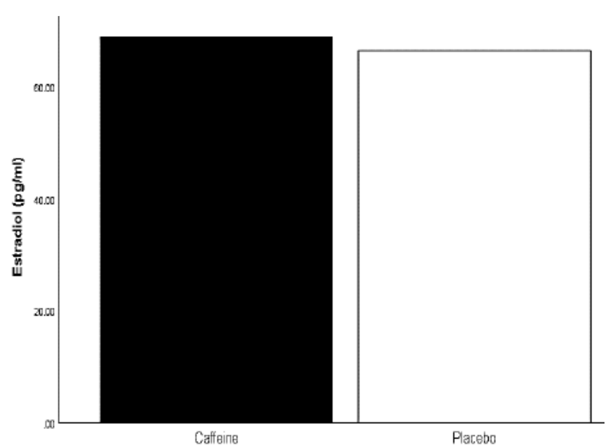

Figure 1. Ergogenic response to caffeine on oestradiol level 30 min after completion the test. No differences between trials were found in oestradiol levels ($p > .05$).

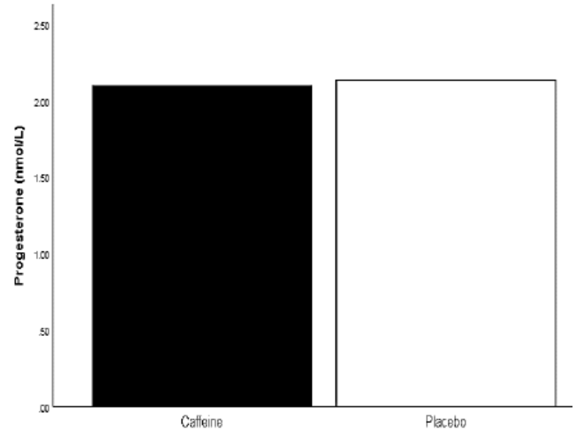

Figure 2. Ergogenic response to caffeine on progesterone level 30 min after completion the test. No differences between trials were found in oestradiol levels ($p > .05$).

In regard to female sex hormone levels (Figures 1 and 2), the paired sample t-test revealed that no differences existed between trials for oestradiol and progesterone levels (t = −1.01, *p* = 0.138; t = 0.62, *p* = .350, respectively).

DISCUSSION

This study investigated the ergogenic response to caffeine in terms of resistance performance, perceived pain, and female sex hormones following muscular endurance training through leg extension and hip adduction in strength eumenorrheic females during the early follicular phase. The main findings of this investigation were as follows: a) repetitions to failure increased after caffeine ingestion for both exercises, b) caffeine led to longer time under tension only in leg extension, with no differences between trials focused on hip adduction, c) perceived pain was rated higher only immediately after leg extension repetitions to failure in the caffeine trial, compared to the placebo, and d) no differences between trials were observed for oestradiol and progesterone levels.

With regard to momentary muscle failure, caffeine induced performance improvements through increased repetitions to failure in both leg extension and hip adduction. This result may be attributed to the ability of caffeine to boost energy expenditure (Goldstein et al., 2010; Warren et al., 2010), altering sodium/potassium ATP_{ase} pump activity (Mohr et al., 2011), and inhibiting adenosine acting on its receptors. This, in turn, delays the feeling of fatigue and stimulates the CNS (Davis & Green, 2009; Mohr et al., 2011), resulting in activation of motor unit recruitment (Warren et al., 2010). This result is in agreement with Norum et al. (2020), who found that 4 mg/kg caffeine increased the number of repetitions to failure at 60% of 1-RM during squat (45 ± 17 rep) and bench press (23 ± 6 rep), compared to placebo (39 ± 17 and 21 ± 6 rep, respectively) in Caucasian female volunteers. They reported that volunteers who performed three familiarization sessions exceeded a coefficient of variation of 10%. In the present study, the participants did not perform familiarization sessions, due to their acclimatization to resistance exercise for at least the four years prior. On the other hand, this result is in disagreement with other prior studies (Filip-Stachnik et al., 2021; Goldstein et al., 2010; Arazi et al., 2016; Sabblah et al., 2015) that did not confirm the ergogenic effects of caffeine on muscular endurance in females. For example, Filip-Stachnik et al. (2021) found no differences between 3 mg/kg or 6 mg/kg of caffeine and placebo on bench press endurance at 50% of 1-RM (33.81 ± 5.46; 35.29 ± 6.99; and 33.05 ± 6.59 rep, respectively) in 21 resistance-trained female university students (23.0 ± 0.9 years age). They suggested that females have a greater proportion of slow oxidative fibres, facilitating beneficial effects for muscular endurance using caffeine in long-term training. Goldstein et al. (2010) showed that bench press repetitions to failure was similar in placebo and 6 mg/kg caffeine groups (23.0 ± 7.1 vs. 23.1 ± 6.2 rep, respectively) in resistance-trained females. They concluded that caffeine habituation may induce intense emotional responses, affecting performance. Sabblah et al. (2015) found no difference (*p* = .059) in bench press endurance performance after ingestion of 5 mg/kg of caffeine, compared to placebo, in eight moderately active resistance females. They suggested that further research should be explored using trained participants. Arazi et al. (2016) also demonstrated no differences between 5 mg/kg or 2 mg/kg of caffeine and placebo in leg press repetitions to failure (39 ± 26.5; 47 ± 22.6; and 46 ± 15.7 reps, respectively) in female karate athletes. They suggested that the type of muscle action performed and volunteer's fitness level leads to a greater variation than the standard deviation, thus affecting the significance level.

The results of the present study indicated that 4 mg/kg caffeine led to a significantly higher time under tension during leg extension, but it had a similar effect to the placebo in hip adduction. This result could have been caused by the type of action/technique performed during leg extension and the greater number of repetitions during the muscular endurance test, increasing the period and, subsequently, the time under tension. During leg extension, the weight is lifted reverse to gravity, whereas a participant squeezes the weight medially in hip adduction, such that gravity is ignored. Recalling the study of Filip-Stachnik et al. (2021), they showed increased time under tension during bench press after both 3 mg/kg and 6 mg/kg caffeine (57.05 ± 10.9 s and 61.76 ± 15.39 s, respectively), compared to placebo (53.52 ± 11.44 s), without any explanation of these results. Therefore, it is still necessary to unveil the ergogenic effects of caffeine on muscular endurance in females during the early follicular phase. On the other hand, Romero-Moraleda et al. (2019) demonstrated that 3 mg/kg of caffeine increased mean movement velocity during a half-squat exercise performed at maximal velocity with loads equivalent to 40%, 60%, and 80% of 1-RM, although the effect was catalogued as being of small magnitude. The authors in that study also did not determine either an explanation of the result or the mechanism through which caffeine improved movement velocity.

Caffeine had no ergogenic effects in attenuation of perceived pain immediately after leg extension repetitions to failure. The explanation of this result could refer to the greater muscular effort when muscle action potentials are activated during each contraction cycle. Motor units in the lower limbs are conditioned to slow movement and, thus, tolerant to fatigue (as occurs in long distance running). However, during muscular endurance with maximal velocity, perceived pain increases dramatically, especially when the repetitions to failure is increased. This finding is in accordance with Norum et al. (2020), who found 4 mg/kg caffeine to insignificantly decrease pain perception during squat and bench press. Similarly, Sabblah et al. (2015) showed that perceived pain during bench press and squat was unaffected by caffeine ingestion. They suggested that the light weight (40% of 1-RM) may be an important factor for failure in the reduction of perceived pain using caffeine. It has been suggested (Goldstein et al., 2010; Sabblah et al., 2015; Davis & Green, 2009; Warren et al., 2010; Sampaio-Jorge et al., 2021) that the analgesic role of caffeine is based on blocking adenosine receptors within the brain and working muscles. Caffeine acts as an adenosine antagonist, causing attenuation of muscle pain and, thus, greater time to exhaustion (Sampaio-Jorge et al, 2021; Wu & Lin, 2010). This is the available explanation for the mechanism by which caffeine enhances performance. In the present study, however, caffeine had no effect on perceived pain in leg extension. In this context, increased pain tolerance rather than a reduction in perceived pain is a governing theory linked to caffeine's effect on resistance performance (Beck et al., 2006; Warren et al., 2010).

Finally, 4 mg/kg caffeine had no effects on both oestradiol and progesterone response during the early follicular phase, with an insignificant increase in oestradiol. To the best of our knowledge, this is only the first study on the ergogenic response to caffeine in main female sex hormones during the early follicular phase of the menstrual cycle. Norum et al. (2020) explained that the absence of consideration of these hormones in their study was due to cost- and time-based limitations, and they recommended further studies on caffeine in females during different phases of the menstrual cycle. Prior studies have not measured these sex hormones due to changes in caffeine metabolism during the phases of the menstrual cycle, along with the effect of OCPs on caffeine's ergogenicity (Arnaud, 2011). Importantly, the early follicular phase has been reported to be characterized by the lowest fluctuation in oestradiol and progesterone concentrations (Elliott et al., 2004). In a systemic review, McNulty et al. (2020) showed that the effects associated with fluctuations in oestradiol and progesterone throughout the menstrual cycle on performance are elusive and conflicting, with some studies demonstrating enhanced performance during early follicular and luteal phases, while other previous studies having reported no changes in performance between different phases. However, the findings assessed in their systemic review were carried out without a caffeine intervention. In addition, female sex hormone levels in the early follicular phase are roughly similar to the same levels in females using OCPs (Norum et al., 2020). Of relevance, females taking OCPs are predisposed to CYP1A2 inactivity (Romero-Moraleda et al., 2019; Granfors et al., 2005). Ethinylestradiol, a substrate found in OCPs, may induce inhibition of CYP1A2 activity (Granfors et al., 2005; Arnaud, 2011). This liver enzyme is responsible for 90%

of caffeine metabolism, where caffeine exerts several of its beneficial effects through antagonistically binding to adenosine $A_{2}a$ receptors (Banks et al., 2019). On the other hand, some prior studies (Norum et al., 2020; Goldstein et al. 2010; Romero-Moraleda et al., 2019; Filip-Stachnik et al., 2021; Sabblah et al., 2015; Lara et al., 2020) have demonstrated the ergogenic effect of caffeine on some parameters of resistance performance in females. These studies, however, did not measure the main female sex hormone levels. It has been speculated that the pharmacokinetics of caffeine might be unaffected by the menstrual cycle (McLean & Graham, 2002; Norum et al., 2020). In the present study, all participants were in eumenorrheic state and unaffected by any menstrual disorder, making investigation of the effects of caffeine on resistance exercise in females during early the follicular phase complex. Hence, further research to establish the role of caffeine on resistance exercise in females during the early follicular phase is warranted.

The present study had two main limitations. First, blood samples were collected from the participants only one time for each trial (i.e., 30 min after completion of the muscular endurance test). This could make the explanation of findings related to female sex hormones unclear. Second, no measurements of catecholamine—precisely, dopamine—were performed, which could be a factor explaining the perceived pain.

CONCLUSION

The ingestion of 4 mg/kg of caffeine in capsule form increased leg extension and hip adduction repetitions to failure and improved, to some extent, the time under tension during the muscular endurance performance, such as hip adduction. However, caffeine had no effect on perceived pain, assessed using the NRS pain scale, immediately after the muscular endurance test. Female sex hormone levels were unaffected by caffeine, although the participants were in eumenorrheic status. These outcomes might indicate that, in trained and eumenorrheic female strength athletes who do not take oral contraceptive pills, caffeine is effective for improving muscular endurance exercise.

AUTHOR CONTRIBUTIONS

Mohammad Fayiz AbuMoh'd involved in conceptualization, methodology, investigation, resources, writing-review & editing, supervision, procedure administration, and final approval the manuscript. Hatem A. Shlool involved in selection of volunteers, validation, formal analysis, data curation and collection, writing-original draft, and final approval the manuscript.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

RESEARCH ETHICS AND ATHLETE CONSENT

The study was approved by the Al-Ahliyya Amman University Ethical Committee (FES-18G- 31/2023). All study procedures and potential side effects of caffeine consumption, such as temporary tachycardia, hypertension, and numbness, were explained, and participants provided written informed consent.

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REFERENCES

Adan, A., Prat, G., Fabbri, M., & Sànchez-Turet, M. (2008). Early effects of caffeinated and decaffeinated coffee on subjective state and gender differences. Progress in neuro-psychopharmacology & biological psychiatry, 32(7), 1698-1703. https://doi.org/10.1016/j.pnpbp.2008.07.005

Aguiar, A. S., Jr, Speck, A. E., Canas, P. M., & Cunha, R. A. (2020). Neuronal adenosine A2A receptors signal ergogenic effects of caffeine. Scientific reports, 10(1), 13414. https://doi.org/10.1038/s41598-020-69660-1

Arazi, H., Hoseinihaji, M., & Eghbali, E. (2016). The Effects of Different Doses of Caffeine on Performance, Rating of Perceived Exertion and Pain Perception in Teenagers Female Karate Athletes. Brazilian Journal of Pharmaceutical Science, 52. https://doi.org/10.1590/s1984-82502016000400012

Arnaud M. J. (2011). Pharmacokinetics and metabolism of natural methylxanthines in animal and man. Handbook of experimental pharmacology, (200), 33-91. https://doi.org/10.1007/978-3-642-13443-2_3

Banks, N. F., Tomko, P. M., Colquhoun, R. J., Muddle, T. W. D., Emerson, S. R., & Jenkins, N. D. M. (2019). Genetic Polymorphisms in ADORA2A and CYP1A2 Influence Caffeine's Effect on Postprandial Glycaemia. Scientific reports, 9(1), 10532. https://doi.org/10.1038/s41598-019-46931-0

Beck, T. W., Housh, T. J., Schmidt, R. J., Johnson, G. O., Housh, D. J., Coburn, J. W., & Malek, M. H. (2006). The acute effects of a caffeine-containing supplement on strength, muscular endurance, and anaerobic capabilities. Journal of strength and conditioning research, 20(3), 506-510. https://doi.org/10.1519/18285.1

Bellar, D., Kamimori, G., & Glickman, E. (2011). The Effects of Low-Dose Caffeine on Perceived Pain During a Grip to Exhaustion Task. Journal of Strength and Conditioning Research / National Strength & Conditioning Association, 25, 1225-1228. https://doi.org/10.1519/JSC.0b013e3181d9901f

Bowtell, J. L., Mohr, M., Fulford, J., Jackman, S. R., Ermidis, G., Krustrup, P., & Mileva, K. N. (2018). Improved Exercise Tolerance with Caffeine Is Associated with Modulation of both Peripheral and Central Neural Processes in Human Participants. Frontiers in nutrition, 5, 6. https://doi.org/10.3389/fnut.2018.00006

Davis, J. K., & Green, J. M. (2009). Caffeine and anaerobic performance: ergogenic value and mechanisms of action. Sports medicine (Auckland, N.Z.), 39(10), 813-832. https://doi.org/10.2165/11317770-000000000-00000

Davis, J.-K., Green, J. M., & Laurent, C. M. (2012). Effects of Caffeine on Resistance Training Performance on Repetitions to Failure. Journal of Caffeine Research, 2(1), 31-37. https://doi.org/10.1089/jcr.2012.0005

Del Coso, J., Muñoz, G., & Muñoz-Guerra, J. (2011). Prevalence of caffeine use in elite athletes following its removal from the World Anti-Doping Agency list of banned substances. Applied physiology, nutrition, and metabolism = Physiologie appliquee, nutrition et metabolisme, 36(4), 555-561. https://doi.org/10.1139/h11-052

Diaz-Lara, F. J., Del Coso, J., García, J. M., Portillo, L. J., Areces, F., & Abián-Vicén, J. (2016). Caffeine improves muscular performance in elite Brazilian Jiu-jitsu athletes. European journal of sport science, 16(8), 1079-1086. https://doi.org/10.1080/17461391.2016.1143036

Duncan, M. J., Stanley, M., Parkhouse, N., Cook, K., & Smith, M. (2013). Acute caffeine ingestion enhances strength performance and reduces perceived exertion and muscle pain perception during resistance exercise. European Journal of Sport Science, 13(4), 392-399. https://doi.org/10.1080/17461391.2011.635811

Elliott, K., Cable, N., Reilly, T., & Diver, M. (2004). Effect of menstrual cycle phase on the concentration of bioavailable oestradiol and testosterone and muscle strength. Clinical Science (London, England : 1979), 105, 663-669. https://doi.org/10.1042/CS20020360

Ferré S. (2016). Mechanisms of the psychostimulant effects of caffeine: implications for substance use disorders. Psychopharmacology, 233(10), 1963-1979. https://doi.org/10.1007/s00213-016-4212-2

Filip-Stachnik, A., Wilk, M., Krzysztofik, M., Lulińska, E., Tufano, J. J., Zajac, A., Stastny, P., & Del Coso, J. (2021). The effects of different doses of caffeine on maximal strength and strength-endurance in women habituated to caffeine. Journal of the International Society of Sports Nutrition, 18(1), 25. https://doi.org/10.1186/s12970-021-00421-9

Goldstein, E., Jacobs, P. L., Whitehurst, M., Penhollow, T., & Antonio, J. (2010). Caffeine enhances upper body strength in resistance-trained women. Journal of the International Society of Sports Nutrition, 7(1), 18. https://doi.org/10.1186/1550-2783-7-18

Graham, T. E., & Spriet, L. L. (1995). Metabolic, catecholamine, and exercise performance responses to various doses of caffeine. Journal of applied physiology (Bethesda, Md.: 1985), 78(3), 867-874. https://doi.org/10.1152/jappl.1995.78.3.867

Granfors, M. T., Backman, J. T., Laitila, J., & Neuvonen, P. J. (2005). Oral contraceptives containing ethinyl estradiol and gestodene markedly increase plasma concentrations and effects of tizanidine by inhibiting cytochrome P450 1A2. Clinical Pharmacology & Therapeutics, 78(4), 400-411. https://doi.org/10.1016/j.clpt.2005.06.009

Grgic, J., & Mikulic, P. (2017). Caffeine ingestion acutely enhances muscular strength and power but not muscular endurance in resistance-trained men. European journal of sport science, 17(8), 1029-1036. https://doi.org/10.1080/17461391.2017.1330362

Grgic, J., Grgic, I., Pickering, C., Schoenfeld, B. J., Bishop, D. J., Virgile, A., & Pedisic, Z. (2020). Infographic. Wake up and smell the coffee: caffeine supplementation and exercise performance. British journal of sports medicine, 54(5), 304-305. https://doi.org/10.1136/bjsports-2019-101097

Grgic, J., Pickering, C., Del Coso, J., Schoenfeld, B. J., & Mikulic, P. (2021). CYP1A2 genotype and acute ergogenic effects of caffeine intake on exercise performance: a systematic review. European journal of nutrition, 60(3), 1181-1195. https://doi.org/10.1007/s00394-020-02427-6

Lara, B., Gutiérrez Hellín, J., Ruíz-Moreno, C., Romero-Moraleda, B., & Del Coso, J. (2020). Acute caffeine intake increases performance in the 15-s Wingate test during the menstrual cycle. British journal of clinical pharmacology, 86(4), 745-752. https://doi.org/10.1111/bcp.14175

Martins, G. L., Guilherme, J. P. L. F., Ferreira, L. H. B., de Souza-Junior, T. P., & Lancha, A. H., Jr (2020). Caffeine and Exercise Performance: Possible Directions for Definitive Findings. Frontiers in sports and active living, 2, 574854. https://doi.org/10.3389/fspor.2020.574854

McCall, A. L., Millington, W. R., & Wurtman, R. J. (1982). Blood-brain barrier transport of caffeine: dose-related restriction of adenine transport. Life sciences, 31(24), 2709-2715. https://doi.org/10.1016/0024-3205(82)90715-9

McLean, C., & Graham, T. E. (2002). Effects of exercise and thermal stress on caffeine pharmacokinetics in men and eumenorrheic women. Journal of Applied Physiology, 93(4), 1471-1478. https://doi.org/10.1152/japplphysiol.00762.2000

Mitchell, D. C., Knight, C. A., Hockenberry, J., Teplansky, R., & Hartman, T. J. (2014). Beverage caffeine intakes in the U.S. Food and chemical toxicology : an international journal published for the British Industrial Biological Research Association, 63, 136-142. https://doi.org/10.1016/j.fct.2013.10.042

Mohr, M., Nielsen, J. J., & Bangsbo, J. (2011). Caffeine intake improves intense intermittent exercise performance and reduces muscle interstitial potassium accumulation. Journal of applied physiology (Bethesda, Md. : 1985), 111(5), 1372-1379. https://doi.org/10.1152/japplphysiol.01028.2010

Norum, M., Risvang, L. C., Bjørnsen, T., Dimitriou, L., Rønning, P. O., Bjørgen, M., & Raastad, T. (2020). Caffeine increases strength and power performance in resistance-trained females during early follicular phase. Scandinavian journal of medicine & science in sports, 30(11), 2116-2129. https://doi.org/10.1111/sms.13776

Notbohm, H. L., Moser, F., Goh, J., Feuerbacher, J. F., Bloch, W., & Schumann, M. (2023). The effects of menstrual cycle phases on immune function and inflammation at rest and after acute exercise: A systematic review and meta-analysis. Acta Physiologica, 238(4), e14013. https://doi.org/10.1111/apha.14013

Polito, M. D., Grandolfi, K., & de Souza, D. B. (2019). Caffeine and resistance exercise: the effects of two caffeine doses and the influence of individual perception of caffeine. European journal of sport science, 19(10), 1342-1348. https://doi.org/10.1080/17461391.2019.1596166

Raastad, T., Bjøro, T., & Hallén, J. (2000). Hormonal responses to high- and moderate-intensity strength exercise. European journal of applied physiology, 82(1-2), 121-128. https://doi.org/10.1007/s004210050661

Richardson, D. L., & Clarke, N. D. (2016). Effect of Coffee and Caffeine Ingestion on Resistance Exercise Performance. Journal of strength and conditioning research, 30(10), 2892-2900. https://doi.org/10.1519/JSC.0000000000001382

Romero-Moraleda, B., Del Coso, J., Gutiérrez-Hellín, J., & Lara, B. (2019). The Effect of Caffeine on the Velocity of Half-Squat Exercise during the Menstrual Cycle: A Randomized Controlled Trial. Nutrients, 11(11), 2662. https://doi.org/10.3390/nu11112662

Sabblah, S., Dixon, D., & Bottoms, L. (2015). Sex differences on the acute effects of caffeine on maximal strength and muscular endurance. Comparative Exercise Physiology, 1, 1-6. https://doi.org/10.3920/CEP150010

Salinero, J. J., Lara, B., Jiménez-Ormeño, E., Romero-Moraleda, B., Giráldez-Costas, V., Baltazar-Martins, G., & Del Coso, J. (2019). More Research Is Necessary to Establish the Ergogenic Effect of Caffeine in Female Athletes. Nutrients, 11(7), 1600. https://doi.org/10.3390/nu11071600

Sampaio-Jorge, F., Morales, A. P., Pereira, R., Barth, T., & Ribeiro, B. G. (2021). Caffeine increases performance and leads to a cardioprotective effect during intense exercise in cyclists. Scientific reports, 11(1), 24327. https://doi.org/10.1038/s41598-021-03158-2

Smilios, I., Tsoukos, P., Zafeiridis, A., Spassis, A., & Tokmakidis, S. P. (2014). Hormonal responses after resistance exercise performed with maximum and submaximum movement velocities. Applied physiology, nutrition, and metabolism = Physiologie appliquee, nutrition et metabolisme, 39(3), 351-357. https://doi.org/10.1139/apnm-2013-0147

Warren, G., Park, N., Maresca, R., McKibans, K., & Millard-Stafford, M. (2009). Effect of Caffeine Ingestion on Muscular Strength and Endurance: A Meta-Analysis. Medicine and Science in Sports and Exercise, 42, 1375-1387. https://doi.org/10.1249/MSS.0b013e3181cabbd8

Wilk, M., Krzysztofik, M., Maszczyk, A., Chycki, J., & Zajac, A. (2019). The acute effects of caffeine intake on time under tension and power generated during the bench press movement. Journal of the International Society of Sports Nutrition, 16(1), 8. https://doi.org/10.1186/s12970-019-0275-x

The effect of 6 weeks functional myofascial line exercises on sprint and agility in 12-14 aged tennis athletes

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ABSTRACT

The aim of this study was to examine the effect of functional myofascial line exercises applied for 6 weeks on sprint and agility in 12-14 years old tennis players. The sample consisted of 13 girls and 13 boys aged 12-14 years who were tennis athletes in Antalya. In addition to tennis training in the experimental group an exercise programme consisting of four exercises for 6 weeks, 2 days in a week was conducted. The control group continued only tennis training. As a result of the research, the girls experimental group's 20 m sprint pre-test and post-test statistically significant difference ($p = .02$) with a large effect size (r = .63); v-cut agility pre-test and post-test with a large effect size (r = .57) a statistically significant difference ($p = .04$) was found. In addition, a statistically significant difference ($p = .01$) was found between the 20 m. sprint pre-test and post-test of the boys experimental group with a large effect size (r = .63); a statistically significant difference ($p = .01$) was found between the v-cut agility pre-test and post-test with a large effect size (r = .63). In the control group, 20 m. sprint in both boys and girls groups there was no statistically significant difference between pre-test and post-test and v-cut agility pre-test and post-test.
Keywords: Performance analysis, Myofascia, Fascial line, Tennis, Speed, Agility.

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INTRODUCTION

Tennis is a game of short, high-intensity repetitive movements, with medium and high intensity (Torres-Luque et al., 2011). Tennis players cover an average distance of 8-15 m for a point, change 4 directions and they hit the ball 4-5 times on average for each point played (Murias et al., 2007). Tennis players have a very good reaction time and are able to have explosive first step speed to react quickly to the ball (Kovacs, 2006). For tennis athletes to be successful, aerobic performance, speed, agility and power must be efficient (Fernandez, 2009). Therefore, strength, power, speed and agility as a prerequisite for success in tennis together (Fernandez-Fernandez, 2018). At the same time to the opponent non-contact tennis; fast change of direction, fast arm movements, jumping and strength is needed (Özcan, 2011). With studies conducted in the early period, enhanced speed and change of direction ability can help children improve their performance in tennis matches (Wang et al., 2022).

Kinetic chain is defined as "*a number of successively arranged motor units forming a complex motor unit joint*" (Karandikar & Vargas, 2011). Although it appears that the ball is sent to the opposite side with the movement of the upper limb in tennis athletes, in relation to upper limb skill performance, the work in the upper limb segments is transmitted to the trunk and spine through a large musculoskeletal surface. There is an exchange of forces across this musculoskeletal surface resulting in a large amount of energy production (Ellenbecker & Aoki, 2020). There are structures in the human body that are not independent of each other and interact with each other. One of them is that the kinetic chain is an interconnected system with fascial lines as a whole and any movement instantly affect each other (Dischiavi et al., 2018). Sports of complex motor skills such as tennis require effective kinetic chain coordination (Colomar et al., 2020). Disruption of a single element in the kinetic chain causes modification of the entire chain, leading to sub-optimal biomechanical adaptations may lead to a decrease in the efficiency of the movement (Kilit, 2017).

Fascia refers to all fibrous connective tissue under tension that both encloses and surrounds muscles, bones, organs, nerves, blood vessels and other structures and extends from head to toe in a continuous, three-dimensional network (Findley, 2009). Fascia is a tissue that contains properties that can respond to mechanical stimuli (Bordoni & Myers, 2020) and consists of fibrous collagenous tissues that are part of the conduction system, a tension force in the whole body (Beardsley & Škarabot, 2015).

Nowadays, fascia has become a very important subject for clinicians, physiotherapists and sports scientists with the development of measurement tools and studies. Fascia are seen as elements of a tensile force transmission network throughout the body and are defined as all collagen fibrous connective tissues in the body (Schleip & Baker, 2015). When muscles contract, they not only move the bones, but also stretch the deep fascia through fascial expansions (Stecco et al., 2009).

Fascia and tendons work together and therefore the movement of one muscle can lead to the movement of other muscles in which this muscle is involved. In this association during movement, the transfer of force from the muscle to the skeletal system is mostly related to the intermuscular myofascia. Muscles transmit 40% of their contractile force not to their own tendons but to other muscles in close neighbourhood via fascial connections. This involves the transfer of force to the antagonist muscles and leads to increased resistance to the movement (Özsu & Kurt, 2018; Kumka & Bonar, 2012).

Fascia appears to be integrally involved in the biomechanics of the musculoskeletal system (Gerlach & Lierse, 1990). There are 12 lines in myofascia and in one line it is thought to have an effect on the intermuscular coordination of the muscles with each other. Among these lines, functional myofascial anterior and posterior lines are important for tennis athletes. Functional myofascial anterior and posterior lines when extending it to the limb on the opposite side of the body, connecting it to the limb on the opposite side of the body, it extends the lever arm and gives us extra strength and sensitivity. An example of this is in tennis, where the movement of the pelvis contributes to the backhand stroke. These lines maintain a constant balance between the shoulder and hip contralaterally during walking (Myers, 2009).

The Functional Posterior Line (Figure 1); starts with the distal adhesion of the latissimus dorsi, joins the superficial lamina of the sacrolumbar fascia, descends towards the sacral fascia and connects with the lower fibres of the gluteus maximus. The lower fibres of the gluteus maximus pass under the posterior edge of the illiotibial tract and thus attach to the posterolateral edge of the femur below the lateral line, approximately 1/3 below the femoral shaft. Continuing in the same direction, fascial fibres are found connecting to the gluteus and vastus lateralis muscles. These fascial fibres continue downwards and connect with the quadriceps tendon, subpatellar tendon and tibial tubercle (Myers, 2009).

The Functional Anterior Line (Figure 2); the distal attachment site crosses the lower lifts of the humerus and attaches to the 5th and 6th costa, the origin of the pectoralis major. Since the claviculapectoral fascia contains the pectoralis minor, it also attaches to the 5th costa. These pectoral fibres connecting to the abdominal aponeurosis and the external oblique and rectus abdominis muscles forms a fascial continuum and runs along the more outer edge of the rectus or along the more inner edge of the oblique fascia towards the pubis as a strip of fascia, also known as the semilunar line. Passing through the pubic region and symphysis pubis, it passes to the other side with the durable tendon of adductor longus. Moving downwards, upwards, outwards and backwards attach to the linear aspera of the femur (Myers, 2009).

Figure 1. Functional back line. Figure 2. Functional front line.

The concept of the myofascial line, i.e. that tension in a contracted area has repercussions and affects other areas near and far, is used in different disciplines from physiotherapy to yoga, sports to meditation (Bordoni & Myers, 2020). Ingber stated that due to the holistic and interconnected structure of the fascia in the body, an increase in tension in one region will cause an increase in tension in the whole structure, not only in the part where the structure is located, but also in the opposite part (Ingber, 1993).

Stress transmission along the myofascial line can contribute to the proper functioning of the movement system (Grieve et al., 2015). Ensuring that the tension on one myofascial line is evenly toned can affect the entire fascia chain. The reason for this may be the comfortable movement of interconnected tissues and the correct distribution of forces (Lindsay & Robertson, 2008).

Studies show that the tension produced by a given muscle is not transmitted entirely to its tendons but can also be transmitted to connective tissues in and around the muscle (endomysium, perimysium, epimysium) and to extra-muscular connective tissues (fascia, neurovascular system) (Huijing, 2009; Purslow, 2010; Smeulders & Kreulen, 2007; Yücesoy, 2010). Ruffini and Pacini bodies, which are mechanoreceptors commonly found in myofascia contains muscle receptors located between the tissue. Pressure applied to mechanoreceptors can stimulate the nervous system and thus cause a reduction in muscle tension (Beardsley & Škarabot, 2015). In an exercise, it can cause a force transfer from the working muscle to the surrounding fascia (Findley et al., 2015).

The force generated by the muscle can be transferred directly between the synergist muscles via the epimysium or indirectly affect the antagonist via the neurovascular tract (Huijing et al., 2011). Muscle contraction directly stretches the overlying fascia and thus changes the stiffness of the connective tissue (Findley et al., 2015).

In addition to bilateral exercises, if exercises are performed to increase muscle strength on one side of the body (unilateral), voluntary strength may increase on the opposite side. Following a unilateral strength training programme, strength increases are observed in the contralateral untrained limb (Carroll et al., 2006).

From a mechanical point of view, the close relationship between fascia and trunk muscles clearly implies that the role of fascia in movements cannot be separated from the movements of muscles, and each time the muscle contracts, selective spatial stretching of the associated fascia must also occur (Stecco et al., 2011).

Speed is physiologically identified with concepts such as perception, reaction, movement and acceleration (Günay, 2008). Speed, power output and forward acceleration are key physical determinants of performance in many activities in sport (Cronin & Sleivert, 2005). Athletes need more speed to react to a sudden movement from a stationary position (Sasa, 2019). The long duration of tennis competitions requires the need for oxidative energy system and phosphagen (ATP-CP) system is used during the ball shots (Ben Kibler & Sciascia, 2004). Good intramuscular and intermuscular coordination skills contribute to the development of speed and speed is greatly improved by the harmonious functioning of muscles and nerves (Karaca, 2016). The 20m sprint, change of direction tests, jumping ability tests and field-based tests are commonly used in tennis players (Cooke et al., 2011).

Various definitions have been made about agility. Agility is the ability to change the direction and/or speed of movement quickly and efficiently (Sekulic et al., 2017), the ability to change body position quickly and accurately, to stop, move, change direction and speed in a controlled manner (Miller, 2006), rapid change of speed and direction of movement in response to an external stimulus and whole body movement (Krolo et al., 2020; Sheppard & Young, 2006).

For the best realisation of agility performance, the neuromuscular system must function efficiently. It is known that the neuromuscular system has the ability to efficiently store, reappear, combine, use and change when more than one motor unit is needed to produce the desired movements (Aaberg, 2007).

In agility, one responds to a pre-planned and known response, but in tennis, one must respond to unpredictable (mostly visual) stimuli, so unplanned agility, change of direction speed (CODS) and reactive agility terms are used in tennis (Sekulic et al, 2017). Tennis is a sport where both agility performances (i.e. CODS and reactive-agility) are important in certain situations (Cooke et al., 2011).

We hypothesise that exercise programmes designed in connection with one of the muscles in the myofascial lines can give effective results. We think that the compatibility of myofascial anterior and posterior lines with the movement mechanics of tennis athletes will provide efficient results for the speed and agility of athletes. With these assumptions, the aim of this study was to investigate the effect of functional myofascial line exercises on speed and agility in tennis athletes.

METHOD

Participants

The study included volunteer boys and girls between the ages of 12-14 years, residing in the province of Antalya in Turkey and playing tennis. For this purpose, groups were formed from the athletes who applied to the sports club. For the study, two groups of 13 athletes each were randomly selected as Experimental Group (EG) and Control Group (CG). In addition to tennis training, the EG was trained with functional fascial line exercises for 30 minutes a day, 2 days a week for 6 weeks. The CG continued tennis training only. The exercise programme was selected according to the developmental level and age of the children.

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 Alanya Alaaddin Keykubat Committee for Research Ethics (Approval No. 3(9)/2022), adhering to the Declaration of Helsinki.

Measures and procedures

In the measurement part of the research, the COD Timer application V-Cut test was used for agility. The COD timer application was found to be in almost perfect agreement with the start and end gates to measure the total time in a change of direction test. Studies have shown that the COD Timer App and My Sprint App are valid and reliable (Silva et al, 2021).

Figure 3. Myofascial line exercises.

For one side, 4 exercises (Figure 3) consisting of 10 repetitions (right and left 20) with 50-70% intensity and fast tempo were performed in 3 sets. 1 minute rest was given between each set. Rest was given for 2 minutes between exercise changes.

The data captured on video with I-phone 7 plus model phone (high-speed video recording, 240 fps) were analysed with COD Timer application (V-Cut Agility Test) and My Sprint application (20-metre Sprint Test) and data entries were made.

To determine the 20 m sprint time, 2 funnels were placed 20 m apart. The athlete was instructed to run from the starting point to the end point in the fastest way. Meanwhile, the athlete's run was videorecorded horizontally at the 10 m line with an iPhone 7 plus model phone and uploaded to My Sprint application. In the application, the time from the starting point to the end point was analysed and recorded.

In the V-Cut test, athletes performed a 25 m sprint with 2 funnels of 5 m each at 45°. For the trial to be valid, the athletes had to cross the line with one foot completely on the ground at each turn. If the attempt was considered unsuccessful, a new attempt was allowed. The distance between each pair of cones was 0.7 m. The fastest trial time was recorded (Gonzalo-Skok et al., 2015).

Statistical analysis

SPSS 25 package programme was used to analyse the data obtained in the study. Frequency and percentage values were used among statistical techniques. Non-parametric tests were preferred due to the limited number of research sample. Wilcoxon signed-rank test was used among non-parametric tests. Significance level was taken as $p < .05$.

RESULTS

The findings obtained from the data of the research are given below in order.

Table 1. Descriptive statistics for experimental and control group.

Group	Gender	Variable	N	Min.	Max.	Mean	Sd
*Exp.	Girls	Age	6	12.00	14.00	12.50	0.83
		Weight	6	36.00	61.00	47.33	10.05
		Height	6	152.00	161.00	156.66	3.66
		N	6				
	Boys	Age	7	12.00	14.00	12.85	1.06
		Weight	7	34.00	76.00	53.71	16.15
		Height	7	143.00	183.00	162.85	16.26
		N	7				
Control	Girls	Age	6	12.00	14.00	12.83	0.75
		Weight	6	37.00	60.00	48.83	9.49
		Height	6	160.00	169.00	164.16	3.43
		N	6				
	Boys	Age	7	12.00	14.00	13.00	0.816
		Weight	7	37.00	57.00	48.00	7.70
		Height	7	147.00	170.00	160.85	7.88
		N	7				

*Note. *Exp = Experimental.*

Table 1 shows the age, body weight and height data of the research group. The average age of the girls experimental group was 12.50 ± 0.83 and the average age of the boys experimental group was 12.85 ± 1.06;

the average age of the girls control group was 12.83 ± 0.75 and the average age of the boys control group was 13.00 ± 0.81. The average body weight of the girls experimental group was 47.33 ± 10.05 and the average body weight of the boys experimental group was 53.71 ± 16.15; the average body weight of the girls control group was 48.83 ± 9.49 and the average body weight of the boys control group was 48.00 ± 7.70. The average height of the girls experimental group was 156.66 ± 3.66 and the average height of the boys experimental group was 162.85 ± 16.26; the average height of the girls control group was 164.16 ± 3.43 and the average height of the boys control group was 160.85 ± 7.88.

Table 2. Skewness and Kurtosis statistics of the data.

Group	Gender	Tests	N	Min.	Max.	Avg.	Sd.	Skewness	Se	Kurtosis	Se
*Exp.	Girls	20 m. Sprint Pre	6	329.00	383.00	359.16	18.57	-0.64	0.84	0.65	1.74
		20 m. Sprint Post	6	311.00	380.00	335.33	27.29	0.99	0.84	-0.24	1.74
		V-Cut Agility Pre	6	803.00	867.00	831.16	27.70	0.40	0.84	-2.24	1.74
		V-Cut Agility Post	6	760.00	834.00	800.33	25.95	-0.47	0.84	0.07	1.74
		N	6								
	Boys	20 m. Sprint Pre	7	303.00	362.00	332.14	22.94	-0.02	0.79	-1.49	1.58
		20 m. Sprint Post	7	292.00	333.00	311.00	14.53	0.12	0.79	-0.91	1.58
		V-Cut Agility Pre	7	713.00	887.00	787.28	56.29	0.67	0.79	0.80	1.58
		V-Cut Agility Post	7	690.00	817.00	746.14	47.47	0.55	0.79	-1.02	1.58
		N	7								
Control	Girls	20 m. Sprint Pre	6	366.00	386.00	371.00	7.84	1.86	0.84	3.44	1.74
		20 m. Sprint Post	6	355.00	410.00	377.16	20.25	0.77	0.84	0.06	1.74
		V-Cut Agility Pre	6	820.00	860.00	834.50	16.65	0.88	0.84	-1.04	1.74
		V-Cut Agility Post	6	820.00	880.00	841.16	23.49	1.15	0.84	-0.11	1.74
		N	6								
	Boys	20 m. Sprint Pre	7	323.00	373.00	343.14	19.28	0.54	0.79	-1.02	1.58
		20 m. Sprint Post	7	320.00	389.00	350.85	25.22	0.30	0.79	-0.98	1.58
		V-Cut Agility Pre	7	767.00	843.00	819.00	30.21	-0.92	0.79	-0.55	1.58
		V-Cut Agility Post	7	760.00	900.00	833.00	48.07	-0.06	0.79	-0.60	1.58
		N	7								

*Note. *Exp: Experimental, Avg.: Average, Sd: Standard deviation, Se: Standard Error.*

Table 3. Wilcoxon Signed Rank test.

Group	Gender	tests	N	Percentiles		
				25th	50th (Median)	75th
Experimental	Girls	20 m. Sprint Pre	6	344.00	362.50	372.50
		V-Cut Agility Post	6	808.25	823.50	861.75
		20 m. Sprint Pre	6	314.00	325.50	361.25
		V-Cut Agility Post	6	777.25	804.00	821.25
	Boys	20 m. Sprint Pre	7	306.00	329.00	356.00
		V-Cut Agility Post	7	747.00	793.00	817.00
		20 m. Sprint Pre	7	296.00	311.00	320.00
		V-Cut Agility Post	7	704.00	741.00	801.00
Control	Girls	20 m. Sprint Pre	6	366.00	367.50	376.25
		V-Cut Agility Post	6	820.00	828.50	852.50
		20 m. Sprint Pre	6	358.75	374.00	395.00
		V-Cut Agility Post	6	825.25	830.00	865.00
	Boys	20 m. Sprint Pre	7	323.00	342.00	363.00
		V-Cut Agility Post	7	797.00	840.00	843.00
		20 m. Sprint Pre	7	325.00	354.00	375.00
		V-Cut Agility Post	7	802.00	840.00	880.00

Table 2 shows the kurtosis skewness values of the experimental and control group data. George & Mallery (2010) stated that when the kurtosis skewness values are between -2 and +2, the data are normally distributed. Although only a few of the data were found to be above these values, non-parametric tests were preferred due to the limited number of research sample.

Table 3 shows the median data of the experimental and control groups. The 20 m sprint median values of the girls experimental group decreased after the implementation (Md = 325.50) compared to before the implementation (Md = 362.50). V-Cut Agility median values of the girls experimental group decreased after the implementation (Md = 804.00) compared to before the implementation (Md = 823.50). The 20 m sprint median values of the boys experimental group decreased after the implementation (Md = 311.00) compared to before the implementation (Md = 329.00). V-Cut Agility median values of the boys experimental group decreased after the implementation (Md = 741.00) compared to before the implementation (Md = 793.00).

Table 4. Wilcoxon Signed Rank test.

Group	Gender		20 m. Sprint Post 20 m. Sprint Pre	V-Cut Agility Post V-Cut Agility Pre
*Exp.	Girls	Z	-2.20[a]	-1.99[a]
		p	.02*	.04*
	Boys	Z	-2.36[a]	-2.37[a]
		p	.01*	.01*
Control	Girls	Z	-1.15[b]	-1.41[b]
		p	.24	.15
	Boys	Z	-1.18[b]	-1.19[b]
		p	.23	.23

*Note. [a]. Based on positive ranks. [b]. Based on negative ranks. *p < .05.*

When Table 4 is analysed, a statistically significant difference (p = .02) was found between the 20 m. sprint pre-test and post-test of the girls experimental group with a large effect size (r = .63); a statistically significant difference (p = .04) was found between the V-Cut Agility pre-test and post-test with a large effect size (r = .57). In addition, a statistically significant difference (p = .01) was found between the 20 m. sprint pre-test and post-test of the boys experimental group with a large effect size (r=.63); a statistically significant difference (p = .01) was found between the V-Cut Agility pre-test and post-test with a large effect size (r = .63). In the control group, no statistically significant difference was found between 20 m. sprint pre-test and post-test and V-Cut Agility pre-test and post-test in both boys and girls. The effect size can be found by dividing the Z value by the square root of N. When evaluated according to Cohen's criteria (1988) (.1 = small, .30 = medium and .5 = large), the value obtained indicates a large effect size (Balcı & Ahi, 2020).

DISCUSSION

As a result of the study, a statistically significant difference (p = .02) was found between the 20 m. sprint pre-test and post-test, and a statistically significant difference (p = .04) was found between the v-cut agility pre-test and post-test of the girls experimental group. In addition, a statistically significant difference (p = .01) was found between the 20 m. sprint pre-test and post-test, and a statistically significant difference (p = .01) was found between the v-cut agility pre-test and post-test of the boys experimental group.

In their meta-analysis study, Cheatham et al. (2015) stated that SMR (self-myofascial release) used in warm-up improves joint range of motion without affecting muscle performance and reduces delayed muscle soreness after exercise.

Wu et al. (2021), in their meta-analysis study on myofascial release in chronic low back pain, stated that myofascial release (SMR) significantly improved pain and physical function in patients with chronic lower back pain, but had no significant effect on balance, pain pressure threshold, trunk mobility, mental health and quality of life.

Fauris et al. (2021) found that performing SMR in any segment of the SBL resulted in a statistically significant increase in hamstring flexibility and ankle dorsiflexion.

Carvalhais et al. (2013), in vivo their study on myofascial force transmission between latissimus dorsi and gluteus maximus, observed that due to contraction or stretching of latissimus dorsi, the force reaching the epimysium is transmitted to TFL (Tensor Fascia Late) and gluteus maximus through connective tissue continuity resulting in the muscle being pulled upwards. When the effects observed after stretching of the latissimus dorsi were analysed, it was stated that there was a functional relationship between the gluteus maximus and the hip joint. The results showing that force is transmitted from the latissimus dorsi to the gluteus maximus support the presence of myofascial force transmission This study supports the force transfer between the gluteus maximus, trocholumbar fascia and latissimus dorsi, which are the functional posterior line muscles that form the exercise choices.

In a systematic review, Krause et al. (2016) found that there is an indication that tension can be transferred between at least some of the adjacent myofascial structures. No studies were found to indicate force transfer between the gluteus maximus and vastus lateralis in the functional back line. In contrast, three studies reported force transfer between the latissimus dorsi and contralateral gluteus maximus, respectively, and a moderate force transfer at the TFL. For the functional anterior line, one study reported force transfer between the adductor longus and the contralateral distal rectus sheath, which was not statistically significant compared to baseline values.

Ajimsha et al. (2020) reported strong evidence for myofascial transitions in three of the six myofascial meridians examined in their study. These are; SBL, BFL and FFL. Myofascial transitions (plantar fascia-gastrocnemius, gastrocnemius-hamstrings and hamstrings-lumbar fascia/erector spine) were confirmed in fifteen studies. Three myofascial transitions in the BFL (latissimus-lumbar fascia, lumbar fascia-gluteus maximus and gluteus maximus-vastus lateralis) were confirmed in eight studies. Six studies were found to support two myofascial transitions (pectoralis major-rectus abdominis and rectus abdominis-adductor longus) for FFL with a 'strong evidence' rating. It is emphasised that the muscles in the fascial lines affect each other in biomotor abilities such as flexibility and strength and that exercise choices should be made accordingly. These evidences support the power and force transfer of the muscles between the BFL and FFL in this study.

Wilke et al. (2016) reported that lower extremity stretching based on myofascial chains increased cervical range of motion in their study. As a result, the existence of a stress transfer along the myofascial lines was pointed out.

Colomar, Baiget & Corbii (2020) examined the relationship between strength, power characteristics, individual muscle stiffness, international tennis number and stroke speed in young tennis players and found that higher stiffness values may increase stroke speed, especially when transferring power from the lower body to the upper body. It is thought that the arrangement of the functional myofascial line muscles and the exercises performed in conjunction with each other support the transfer of power from the lower body to the upper body during ball striking in tennis.

Core strength is related to the force and power produced by these muscles, whereas core stability refers to the capacity of the muscles to control trunk position and movement over the pelvis and leg to allow force production to the terminal segment in the integrated kinetic chain (Poór & Zemková, 2018). Functional myofascial line exercises look like core exercises. However, you can do core exercises in isolation by working the muscles, or you can include all core muscles in the movement and provide a total improvement in performance improvement. However, when choosing functional myofascial anterior or posterior exercises, an exercise is selected in which only the muscles in this line will be activated. The purpose of this is not to ensure the development of the muscles individually, but to ensure that they work efficiently while transferring force or power to the muscle group that should work together in a movement pattern. In other words, it is thought that the myofascial line exercises are not related to the development of the muscles, but the muscles are thought to be due to the efficient operation of the force and power transfer with the muscles in the myofascial line.

CONCLUSION

It can be said that the efficiency of the interaction of the muscles in the functional myofascial lines within the efficiency of the neuromuscular system to develop features that require fast reactions such as speed or agility can provide efficient results in performance.

Myofascia has an important role in joint range of motion. Trigger points formed in the superficial or deep fascia affect the flexibility of the muscle and accordingly the range of motion of the joint. Considering that the muscles in the myofascial lines affect each other, the trigger point of a muscle in this line may be inefficient in contraction at the moment of movement in line with the length-tension relationship due to its connection with each other. In this case, it can be said that it may also affect the muscles with myofascial connections working together with this muscle in the movement.

When exercising athletes are observed, it is noteworthy that isolated muscle exercises or exercises without paying attention to myofascial lines are usually performed in resistance exercise programmes. However, considering the interconnected joint movements during sportive activity and the movements in which many muscles are active at the same time in these joint movements, it can be thought that this coordination between muscles and myofascia may be impaired.

When designing resistance training programmes for athletes, it is thought that creating and implementing functional exercises by combining the biomechanical needs of the branch with myofascial lines will increase efficiency.

AUTHOR CONTRIBUTIONS

Study concept and design, drafting the article: Erhan Toprak Çağlın and Halil Orbay Çobanoğlu. Its critical revision: Halil Orbay Çobanoğlu. Data collection: Erhan Toprak Çağlın. Analysis: Halil Orbay Çobanoğlu. Final approval of the version to be published: Halil Orbay Çobanoğlu.

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REFERENCES

Aaberg, E. (2007). Resistance Training Instruction. 2st ed. Texas: Human Kinetics, 29-50.

Ajimsha, MS, Shenoy, PD, Gampawar, N. (2020). Role of fascial connectivity in musculoskeletal dysfunctions: A narrative review. Journal of bodywork and movement therapies, 24(4), 423-431. https://doi.org/10.1016/j.jbmt.2020.07.020

Balcı, S. & Ahi, B. (2020). SPSS Kullanma Kılavuzu: SPSS ile Adım Adım Veri Analizi. (3. Baskı), Ankara: Anı Yayıncılık, 253-255.

Beardsley, C, Škarabot, J. (2015). Effects of self-myofascial release: A systematic review. Journal of bodywork and movement therapies, 19(4), 747-758. https://doi.org/10.1016/j.jbmt.2015.08.007

Ben Kibler, W., & Sciascia, A. (2004). Kinetic chain contributions to elbow function and dysfunction in sports. Clinics in sports medicine, 23(4), 545-viii. https://doi.org/10.1016/j.csm.2004.04.010

Bordoni, B, Myers, T. (2020). A Review of the Theoretical Fascial Models: Biotensegrity, Fascintegrity and Myofascial Chains. Cureus, 12(2), e7092. https://doi.org/10.7759/cureus.7092

Carroll, TJ, Herbert, RD, Munn, J, Lee, M, Gandevia, SC. (2006). Contralateral effects of unilateral strength training: evidence and possible mechanisms. Journal of applied physiology (Bethesda, Md.: 1985), 101(5), 1514-15222006. https://doi.org/10.1152/japplphysiol.00531.2006

Carvalhais, VO, Ocarino, J, Araújo, VL, Souza, TR, Silva, PL, Fonseca, ST. (2013). Myofascial force transmission between the latissimus dorsi and gluteus maximus muscles: an in vivo experiment. Journal of biomechanics, 46(5), 1003-1007. https://doi.org/10.1016/j.jbiomech.2012.11.044

Cheatham, SW, Kolber, MJ, Cain, M, Lee, M. (2015). The Effects Of Self-Myofascıal Release Usıng A Foam Roll Or Roller Massager On Joınt Range Of Motıon, Muscle Recovery, And Performance: A Systematıc Revıew. International journal of sports physical therapy, 10(6), 827-838.

Colomar, J, Baiget, E, Corbi, F. (2020). Influence of Strength, Power, and Muscular Stiffness on Stroke Velocity in Junior Tennis Players. Frontiers in physiology, 11, 196. https://doi.org/10.3389/fphys.2020.00196

Cooke, K, Quinn, A, Sibte, N. (2011). Testing speed and agility in elite tennis players. Strength and Conditioning Journal 33, 69-72. https://doi.org/10.1519/SSC.0b013e31820534be

Cronin, J, Sleivert, G. (2005). Challenges in understanding the influence of maximal power training on improving athletic performance. Sports Medicine, 35(3), 213-234. https://doi.org/10.2165/00007256-200535030-00003

Dischiavi, SL, Wright, AA, Hegedus, EJ, Bleakley, CM. (2018). Biotensegrity and myofascial chains: A global approach to an integrated kinetic chain. Medical hypotheses, 110, 90-96. https://doi.org/10.1016/j.mehy.2017.11.008

Ellenbecker, TS, Aoki, R. (2020). Step by Step Guide to Understanding the Kinetic Chain Concept in the Overhead Athlete. Current reviews in musculoskeletal medicine, 13(2), 155-163. https://doi.org/10.1007/s12178-020-09615-1

Fauris, P, López-de-Celis, C, Canet-Vintró, M, Martin, JC, Llurda-Almuzara, L, Rodríguez-Sanz, J, Labata-Lezaun, N, Simon, M, Pérez-Bellmunt, A. (2021). Does Self-Myofascial Release Cause a Remote Hamstring Stretching Effect Based on Myofascial Chains? A Randomized Controlled Trial. International journal of environmental research and public health, 18(23), 12356. https://doi.org/10.3390/ijerph182312356

Fernandez, JF, Sanz-Rivas, D, Mendez-Villanueva, A. (2009). A review of the activity profile and physiological demands of tennis match play. J Strength Cond Res., 31(4): 15-26. https://doi.org/10.1519/SSC.0b013e3181ada1cb

Fernandez-Fernandez, J, Granacher, U, Sanz-Rivas, D, Sarabia Marín, JM, Hernandez-Davo, JL, Moya, M. (2018). Sequencing effects of neuromuscular training on physical fitness in youth elite tennis players. Journal of Strength and Conditioning Research 32, 849-856. https://doi.org/10.1519/JSC.0000000000002319

Findley, TW. (2009). Second international fascia research congress. International Journal of Therapeutic Massage & Bodywork 2(2), 1-6. https://doi.org/10.3822/ijtmb.v2i2.52

Findley, T, Chaudhry, H, Dhar, S. (2015). Transmission of muscle force to fascia during exercise. J Bodyw Mov Ther 19, 119-123. https://doi.org/10.1016/j.jbmt.2014.08.010

George, D, Mallery, M. (2010). SPSS for Windows Step by Step: A Simple Guide and Reference, 17.0 update (10'a ed.) Boston: Pearson.

Gerlach, UJ, Lierse, W. (1990). Functional construction of the superficial and deep fascia system of the lower limb in man. Cells Tissues Organs 139, 11e25. https://doi.org/10.1159/000146973

Gonzalo-Skok, O, Tous-Fajardo, J, Suarez-Arrones, L, Arjol-Serrano, JL, Casajús, JA, Mendez-Villanueva, A. (2015). Validity of the V-cut Test for Young Basketball Players. International journal of sports medicine, 36(11), 893-899. https://doi.org/10.1055/s-0035-1554635

Grieve, R, Goodwin, F, Alfaki, M, Bourton, AJ, Jeffries, C, Scott, H. (2015). The immediate effect of bilateral self myofascial release on the plantar surface of the feet on hamstring and lumbar spine flexibility: A pilot randomised controlled trial. J Bodyw Mov Ther. Jul;19(3):544-52. https://doi.org/10.1016/j.jbmt.2014.12.004

Günay, M, Yüce, Aİ. (2008). Futbol Antrenmanının Bilimsel Temelleri, Genişletilmiş 3. Baskı. Ankara: Gazi Kitapevi.

Huijing, PA, Yaman, A, Ozturk, C, Yucesoy, CA. (2011). Effects of knee joint angle on global and local strains within human triceps surae muscle: MRI analysis indicating in vivo myofascial force transmission between synergistic muscles. Surgical and radiologic anatomy, 33(10), 869-879. https://doi.org/10.1007/s00276-011-0863-1

Huijing, PA. (2009). Epimuscular myofascial force transmission: a historical review and implications for new research. International Society of Biomechanics Muybridge Award Lecture, Taipei, 2007. Journal of Biomechanics 42, 9-21. https://doi.org/10.1016/j.jbiomech.2008.09.027

Ingber, DE. (1993). Cellular tensegrity: defining new rules of biological design that govern the cytoskeleton. Journal of cell science, 104, 613-613. https://doi.org/10.1242/jcs.104.3.613

Karaca, BÇ. (2016). 12-14 yaş kız badmintoncuların ve voleybolcuların sürat özelliklerinin karşılaştırılması. (Yayımlanmış Yüksek Lisans Tezi). İstanbul: Gelişim Üniversitesi, Sağlık Bilimleri Enstitüsü.

Karandikar, N, Vargas, OO. (2011). Kinetic chains: a review of the concept and its clinical applications. PM & R: the journal of injury, function, and rehabilitation, 3(8), 739-745. https://doi.org/10.1016/j.pmrj.2011.02.021

Kilit, B, Arslan, E. (2017). Tenis müsabakalarında fizyolojik gereksinimler. Spormetre Beden Eğitimi ve Spor Bilimleri Dergisi, 15 (3), 157-164. https://doi.org/10.1501/Sporm_0000000320

Kovacs, MS. (2006). Applied Physiology of Tennis Performance. Br J Sports Med, 40 (5),381-386, 2006. https://doi.org/10.1136/bjsm.2005.023309

Krause, F., Wilke, J., Vogt, L., & Banzer, W. (2016). Intermuscular force transmission along myofascial chains: a systematic review. Journal of anatomy, 228(6), 910-918. https://doi.org/10.1111/joa.12464

Krolo, A, Gilic, B, Foretic, N, Pojskic, H, Hammami, R, Spasic, M, Uljevic, O, Versic, S, Sekulic, D. (2020). Agility Testing in Youth Football (Soccer)Players; Evaluating Reliability, Validity, and Correlates of

Newly Developed Testing Protocols. International journal of environmental research and public health, 17(1), 294. https://doi.org/10.3390/ijerph17010294

Kumka, M, Bonar, J. (2012). Fascia: a morphological description and classification system based on a literature review. J. Can. Chiropr. Assoc. 56 (3), 179.

Lindsay, M, Robertson, C. (2008). Fascia: clinical applications for health and human performance. Clifton Park, N.Y.: Delmar.

Miller, DK. (2006). Measurement by the physical educator, why and how (5.baskı). Published by Mcgraw-Hill.

Murias, JM, Lanatta, D, Arcuri, CR, Laiño, FA. (2007). Metabolic and functional responses playing tennis on different surfaces. Strength Cond. J. 21, 112-117. https://doi.org/10.1519/00124278-200702000-00021

Myers, TW. (2009). Anatomy trains: myofascial meridians for manual and movement therapists: Elsevier Health Sciences.

Özcan, S. (2011). Temel Tenis Teknik Öğretiminde İki Farklı Antrenman Metodunun Teknik Biyomotorik ve Fizyolojik Özellikler üzerine Etkisinin Araştırılması. (Yayımlanmış Yüksek Lisan Tezi). Isparta: Süleyman Demirel Üniversitesi Sağlık Bilimleri Enstitüsü Spor Bilimleri Anabilim Dalı, 2011.

Özsu, İ, Kurt, C. (2018). Myofasyal Antrenman Yaklaşımı. International Journal of Sport, Exercise & Training Sciences. 4. 131-139. https://doi.org/10.18826/useeabd.492721

Poór, O, Zemková, E. (2018). The Effect of Training in the Preparatory and Competitive Periods on Trunk Rotational Power in Canoeists, Ice-Hockey Players, and Tennis Players. Sports (Basel). Oct 9;6(4):113. https://doi.org/10.3390/sports6040113

Purslow, PP. (2010). Muscle fascia and force transmission. Journal of Bodywork and Movement Therapies. 14, 411-417. https://doi.org/10.1016/j.jbmt.2010.01.005

Sasa, D. (2019). Milli takım düzeyindeki bay ve bayan atletlerin ve kayak sporcularının esneklik, dayanıklılık ve sürat parametrelerinin karşılaştırılması. (Yayımlanmış Yüksek Lisans Tezi). İstanbul: İstanbul Gelişim Üniversitesi Sağlık Bilimler Enstitüsü, Antrenörlük Eğitimi Anabilim Dalı.

Schleip, R, Baker, A. (Eds.) (2015). Fascia in sport and movement. Handspring Publishing.

Sekulic, D, Pehar, M, Krolo, A, Spasic, M, Uljevic, O, Calleja-González, J, Sattler, T. (2017). Evaluation of Basketball-Specific Agility: Applicability of Preplanned and Nonplanned Agility Performances for Differentiating Playing Positions and Playing Levels. Journal of strength and conditioning research, 31(8), 2278-2288. https://doi.org/10.1519/JSC.0000000000001646

Sheppard, JM, Young, WB. (2006). Agility literature review: classifications, training and testing. Journal of sports sciences, 24(9), 919-932. https://doi.org/10.1080/02640410500457109

Silva, R, Rico-González, M, Lima, R, Akyildiz, Z, Pino-Ortega, J, Clemente, FM. (2021). Validity and Reliability of Mobile Applications for Assessing Strength, Power, Velocity, and Change-of-Direction: A Systematic Review. Sensors (Basel, Switzerland), 21(8), 2623. https://doi.org/10.3390/s21082623

Smeulders, MJ, Kreulen, M. (2007). Myofascial force transmission and tendon transfer for patients suffering from spastic paresis: a review and some new observations. Journal of electromyography and kinesiology: official journal of the International Society of Electrophysiological Kinesiology, 17(6), 644-656. https://doi.org/10.1016/j.jelekin.2007.02.002

Stecco, C., Macchi, V., Porzionato, A., Duparc, F., & De Caro, R. (2011). The fascia: the forgotten structure. Italian journal of anatomy and embryology = Archivio italiano di anatomia ed embriologia, 116(3), 127-138. PMID: 22852442.

Stecco, C, Lancerotto, L, Porzionato, A, Macchi, V, Tiengo, C, Parenti, A. (2009). The palmaris longus muscle and its relations with the antebrachial fascia and the palmar aponeurosis. Clin Anat., 22(2):221-229. https://doi.org/10.1002/ca.20747

Torres-Luque, G, Sanchez-Pay, A, Jesús, M, Belmonte, B, Moya, M. (2011). Functional aspects of competitive tennis. Journal of Human Sport and Exercise, 6(3), 528-539. https://doi.org/10.4100/jhse.2011.63.07

Wang, ZH, Pan, RC, Huang, MR, Wang, D. (2022). Effects of Integrative Neuromuscular Training Combined With Regular Tennis Training Program on Sprint and Change of Direction of Children. Frontiers in physiology, 13, 831248. https://doi.org/10.3389/fphys.2022.831248

Wilke, J, Niederer, D, Vogt, L, Banzer, W. (2016). Remote effects of lower limb stretching: preliminary evidence for myofascial connectivity? J. Sports Sci. 34 (22), 2145e2148. https://doi.org/10.1080/02640414.2016.1179776

Wu, Z, Wang, Y, Ye, X, Chen, Z, Zhou, R, Ye, Z, Huang, J, Zhu, Y, Chen, G, Xu, X. (2021). Myofascial Release for Chronic Low Back Pain: A Systematic Review and Meta-Analysis. Frontiers in medicine, 8, 697986. https://doi.org/10.3389/fmed.2021.697986

Yücesoy, CA. (2010). Epimuscular myofascial force transmission implies novel principles for muscular mechanics. Exercise and sport sciences reviews, 38(3), 128-134. https://doi.org/10.1097/JES.0b013e3181e372ef

ORIGINAL ARTICLE

Mitigating potential injuries in gymnastics: Human factors research approach on colour coding and visual perception in high-bar training

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ABSTRACT

If appropriate colour coding is applied, gymnasts' visual perception during landing may improve, potentially leading to reduced injuries and enhanced performance. An experiment and a survey were conducted with professional gymnasts at the University of Oklahoma. For the experiment, gymnasts' visual perceptions were assessed for different manoeuvres using distinctive colours: floral white, lime yellow, and deep blue. Subsequently, we conducted a survey to investigate their preferred colour(s), reasons behind their choices, and any previous injury experiences related to poor visibility. Significant differences between floral white and lime yellow for more complex manoeuvres (e.g., double layout flip with single twist, $p = .01$, and double layout flip with double twist, $p = .03$). Survey results indicate that floral white colour was not preferred since the gymnasts reported difficulty distinguishing the floor from the ceiling. Lime yellow was preferred due to its high contrast, and deep blue was similarly favoured because gymnasts were accustomed to it. Additionally, the gymnasts reported other potential colour(s) and/or patterns that could enhance visual perception. The study provides insights into the potential benefits of colour-coded landing areas and establishes a foundation for further research on utilizing other hue variations, lightness, chroma intensity, patterns, and related factors.
Keywords: Performance analysis, Sports health, Sports performance, High-bar training, Colour coding, Human factors, Visual perception.

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INTRODUCTION

One of the pioneering research projects, which is based on interviews with gymnasts, highlights their limited control over external factors such as mats, lighting, and equipment, and as a result, gymnasts are advised to anticipate and prepare to maximize their control over those external factors (Ravizza & Rotella, 1982). Specific to the mat standards, the International Federation of Gymnastics maintains updated specifications that outline dimensions and composition to prevent potential injuries (Fédération Internationale de Gymnastique, 2024), and previous research efforts have centred around improving the materials used in energy-absorbing mats (Sundholm, 2014; Tomin & Kmetty, 2022).

However, to the best of our knowledge, there are no specific standards or specifications format colour. The choice of mat colour is not a personal preference for gymnasts; rather, it is determined by equipment manufacturers or competition organizers. Therefore, mat colours may vary depending on the region. As an example, American Athletics Inc. is known to provide blue-coloured mats in the United States ("*Competition Landing Mats*," n.d.), while Gymnova offers white-coloured mats in Europe for certain official competitions ("*Gymnova*," n.d.). These two brands are used for specific meets based on the sponsor and location of the competition. Furthermore, many gyms may choose mat colours that align with their branding.

Despite any personal preferences gymnasts may have, the gymnasts often lack the opportunity to utilize their preferred mat colour. Certain colours may be easier for gymnasts to spot, potentially enhancing their perception during landings. Improved perception can contribute to safer landings and better overall performance. Interestingly, scientific evidence or experiments specifically examining the effect of mat colour in professional gymnastic events, such as the high-bar (also known as horizontal-bar), are scarce. However, the visibility of landing mats likely plays a crucial role in gymnasts' sense of self-security and may help reduce the risk of injuries.

In the context of gymnastics injuries, prior research indicates that the absence of a spotter—someone who observes and reacts to orient or position the athlete when they lose spatial awareness—accounts for a significant portion of injuries. Specifically, studies report that not having a spotter contributes to 85% (Lindner and Caine, 1990) of all gymnastics-related injuries. Among these injuries, knee and ankle injuries during twisting manoeuvres and other lower limb injuries are the most common types (Grapton et al., 2013; Greier, Drenowatz, & Mairoser, 2022; Katz, 2020; Williams et al., 2023). Consequently, emphasizing correct landing techniques and maintaining proper body posture is essential for preventing gymnastics injuries (Daly, Bass, & Finch, 2001).

Especially, visual perception might play a critical role in maintaining spatial awareness and preventing injuries in gymnastics. When gymnasts lack vision, their stability significantly decreases (Davlin, 2001). High-bar routines, in particular, require gymnasts to execute intricate movements before landing on the mat. Visual perception of the mat's location enables gymnasts to align their bodies for controlled landings, effectively absorbing impact forces and reducing injury risks. This heightened awareness allows precise execution of movements and optimal body control throughout the dismount phase. Gymnasts must perform manoeuvres while simultaneously preparing for a controlled landing on the mat (Takei et al., 1999). Therefore, athletes often maintain spatial awareness by looking down at the mat whenever possible. Existing research demonstrates that gymnasts observe the landing location during preparatory giant swings (Heinen, Velentzas, & Vinken, 2012).

Considering the importance of visual perception, appropriate colour coding could be implemented to enhance the visibility of landing mats. Humans naturally draw explicit attention to colour stimuli (Elliot and Maier, 2014). As an example, in long jump approach runs, using a yellow-coloured take-off board (complementary to the runway's blue track surface) instead of the traditional white board allowed athletes to initiate their regulation two strides earlier. This adjustment resulted in better pre-jump positioning due to increased visual perception (Theodorou et al., 2013). Similarly, in another study, athletes wearing coloured lenses demonstrated significantly shorter hand-eye coordination times with light-yellow and dark-yellow lenses compared to dark-grey lenses (Kohmura, Murakami, & Aoki, 2013).

In the field of Human Factors research, two critical colour principles enhance visual perception: conspicuity and visibility. These principles play a crucial role in clearly identifying the location of objects, such as gymnastics mats, under various viewing conditions. High conspicuity and visibility are achieved through the use of prominent colours or strong contrasts, and existing research shows that humans exhibit high sensitivity to lime yellow colour (Federal Emergency Management Agency, 2009; Proctor and Zandt, 2018; Solomon & King, 1995).

In this research, we investigated high-bar gymnasts' visual perception levels and colour preferences from several aspects. First an experiment was conducted with the professional gymnasts who conducted simple to complex manoeuvres. During the experiment, we evaluated the gymnasts' visual perception levels of the coloured mats using a Likert-scale question. After, we conducted a survey to assess their colour preferences, reasons for choosing such colour(s), previous injury experiences, among others. Details are provided in the following section.

MATERIAL AND METHODS

Participants

Nine professional gymnasts, having an average age of 20.2 (*S.D.* = 1.1), were recruited from the University of Oklahoma (OU) Men's Gymnastics Team. The participants had an average of 14.6 years of experience (*S.D.* = 2.6) and were active professional gymnasts.

Measures

Regarding the experiment (i.e. gymnasts performing manoeuvres), the visual perception level of the mat (i.e. the ability of a gymnast to see the mat between the time when they release their hands from the high bar until they land on the mat) was measured. In detail, gymnasts were asked to provide a Likert-scale value between 0 (no visibility: didn't see at all) and 10 (perfect visibility: perfectly visible throughout the manoeuvre) immediately after each manoeuvre for each mat colour. Mor details of the manoeuvres and mat colours are explained in the *Procedures* section below.

After the experiment ended, a survey was administered. The survey questions included: (1) preferences (i.e., positive, neutral, negative) on using a certain mat colour (e.g., floral white, lime yellow, deep blue), (2) the reason for choosing such a preference for each colour, (3) which mat colours they have used during their professional career, (4) whether they had any injuries because they were not able to see the floor or mat, (5) a detailed reason for why the injury occurred, (6) any colour, colours, colour combinations, and/or patterns they would choose if they had a choice, and (7) the reason behind their choices for colour, colours, colour combinations, and/or patterns.

Procedures

The experiment was approved by the Institutional Review Board (#15861) and the gymnastics Head Coach at OU. The second author, who is a professional gymnast at OU, recorded the data. Three types of mat colours along with the corresponding colour codes (i.e. floral white (Hex #FFFAF1, RGB (255, 250, 241)), golden poppy yellow (Hex #FFC500, RGB (255, 197, 0)), and deep blue (Hex #434A75, RGB (67, 74, 117)) are provided in Figure 1. Note that golden poppy yellow can create a strong contrast that might accentuate the visual impact, therefore, we chose this colour as a proxy for the lime-yellow colour for this experiment. Deep blue is the same colour used for training at OU.

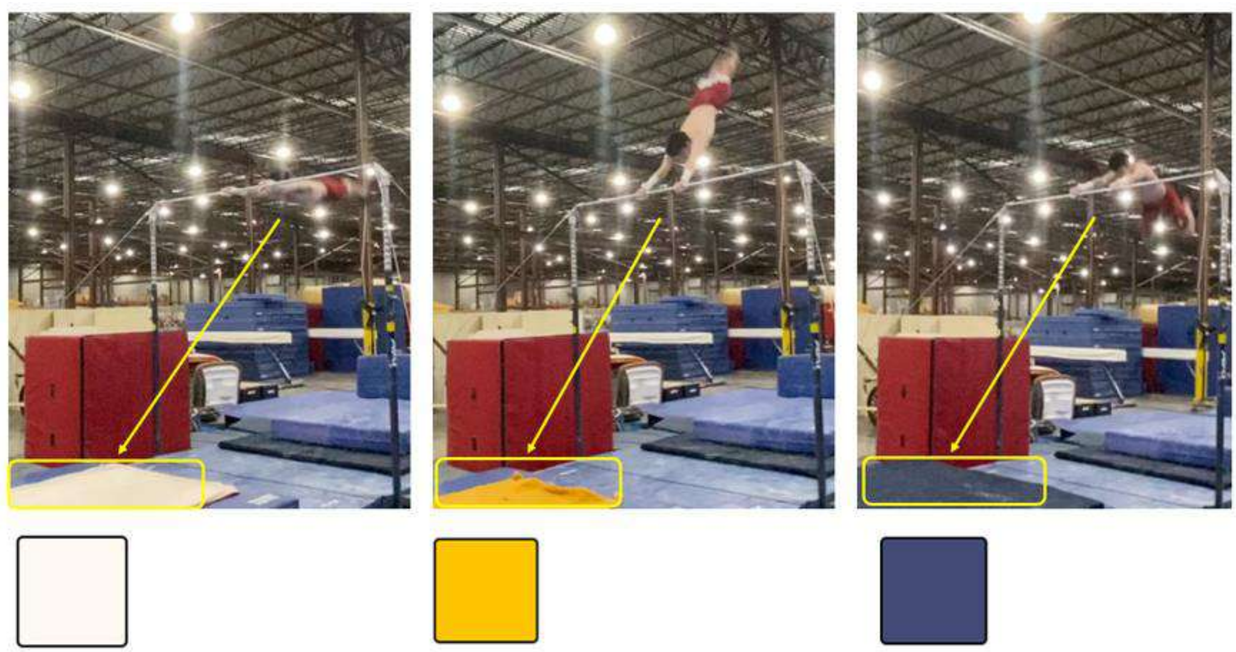


Figure 1. Experiment environment and mat colours used.

The manoeuvres included gymnasts executing three tasks in random order: single layout flip (SF), double layout flip with a single twist (DFST), and double layout flip with a double twist (DFDT). The gymnasts performed these each manoeuvre using three mat colours: floral white, lime yellow, and deep blue. The sequence of providing different mat colours was also randomly ordered. After each manoeuvre, the gymnasts provided their visual perception level by assigning a Likert-scale value. Professional gymnasts participated in the survey after executing the manoeuvres. Unfortunately, data for the deep blue colour mat were not saved for the DFDT manoeuvre due to an unexpected issue, and it was not feasible to schedule another time. Therefore, the analysis of the SF and DFST manoeuvres was possible for the floral white, lime yellow, and deep blue colours, while the analysis of the DFDT manoeuvre was possible for floral white and lime yellow colours.

Analysis

First, recorded videos were observed to obtain sample snapshots that better illustrate when the mat is observed during the manoeuvres. Next, descriptive statistics (i.e. means and standard errors) of the reported visual perception levels were plotted to identify any trends or differences. Since the data were not normally distributed, non-parametric statistical tests were used. Specifically, for the SF and DFST manoeuvres, Kruskal-Wallis tests were applied, followed by post-hoc pairwise comparisons using α-adjusted Wilcoxon tests to consider the familywise error rate. For the DFDT manoeuvre, a Wilcoxon test was applied since only two levels, floral white and lime yellow, were compared. Additionally, nonparametric bootstrapping was conducted to gain additional insights for future research. Finally, self-report analysis was used to tally and summarize the answers to all the questions listed in the Measures section above.

RESULTS

Experiment results

Examples of the gaze behaviours of the gymnasts are provided in Figure 2. In Figure 2, we can observe that the gymnasts can spend most of their time seeking and looking down at the mat during the SF and DFST manoeuvres, whereas the gymnasts lose contact with the mat for a longer duration for the DFDT manoeuvre. Note that the SF and DFST experiments were conducted during the evening, whereas the DFDT experiment took place during the daytime at a different location; however, despite these variations, no confounding effects exist, as the visibility level evaluations were assessed and compared for each independent manoeuvre.

Figure 2a. Examples of eye gaze directions during manoeuvres. Single layout flip (SF).

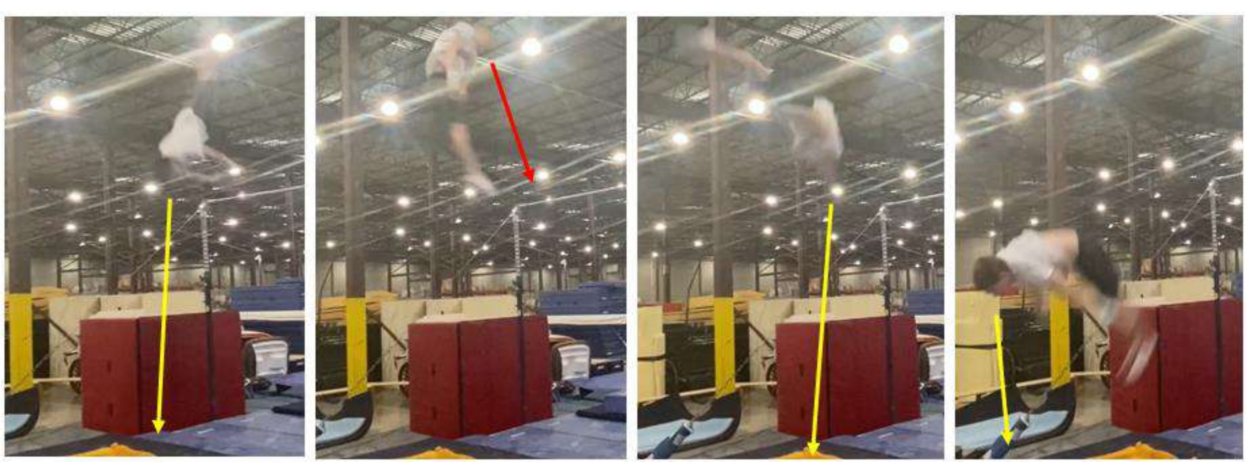


Figure 2b. Examples of eye gaze directions during manoeuvres. Double layout flip with single twist (DFST).

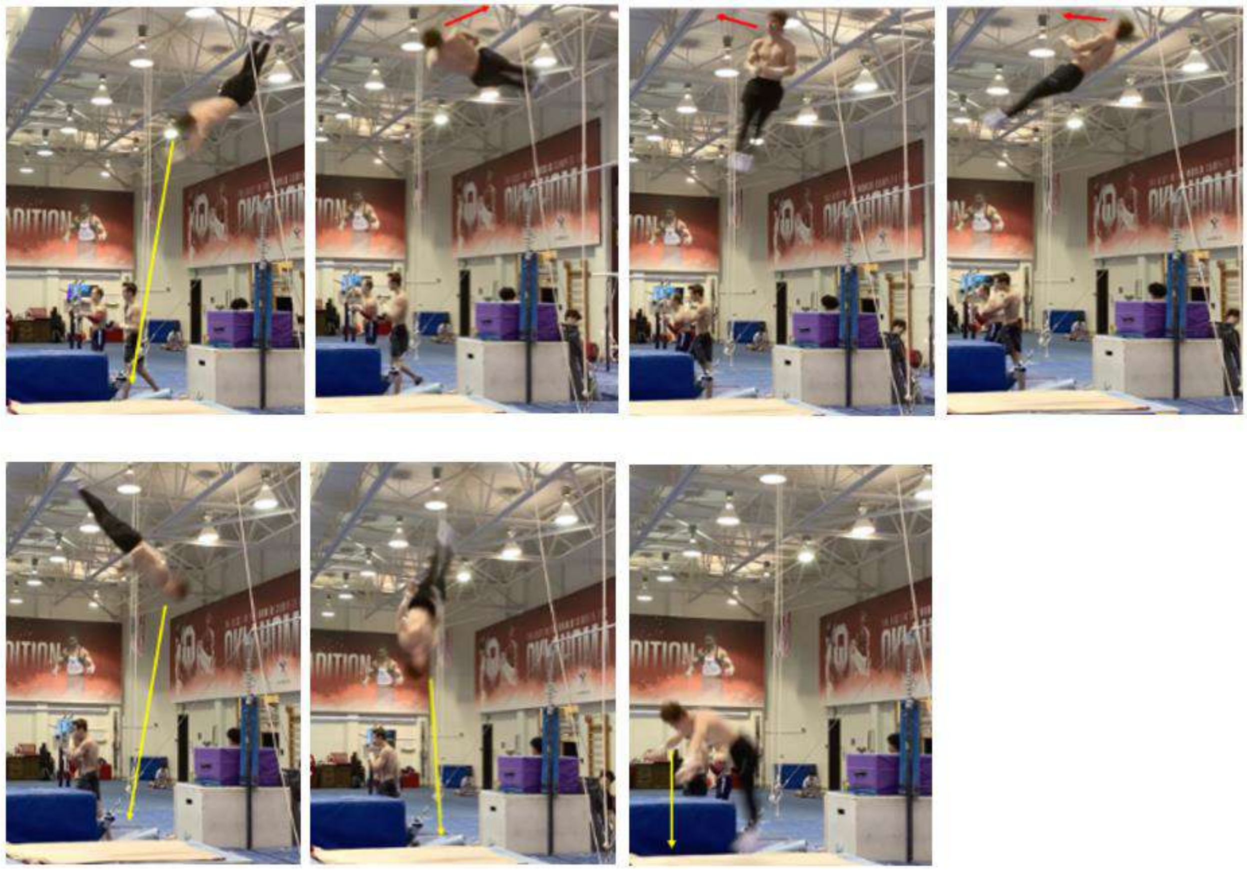


Figure 2c. Examples of eye gaze directions during manoeuvres. Double layout flip with double twist (DFDT).

The descriptive statistics (i.e. Means and Standard Errors) of the participants' visual perception levels are plotted in Figure 3. In Figure 3, we can see trends that yellow-coloured mat was easier to spot than the white-coloured mat as the task difficulty increased.

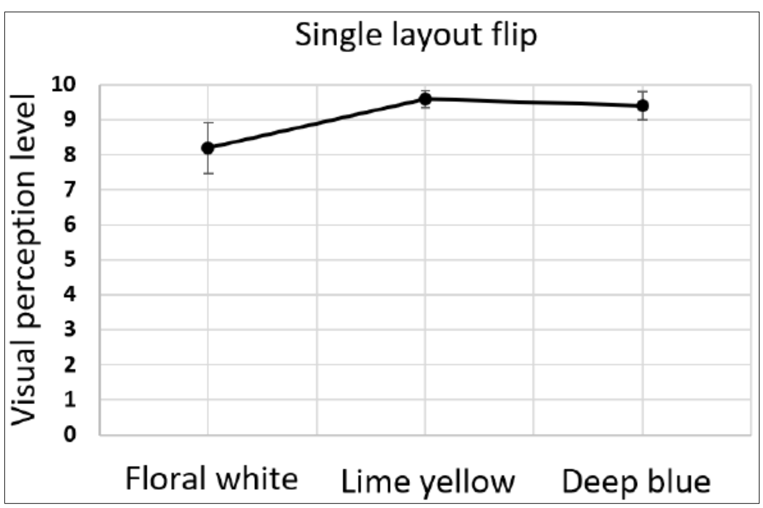


Figure 3a. Visual perception levels (Likert scale values) on each colour during each manoeuvre. Single layout flip (SF).

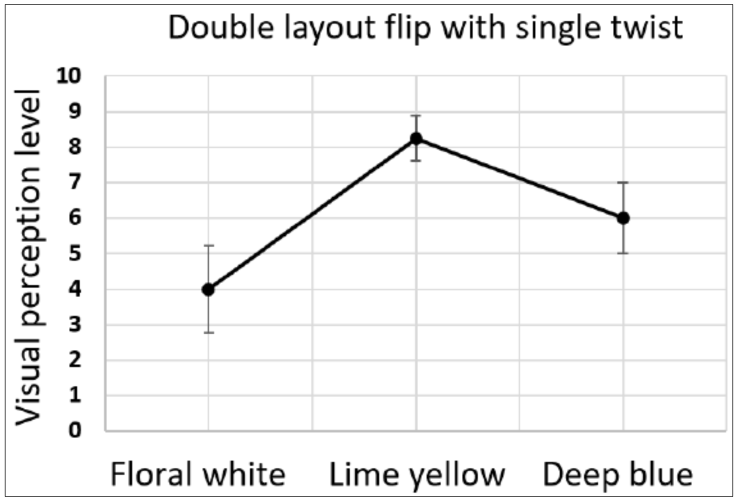


Figure 3b. Visual perception levels (Likert scale values) on each colour during each manoeuvre. Double layout flip with single twist (DFST).

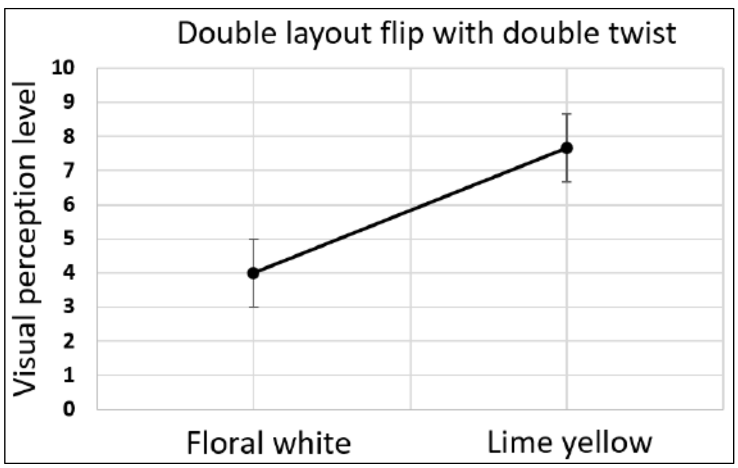


Figure 3c. Visual perception levels (Likert scale values) on each colour during each manoeuvre. Double layout flip with double twist (DFDT).

Table 1. Bootstrapping (1,000 repetitions): CI indicates confidence interval. Results are rounded to 1 decimal place.

Task	Task	Colour	Mean	95% CI
Visual perception (Likert scale)	Single layout flip (SF)	Floral white	8.2	[7.0, 9.5]
		Lime yellow	9.6	[9.2, 9.5]
		Deep blue	9.4	[8.7, 10.0]
	Double layout flip with single twist (DFST)	Floral white	4.0	[2.5, 5.5]
		Lime yellow	8.3	[7.6, 9.2]
		Deep blue	6.0	[4.8, 7.3]
	Double layout flip with double twist (DFDT)	Floral white	3.9	[2.9, 5.1]
		Lime yellow	7.7	[6.5, 8.8]

For the manoeuvres single layout flip (SF) and double layout flip with a single twist (DFST), Kruskal–Wallis tests on colours revealed significant differences in the gymnasts' visual perceptions ($H = 9.48$, $p = .01$). Post hoc analyses (i.e., multiple comparisons) were performed using Wilcoxon tests with $\alpha = 0.017$ (or 0.05/3). The results showed that white vs. yellow were significantly different (W = 6.52, $p = .01$) for the DFST manoeuvre, but other pairs (i.e., yellow vs. blue, and white vs. blue) were not significantly different. Regarding the manoeuvre double layout flip with a double twist (DFDT), the Wilcoxon test with $\alpha = 0.05$ indicated that a significant difference existed between white and yellow (W = 4.96, $p = .03$). Bootstrapping results for both visual perception and mat gaze duration are provided in Table 1.

Self-report analysis results

Self-report analysis on the gymnasts' preferences after participating in the experiment is provided in Table 2. Most participants preferred the lime yellow or the deep blue mats, while the majority did not prefer the floral white mat. The critical reason for not preferring the floral white mat was the difficulty in clearly distinguishing the ceiling (which has white lights) from the floor. In addition, the reasons for their preference for the lime yellow or deep blue were distinctly different. Lime yellow was preferred because it provided high contrast, making it easy to locate the floor, whereas deep blue was preferred because it doesn't stand out too much but still provides enough contrast to distinguish the ceiling and floor. More importantly, deep blue was the colour to which they were accustomed.

Table 2. Self-report analysis of the gymnasts' preferences for the tested three colours.

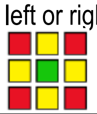
Colour	Classification (count)	Representative or notable quotes
Floral white	Positive (1)	"The contrast between the blue surroundings in the gym (during training) and the white landing mat helped me spot the mat easier. However, if the surroundings are floral white, it would be difficult to distinguish it from the white ceiling and walls, which I would not have liked."
	Undecided (1)	"I didn't feel noticeable impact on ground visibility."
	Negative (7)	"Floral white mat blends with ceiling due to the colour and glare of the lights." "Confusing, feels like staring at the ceiling instead of the ground." "Brightness is excessive and merges with the ceiling lights which are white." "Hard to judge distance since the colour is too bright."
Lime yellow	Positive (7)	"The (lime yellow) colour made it easier to tell the difference between the floor and ceiling, and the brightness of the colour made it easier to see." "Lime yellow was easier to spot because it was brighter than the surrounding colours." "Easier to judge distances." "Lime yellow is a very vivid colour, and it isn't a distraction nor is hard to find." "Because of the bright nature of lime yellow, I was able to see the mat decently well when moving fast and preparing for the landing."
	Undecided (1)	"It was not too distracting; however, I'm not too used to the colour lime yellow when it comes to landing mats."
	Negative (1)	"I am able to see the mat better, but it stands out too much."
Deep blue	Positive (8)	"It's what I am used to. It does not blend into the ceiling and doesn't stand out too much." "I used deep blue since I started gymnastics, so that's what I'm used to seeing." "I'm used to using deep blue, and the contrast between the celling and floor is good." "I like deep blue since it is mainly the colour I land on. Although the colour isn't vibrant and as easy to spot as the others, I can still see my landing. I feel as though partially because I mostly use this colour (blue) for a landing mat. It's most natural to me. Because the colour isn't vibrant, I am able to not feel rushed nor excited when I prepare for landing." "It just seems normal."
	Negative (1)	"The mat colour is similar as the floor around it, so it is difficult to judge the correct distance."

Regarding which colour mats were used by the participants, various answers were obtained. The colours and the number of responses provided by the participants are as follows: white (3), yellow (2), blue (9), dark blue (1), teal (2), red (7), green (1), grey (1), orange (1), and black (2). The question of whether the participants had any injuries because they were not able to see the floor or mat resulted in the following responses: Four participants answered "*yes*," while five participants answered "*no*." For those who responded "*yes*," the reasons provided were as follows:

> "*I was not able to see the floor and opened up too late to prepare for the landing."*
> *"I didn't absorb the landing correctly because I got confused by the ceiling lights."*
> *"I didn't see the mat and over-rotated, so I landed on my back."*
> *"The grey-coloured mat was always hard to see, and I would either think that I saw it and open out too early or didn't see the mat at all and opened too late*."

Finally, we provided an option for the participants to choose whichever colour, combination of colours, and/or layout of colours, and the results are provided in Table 3.

Table 3. Self-report analysis of the gymnasts' preferences for any colour, colours, colour combinations, and/or patterns.

Colour or colours	Classification (count)	Reason of choosing the colour or colours
Single colour	White (0)	n/a.
	Yellow (2)	"I feel like there are other combinations that would be a lot better but yellow has been the only one I tried, and I like it so far." "I really liked that colour during the experiment. however, this made me think a lot and I feel like other combinations with forms might help too but I would have to try it."
	Yellow or orange (1)	"Darker colours are usually hard to find and white and cream is a reflection of the ceiling. Yellow and orange makes it easy to see the ground while preparing for any landing."
	Blue (2)	"Blue is the easiest on the eye in my opinion, but I've always used this colour so it makes sense that it is the most familiar." "It's what I'm used to."
	Blue or red (1)	"Blue and red are vastly different colours from the ceiling lights. Interestingly enough, I think even tan could work."
Combination of colours	Striped yellow and red (1)	"It would really stand out against the ceiling and other colours in the mix of things."
	Striped blue and red (1)	"They give you a mixture of colour recognition in order to better recognize distance to the ground and where you are going to land."
	Tic-tac-toe pattern (1)	"A tic-tac-toe pattern, red on the corners, yellow one the middle borders, and green in the middle. This pattern will allow me the figure where I am in the air and how I need to adjust before landing. If I'm going to land short or if I need to pull less to slow the rotation down. I could also see if I need to get ready if I'm too much to the left or right side with the corners." 

DISCUSSION

The comparisons of visual perception levels provided a clear insight into how mat colour significantly affects gymnasts' ability to see the floor or mat. The vivid colour, lime yellow, which provides high contrast, stands out as particularly effective. Interestingly, the visual perception levels for lime yellow and deep blue were not significantly different. The results of the visual perception levels align with the survey responses. The majority of gymnasts mentioned that they were unable to distinguish the ceiling from the floor when the floral white mat was used. Although the gymnasts showed similar preferences for lime yellow and deep blue, but their reasons differed. Those who preferred yellow emphasized its vivid colour, making it easier to spot. In contrast, those who preferred blue cited comfort, as it was the colour they had been using since childhood. However, both colours (blue and yellow) were acceptable because they allowed differentiation between the ceiling and floor. The effect of the mat colour can be crucial for difficult manoeuvres like the double layout flip with a double twist, during which gymnasts lose eye contact with the mat or floor for longer periods of time. While the results suggest that lime yellow might be a viable alternative to floral white, it's essential to consider various aspects of colour. These include lightness and chroma intensity, which were not specifically investigated in this research. While this study focused on varying colour hue, future research could explore the impact of other factors listed above.

When examining the survey results, it becomes evident that gymnasts had the opportunity to use various mat colours, even if they primarily trained on blue mats. Their exposure to different mat colours, combined with the use of yellow mats during this experiment, seems to have piqued their interest in exploring alternative colour options or combinations. In more detail, when asked to choose any colour (or colours) if given the chance, approximately one-third of the gymnasts preferred yellow, another one-third favoured blue, and the remaining one-third opted for a combination represented as strips or a tic-tac-toe pattern. This tic-tac-toe pattern resembles the "*double mini*" pattern (with blue on the boundary, yellow in the middle, and red in the centre) used in some competitions. Using such a pattern might improve their ability to adjust their landings, potentially reducing the risk of injuries.

Regarding the survey responses on injuries, some participants reported that injuries occurred due to poor visibility of the mat. Although we couldn't verify the exact mat colour used during each injury, one gymnast mentioned an injury while using a grey mat, while another expressed difficulty distinguishing the ceiling from the floor. These survey results highlight that the white mat might not be an optimal solution, especially considering that ceiling lights are typically white. Note that, if changing the mat colour proves challenging, it might be worthwhile to explore the possibility of gymnasts using coloured lenses. Research conducted in other athletic environments has utilized coloured lenses to investigate the effects of colour changes on manoeuvres (Kohmura, Murakami, & Aoki, 2013).

We did attempt to calculate mat gaze durations during high-bar manoeuvres by observing recorded videos, but the results are not included in this paper as we encountered many challenges. The quality of still images captured from the videos was lower than expected, and determining the duration was highly subjective, relying on analysts' judgments. However, there's a promising avenue for better quantifying mat gaze duration using eye tracking glasses (Hüttermann, Noël, & Memmert, 2018; Aksum et al., 2020). Eye tracking research specific to high-bar activities has been limited (Heinen, Velentzas, & Vinken, 2012). Fortunately, recent advancements in eye tracking technology might offer the potential to enhance our analysis of gymnasts' visual perception. If eye tracking technology can be accurately applied, it could revolutionize our understanding of the gymnasts gave behaviours. Beyond eye fixations or durations, we could explore characteristics of visual scan paths using algorithms developed in other research areas, such as visual entropy (Jeong, Kang, & Liu, 2019), visual grouping (Kang & Landry, 2015), dynamic visual scanning networks (Mandal & Kang, 2018), among others.

Finally, the research results were based on professional gymnasts in the United States. To draw more generalized conclusions, additional participants are needed, including gymnasts from other regions, female gymnasts, and different age groups. Nevertheless, our research provides a foundation and may spark wider interest among stakeholders to explore the possibility of using colours to enhance visibility.

CONCLUSIONS

We hypothesized that using a lime-yellow mat colour could potentially enhance the visual perception of professional gymnasts and contribute to their spatial awareness, specifically in terms of knowing the location of the floor (i.e. mat). The lime yellow or deep blue mats were significantly more visible compared to the floral white mat, and the biggest issue with using a floral white mat was that the ceiling and floor were difficult to distinguish. Losing spatial awareness can lead to injuries, and creating good colour contrast can enhance the visual perception levels. Our hypothesis was validated through both an experiment and a survey, paving the groundwork for more in-depth future research and fostering interest in using appropriate or preferred colours from a wider audience in sports. Applying appropriate colour principles to gymnastics mats, through selecting colours or colour combinations that offer strong contrast or stand out prominently, might enhance visual perception and assist the gymnasts in accurately identifying the mat's location, potentially reducing injuries.

AUTHOR CONTRIBUTIONS

Corresponding author, Dr. Ziho Kang, designed the experiment and survey. The second author, Mr. Cesar E. Gracia Salgado, conducted the experiment and survey, processed all collected data, and assisted in designing the experiment and survey. The third author, Ms. Sarah C. Gates, assisted in developing the structure of the article and conducting the statistical analysis. In addition, all three authors collaborated closely to analyse the data and compose all sections of the article.

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No potential conflict of interest was reported by the authors.

REFERENCES

Aksum, K. M., Magnaguagno, L., Bjørndal, C. T., & Jordet, G. (2020). What do football players look at? An eye-tracking analysis of the visual fixations of players in 11 v 11 elite football match play. Frontiers in psychology, 11, 562995. https://doi.org/10.3389/fpsyg.2020.562995

Competition Landing Mats: American Athletic Inc (AAI): Retrieved from [Accessed 2024, June 27]: https://www.americanathletic.com/product-category/gymnastics/mats-pads/competition-landing-mats/

Daly, R. M., Bass, S. L., & Finch, C. F. (2001). Balancing the risk of injury to gymnasts: how effective are the counter measures? British Journal of Sports Medicine, 35(1), 8-19. https://doi.org/10.1136/bjsm.35.1.8

Davlin, C.D. Peripheral vision and Back Tuck Somersaults. Perceptual and Motor Skills 2001, 93(6), 465.

Elliot, A.J. & Maier, M.A. (2014). Effects of perceiving color on psychological functioning in humans. Annual Review of Psychology, 65(1), 95-120. https://doi.org/10.1146/annurev-psych-010213-115035

Federal Emergency Management Agency (2009). Retrieved from [Accessed 2024, June 27]: https://www.usfa.fema.gov/downloads/pdf/publications/fa_323.pdf

Fédération Internationale de Gymnastique (2024). Retrieved from [Accessed 2024, June 27]: https://www.gymnastics.sport/site/rules/

Greier, K., Drenowatz, C., & Mairoser, J. (2022). Injuries in Competitive Austrian Gymnasts. European Journal of Sport Sciences, 1(2), 10-15. https://doi.org/10.24018/ejsport.2022.1.2.10

Grapton, X., Lion, A., Gauchard, G. C., Barrault, D., & Perrin, P. P. (2013). Specific injuries induced by the practice of trampoline, tumbling and acrobatic gymnastics. Knee surgery, sports traumatology, arthroscopy, 21, 494-499. https://doi.org/10.1007/s00167-012-1982-x

Gymnova. Tapis et matelas De Gym. Retrieved from [Accessed 2024, June 27]: https://www.gymnova.com/fr/tapis-matelas-et-protections

Heinen, T., Velentzas, K., & Vinken, P. M. (2012). Functional relationships between gaze behavior and movement kinematics when performing high bar dismounts-an exploratory study. Human movement, 13(3), 218-224. https://doi.org/10.2478/v10038-012-0025-2

Hüttermann, S., Noël, B., & Memmert, D. (2018). Eye tracking in high-performance sports: Evaluation of its application in expert athletes. International Journal of Computer Science in Sport, 17(2), 182-203. https://doi.org/10.2478/ijcss-2018-0011

Jeong H., Kang. Z., & Liu Y. (2019). Driver glance behaviors and scanning patterns: Applying static and dynamic glance measures to the analysis of curve driving with secondary tasks. Human Factors and Ergonomics in Manufacturing & Service Industries, 29(6), 437-446. https://doi.org/10.1002/hfm.20798

Kang, Z. & Landry, S.J. (2015). An eye movement analysis algorithm for a multi-element target tracking task: Maximum transition-based agglomerative hierarchical clustering. IEEE Transactions on Human-Machine Systems, 45(1), 13-24. https://doi.org/10.1109/THMS.2014.2363121

Katz, N. B., Casey, E., Gagliardi, A. G., & Albright, J. C. (2020). Lower Extremity Injuries in Gymnasts. Gymnastics Medicine: Evaluation, Management and Rehabilitation, 209-231. https://doi.org/10.1007/978-3-030-26288-4_10

Kohmura, Y., Murakami, S., & Aoki, K. (2013). Effect of yellow-tinted lenses on visual attributes related to sports activities. Journal of Human Kinetics, 36(1), 27-36. https://doi.org/10.2478/hukin-2013-0003

Lindner KJ, Caine DJ. Injury patterns of female competitive club gymnasts. Can J Sport Sci 1990;15:254-61.

Mandal, S. & Kang. Z. (2018). Using eye movement data visualization to enhance training of air traffic controllers: A dynamic network approach. Journal of Eye Movement Research, 11(4), 1-20. https://doi.org/10.16910/jemr.11.4.1

Proctor, R. W., & Van Zandt, T. (2018). Human factors in simple and complex systems. CRC press.

Ravizza, K., & Rotella, R. (1982). Cognitive somatic behavioral interventions in gymnastics. Stress management for sport, 25-35.

Solomon, S. S., & King, J. G. (1995). Influence of color on fire vehicle accidents. Journal of Safety Research, 26(1), 41-48. https://doi.org/10.1016/0022-4375(95)00001-1

Sundholm, M., Cheng, J., Zhou, B., Sethi, A., & Lukowicz, P. (2014). Smart-mat: Recognizing and counting gym exercises with low-cost resistive pressure sensing matrix. In Proceedings of the 2014 ACM international joint conference on pervasive and ubiquitous computing (pp. 373-382), Sep. 13-17, Seattle, WA. https://doi.org/10.1145/2632048.2636088

Takei, Y.; Nohara, H.; Kamimura, M. Techniques used by elite gymnasts in the 1992 olympic compulsory dismount from the horizontal bar. International Journal of Sport Biomechanics 1999, 8(3), 207-232. https://doi.org/10.1123/ijsb.8.3.207

Theodorou, A., Ioakimidou, E., Kouris, P., Panoutsakopoulos, V., & Smpokos, E. (2013). Colour contrast and regulation of the long jump approach run. Journal of Human Sport and Exercise, 8(3), S681-S687. https://doi.org/10.4100/jhse.2013.8.Proc3.14

Tomin, M., & Kmetty, Á. (2022). Polymer foams as advanced energy absorbing materials for sports applications - A review. Journal of Applied Polymer Science, 139(9), 1-23. https://doi.org/10.1002/app.51714

Williams E., Lloyd R., Moeskops S., & Pedley J. (2023). Injury Pathology in Young Gymnasts: A Retrospective Analysis. Children. 10(2), 1-11. https://doi.org/10.3390/children10020303

ORIGINAL ARTICLE

Impact of early leadership on performance in volleyball sets

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ABSTRACT

The aim of this study was to determine the impact of different contextual variables on winning volleyball sets. The variables were selected based on their significance as determined by expert coaches. The sample consisted of 1,849 sets, representing all matches played in both categories during the 2022 and 2023 Volleyball Nations League and the 2021 Olympic Games. To analyse the variables, multivariate logistic regressions and Markov chains were applied. The results showed that opponent level explained 21.6% of the variability found; being especially relevant when playing against opponents separated by two competitive levels. Winning the previous set increased the chances of winning the next set by 7.83%. Leading the score at the end of both set periods enhanced the likelihood of winning the set, reaching 87.12% when finishing ahead in both periods. Moreover, at the end of the second period, each additional point increased the likelihood of winning the set by 1.54%. These results signify an advancement in comprehending the impact of contextual variables on winning high-level volleyball sets.

Keywords: Performance analysis, Scoreline, Set period, Score difference, Contextual variables, Scoreboard.

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INTRODUCTION

The influence of contextual variables on game performance is an aspect considered relevant by elite volleyball coaches (López-Serrano et al., 2022). Various studies have investigated how contextual variables impact team performance in matches, sets, rallies, and technical actions; understanding a match as a constant dynamic interaction between two teams that affects their performance (Garciá-De-Alcaraz & Usero, 2019; Ramos, Coutinho, Silva, Davids, Guimarães, et al., 2017).

The opponent's level, as a contextual variable, has generated attention in research on team dynamics. The quality of the opponent may affect the performance of some of the individual technical actions among high-level teams, with better performances found in higher-ranked teams (Ciemiński, 2018; Drikos et al., 2021; Mulazimoglu et al., 2021; Palao et al., 2004). Although Araújo et al. (2020), did not find differences when comparing the phases of the Olympic Games, these could depend on the specific characteristics of the competition or its stage, which may affect the balance of the matches (Sánchez-Moreno et al., 2018). In this regard, López et al. (2023) observed no variations in the balance of scores at the conclusion of sets, regardless of the competition phase or team rankings. However, they noted more balanced sets in the women's Nations League and more unequal sets in the NORCECA Championship and the African Championship.

In a competitive sports context, the main objective of any team is to score as many points as possible to ensure victory at the end of the match. However, the division of matches into sets in disciplines such as volleyball may mean that the team with the most points at the end of the match does not necessarily win, due to the set-based scoring system, in what Lisi et al. (2019) called the "*Quasi-Simpson paradox*". With regard to winning sets', Marcelino et al. (2009) analysed matches from the Men's World Volleyball League and found no significant differences linking the outcome of one set to the next. This implies that a volleyball match can be seen as a series of three, four, or five independent micro-games (Marcelino et al., 2010b).

However, the number of sets in a match seems to affect the final score balance at the end of the sets. López et al. (2023) found that in high-level samples, the final scores of matches played over three sets were less balanced. In contrast, matches that extended to four or five sets in women's categories and five sets in men's categories exhibited greater balance in the scores. Moreover, each set of the match may affect physical and psychological stress differently, as well as the performance of specific game actions (Drikos & Vagenas, 2011; Giatsis et al., 2022; Marcelino et al., 2009, 2010b, 2012).

Each set is characterised by unique situations, intensified by changes in the score or the proximity of the end of the set. These circumstances can increase the psychological pressure on the players. Bar-Eli and Tractinsky (2000) discuss the concept of "*psychological phases*" throughout a match, identifying the final period as the most critical. Critical moments and score fluctuations in a match can influence the outcome of a set and may alter the tactical behaviours and technical performance of players or teams (Hill et al., 2010). In the men's category, it was noted that players utilised simpler blocking strategies and took fewer risks when serving during critical moments of the set and in tight scoring situations (Marcelino et al., 2011, 2012). However, when the score was unbalanced, the teams took greater risks (Drikos & Vagenas, 2011; Marcelino et al., 2011). In contrast, Ramos et al. (2017) found no differences in tactical performance based on the scoreline in high-level women's play, although national-level players reported greater tactical variations at critical moments of the set (Ramos, Coutinho, Silva, Davids, & Mesquita, 2017). Furthermore, scoring dynamics related to scoring sequences may influence the performance of subsequent actions (Raab et al., 2012). This notion is supported by the way volleyball coaches use time-outs to interrupt the opponent's scoring run (Fernández-Echeverria et al., 2013; Zetou et al., 2008), having reported evidence of its effectiveness in balanced sets with players in initial training (Fernández-Echeverría et al., 2019).

In accordance with the perceptions of elite coaches as provided by López-Serrano et al. (2022) about the contextual variables that influence the performance of high-level teams, the aim of this study was to investigate the impact of these variables on winning sets and matches in high-level competitions.

MATERIAL AND METHODS

Data set

A total of 1,849 sets from international volleyball events were analysed: 771 from the 2022 Nations League (VNL), 798 from 2023, and 280 from the Tokyo 2021 Olympic Games, covering all matches from these competitions. The gender distribution was balanced, with 923 sets in the men's category and 926 sets in the women's category. The data were obtained from the public and open access results found on the official website of the Fédération Internationale de Volleyball (FIVB). The research protocol received full approval from the Research Ethics Committee of the Technical University of Madrid (Spain).

Variables

In this study, fixed descriptor variables were used, including:

a) WinSet: dependent variable that includes binary values that identify whether the main team won/lost the entire set.
b) 1st Period and 2nd Period: following López-Serrano et al. (2022), these indicate whether the main team won the first period of the set (0 to 9 points) or the second period of the set (10 to 19 points), respectively.
c) SD1ºP and SD 2ºP: score difference between the two opponents at the end of the first period and second period, respectively.
d) Opposition Level (OL): determines the level differences between the two opponents, classified into five levels, following López-Serrano et al. (2022).
e) Competitive Load (CL): reflects the importance for the outcome of the match: it is considered low if the set is not decisive for the victory, and high if it is decisive (López-Serrano et al., 2022).
f) Result of the previous set (SETp): the value can be "*Tied*" at the start of the match with a 0-0 set draw, "*Lost*" if the previous set was lost, or "*Won*" if the previous set was won (López-Serrano et al., 2022).
g) Round: identifies two championship rounds, the opening round or first round and the final round.
h) Gender: male or female.
i) Competition: Volley Nations League or Olympic Games.

Univariable logistic regression model

Logistic regression was used to understand how the independent variables *1st Period, 2nd Period, SD1ºP, SD2ºP, Gender, Competition, OL, CL* and *SETp*, affect the probability of winning a set (*WinSet*).

The relationship between the dependent variable (WinSet) and each independent variable is modelled using the following logistic function:

$$\mathrm{logit}(p) = \ln\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 X$$

In the text, *p* is the probability that the event of interest (winning the set) occurs. *logit(p)* is the logistic transformation of *p*. β_0 is the intersection. β_1 is the coefficient of the independent variable *X* (i.e. *SD1ºP* or *SD2ºP*).

The probability of winning the set is calculated by inverting the logistic function:

$$p = \frac{e^{\beta_0+\beta_1 X}}{1+e^{\beta_0+\beta_1 X}}$$

For each change in *SD1ºP* and *SD2ºP*, the likelihood of winning the set was estimated using a logistic regression model.

Multivariable logistic regression models

Two multivariate logistic regression models were run to assess the combined effect of multiple variables. The first model assessed the influence of the score difference in the first part of the set (*SD1ºP*). This means understanding how an early score difference in the set influences the likelihood of winning the set and how other variables such as *OL*, *CL*, *Gender*, *Competition* or *SETp* affect this likelihood of winning (*WinSet*). The second model analysed the score difference in the second half of the match similarly (*SD2ºP)*.

The relationship between the binary dependent variable *WinSet* and the independent variables is modelled using the logistic function:

$$p(X) = \frac{1}{1+e^{-(\beta_0+\beta_1 X_1+\beta_2 X_2+\cdots+\beta_k X_k)}}$$

Where $p(X)$ is the probability of winning the set, $X1$, $X2$,...,Xk are the independent variables, and β_0, β_1,...,β_k are the coefficients of the model.

Markov chain analysis

A stochastic Markov chain model was used to investigate how wins in each period of a set affect the likelihood of winning the entire set. The scoreline was divided into three sections: the outcomes of the two periods and the conclusion of the set. According to this model, the likelihood of winning the set depends only on the current results of the periods and is unaffected by earlier events or previous sets.

To represent the possible outcomes in the different periods of the set, the states were defined as:

- State 'Lost vs Lost': Lost both periods (first and second).
- State 'Lost vs Win': Lost the first period but won the second.
- State 'Win vs Lost': Won the first period but lost the second.
- State 'Win vs Win': Won both periods.

A transition matrix *P* of size 4 × 2 was calculated, where P*ij* represents the likelihood of transitioning from state *i* (*1st Period* and *2nd Period* combinations) to state *j* (*WinSet*), with *j* being 0 or 1. This matrix was calculated as follows:

$$\mathrm{P}_{ij} = \frac{\text{Number of transitions from } i \text{ to } j}{\text{Total observations in state } i}$$

Additionally, the transition matrices were calculated by incorporating an additional variable: OL and SETp, mathematically defined as follows:

$$P\ (i, v \rightarrow j) = \frac{\text{Number of transitions from (i, v) to j}}{\text{Total transitions from the combined state (i, v)}}$$

Where:

- (i, v) represent the combination of the transition state i and the value of the additional variable v (*OL* or *SETp*, in each case).
- j is the next state of *WinSet*.
- The numerator denotes the frequency of transition from the combined state (i, v) to j.
- The denominator represents the total number of transitions originating from the combined state (i, v).

Heat maps were used to illustrate the probabilities derived from different transition matrices. These represented the combination of states (*1st/2nd period*) and additional variables (*OL* and *SETp*) on the axes, while the colours reflected the probability of winning the entire set, visually showing the effect of winning specific set period in different playing conditions.

Likelihood curves

Probability curves were created using logistic regression models based on score difference to show how the probability of winning a set is altered with each unit change in *SD1ºP* and *SD2ºP*. The probability *p* was calculated for each value within the range using the previously mentioned equation.

To find the critical point (or inflexion point) on a probability curve of a logistic regression model, differential calculus is used. Specifically, we look for the point at which the second derivative changes, indicating the largest change in the slope of the curve.

To find the inflexion point, we need to calculate the second derivative of *p*(*X*) and identify the value of X where this derivative equal zero. The first derivative of *p*(*X*) is:

$$p'(X) = \frac{d}{dX}\left(\frac{1}{1 + e^{-(\beta_0 + \beta_1 X)}}\right) = \frac{\beta_1 e^{-(\beta_0 + \beta_1 X)}}{(1 + e^{-(\beta_0 + \beta_1 X)})^2}$$

The second derivative, p''(X), where we need to find the inflexion point, is the derivative of p'(X). We calculate this as:

$$p''(X) = \frac{d}{dX}\left(\frac{\beta_1 e^{-(\beta_0 + \beta_1 X)}}{(1 + e^{-(\beta_0 + \beta_1 X)})^2}\right)$$

The numerical calculation of the second derivative of the probability function is carried out to identify the inflection inflexion point, though its expression in closed form is complex due to the characteristics of the exponential and logistic functions. Once this value of X has been identified, it is replaced in the probability function to determine the corresponding p-coordinate.

Therefore, the point coordinates of the critical point ($X_{inflexion}$, $p_{inflexion}$) are the value of *X* where the second derivative reaches its absolute maximum, and the value of *p* computed from the probability function for that *X.*

Effectiveness of models

ROC (Receiver Operating Characteristic) curves were used to evaluate predictive models of score differences per period, depending on the opposition level. These curves represent the true positive rate (sensitivity) versus false positive rate (1 - specificity) for different decision thresholds. Mathematically, for a threshold t, the sensitivity and specificity are calculated as:

$$\text{Sensitivity: } TPR(t) = (TP(t))/(TP(t)+FN(t))$$

$$\text{Specificity: } FPR(t) = (FP(t))/(FP(t)+TN(t))$$

Where TP, FP, TN y FN are, respectively, true positives, false positives, true negatives and false negatives. An AUC of 1 denotes perfect discrimination, while an AUC of .5 suggests performance no better than random.

Data analysis

Python 3 was used to analyse Markov chains, create heat maps, and generate probability curves. A cluster analysis was used to classify the teams into three competitive levels. The variables used to establish the groups were: points scored per win (two points for a victory, one for a defeat), the ratio of won to lost sets, the points won versus lost, and the percentage of sets won (Marcelino et al., 2011). Logistic regressions were checked for correct diagnosis and all tests were performed using the SPSS v.26 statistical package (IBM Corp., Armank, NY, USA). The significance was set at $p < .05$.

RESULTS

Univariate logistic regression

The logistic regression results, shown in Table 1, assess the probability of winning a set in volleyball, based on wins in the *1st Period*, and *2nd Period*, in addition to *SD1ºP* and *SD2ºP*, respectively, *Gender*, *Competition*, *OL*, *CL* and the *SETp.*

Our findings show that certain factors are significant ($p < .001$) for predicting the likelihood of winning a set in volleyball. These include *1st* and *2nd Period* wins, *SD1ºP* and *SD2ºP*, *OL* and *SETp*, indicating:

1st Period and *2nd Period*

Low values of .105 and .130 suggest high reliability of these estimates. Significantly, the high odds ratios (ORs) of 7.569 for the *1st period* and 30.235 for the *2nd period* show that securing these periods considerably boosts the likelihood of winning the set, with the *2nd period* being especially decisive.

Furthermore, R^2_N values, 26.9% for the *1st period* and 54.2% for the *2nd*, indicate that both periods are strong predictors of winning a set, with the *2nd period* being particularly influential.

Finally, values close to 1 for VIF and Tolerance suggest there are no multicollinearity problems, meaning these variables function independently in prediction.

Table 1. Influence of score differences and other contextual variables on the probability of winning a set in volleyball: A univariate and multivariate logistic regression analysis.

Predictor	**Estimator**	**EE**	**Z**	***p*-value**	**OR**	**R^2_N**	**IC(95%) OR**	**IC(95%) OR**	**Collinearity analysis**	
							Inf	**Sup**	**VIF**	**Tolerance**
Constant	-.878	.074	-11.83	***<.001***	.416		.359	.481	2.10	.475
1st Period	2.024	.105	19.19	***<.001***	7.569	.269	6.155	9.306	1.00	1.00
Constant	-1.72	.098	-17.64	***<.001***	.179		.148	.216	2.26	.442
2nd Period	3.41	.130	26.25	***<.001***	30.235	.542	23.439	38.998	1.00	1.00
Constant	.140	.054	2.596	.009*	1.150		1.035	1.278	1.00	.998
SD1ºP	.375	.019	19.331	***<.001***	1.455	.318	1.401	1.512	1.00	1.00
Constant	-.001	.065	-.021	.983	.998		.878	1.135	1.01	.990
SD2ºP	.443	.019	22.743	***<.001***	1.558	.584	1.499	1.618	1.00	1.00
Constant	.261	.148	1.769	.077	1.299		.972	1.735	10.01	.990
Gender	-.072	.093	-.775	.438	.930	.000	.775	1.117	1.00	1.00
Constant	.191	.111	1.721	.085	1.210		.974	1.504	5.64	.177
Competition	.019	.051	-.378	.705	.981	.000	.888	1.083	1.00	1.00
Constant	.064	.051	1.250	.211	1.066		.964	1.179	1.01	.987
Opposition Level (OL)	-1.036	.065	-16.014	***<.001***	.345	.216	.312	.403	1.00	1.00
Constant	.058	.140	.413	.679	1.059		.805	1.394	9.02	.111
Competitive Load (CL)	.070	.097	.718	.473	1.072	.000	.886	1.298	1.00	1.00
Constant	-.043	.072	-.60	.535	.957		.831	1.103	2.40	.416
SETp	.215	.061	3.55	***<.001***	1.239	.009	1.101	1.396	1.00	1.00
Constant	.416	.304	1.370	.171	1.517		.836	2.754	41.97	.024
Round	-.138	.158	-.878	.380	.870	.001	.639	1.186	1.00	1.00

Predictor	**Estimator**	**EE**	**Z**	**p-value**	**OR**	**R^2_N**	**IC(95%) OR**	**IC(95%) OR**	**Collinearity analysis**	
							Inf	**Sup**	**VIF**	**Tolerance**
Constant	-1.594	.201	7.925	***<.001***	4.924		3.320	7.304	11.85	.084
SD1ºP	.357	.021	17.331	***<.001***	1.429	.427	1.373	1.488	1.08	.928
Gender : Masc – Fem	.186	.116	1.604	.109	1.204		.959	1.511	1.01	.993
Competition: VNL22 & 23 – JJOO21	.062	.059	.984	.325	1.064		.940	1.204	1.01	.994
Opponent Level (OL): 5 Level	-9.401	.073	-12.850	***<.001***	.390		.338	.450	1.11	.903
Competitive Load (CL): High Load – Attenuated Load	.153	.130	1.182	.237	1.166		.904	1.503	1.17	.850
SETp: Tied– Lost– Won	.138	.080	1.731	.083	1.148		.981	1.343	1.19	.835

Predictor	**Estimator**	**EE**	**Z**	**p-value**	**OR**	**R^2_N**	**IC(95%) OR**	**IC(95%) OR**	**Collinearity analysis**	
							Inf	**Sup**	**VIF**	**Tolerance**
Constant	1.342	.239	5.615	***<.001***	3.827		2.395	6.114	12.13	.082
SD2ºP	.435	.021	21.082	***<.001***	1.545	.631	1.501	1.621	1.14	.876
Gender: Masc – Fem	.272	.137	1.980	.048*	1.313		1.483	1.608	1.01	.994
Competition: VNL22 & 23 – JJOO21	-.070	.074	-.094	.925	.983		.858	1.149	1.00	.994
Opponent Level (OL): Equal-One-Two Level	-.858	.087	-9.869	***<.001***	.424		.357	.502	1.17	.885
Competitive Load (CL): High Load – Attenuated Load	1.113	.156	.724	.469	1.119		.825	1.519	1.17	.850
SETp: Tied– Lost– Won	.127	.096	1.326	.185	1.135		.941	1.369	1.19	.835

*Note. Estimators represent the log odds of "Win set = False" vs. "Win set = True"; EE - standard error; Z - Wald value. ; p-value - p-value of the Wald test; OR – Odds ratio; IC 95% OR - confidence intervals for the odds ratio; R2N: R2 de Nagelkerke ; VIF – Variance Inflation Factor (1 / (1 - R^2). Tolerance: Proportion of variance (1/VIF); Significance (bilateral): ** p < .001; * p < .05.*

SD1ºP and SD2ºP

Low standard error (SE) values, such as 0.019, denote precise estimates. Conversely, ORs of 1.455 and 1.558 indicate that larger point margins increase the likelihood of winning a set. The R^2_N of 31.8% y 58.4% respectively, show that these variables are significant in explaining variability in wins.

OL

With a low EE of .065 and an OR of .345, the values indicate that an increase in the opposition level decreases the probability of winning. The R^2_N value of .216, shows that this variable explains 21.6% of the probability of winning the set.

SETp

An OR of 1.239 suggests that winning a set marginally increases the likelihood of winning the next, while the R^2_N of .009 shows that its impact on the overall win is minimal.

A high p-value ($p > .05$) associated with the other variables of Gender, Competition, *OL* and *CL*, suggest that there is no statistically significant relationship with winning a set. Furthermore, an R^2_N of .000 in all instances signifies that they do not contribute to explaining the variability in winning a set.

Multivariate logistic regression

The logistic regression data (see Table 1) reveal that both, *SD 1ºP* and *SD 2ºP models* are significant predictors of winning a set ($p < .001$). The OR values of 1.429 and 1.545 indicate that each additional point increases the likelihood of winning the set by a factor of 1.429 and 1.545, respectively. Moreover, the R^2_N values (.427 for *SD 1ºP* and .631 for *SD 2ºP*) indicate that both models are relevant for predicting set victories, with the *SD 2ºP* explaining a greater variability (63.1%) in the outcomes.

The data showed that the *OL* variable is significant in both periods ($p < .001$), indicating a substantial influence. The *Gender* variable is relevant only in the second period (*SD 2ºP*), with an OR of 1.313. This suggests that male teams are 1.313 times more likely to win sets when starting with an advantage. However, the *Competition* and *CL* variables did not show a significant impact.

Markov chain analysis

Figure 1 illustrates the probabilities of winning or losing a set based on the various combinations of outcomes during each period of the set.

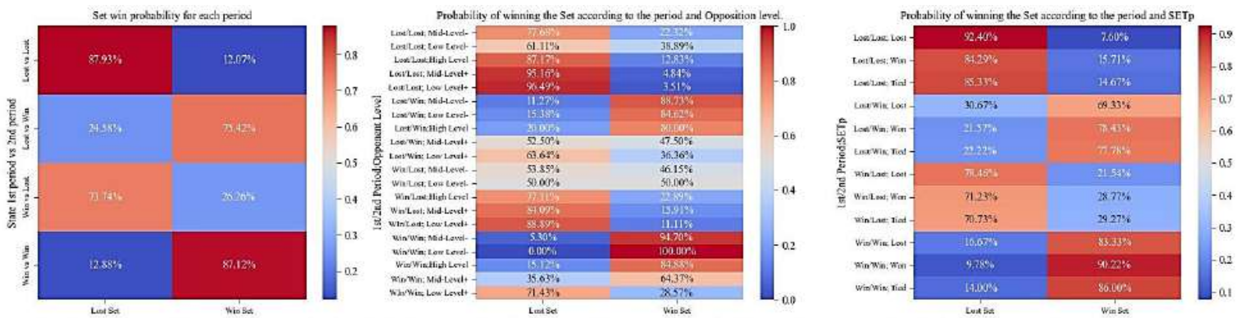
- State 'Lost vs Lost': 87.93% chance of losing the set and 12.07% chance of winning it.
- State 'Lost vs Win': 24.58% chance of losing the set and 75.42% chance of winning it.
- State 'Win vs Lost': 73.74% chance of losing the set and 26,26% chance of winning it.
- State 'Win vs Win': 12.88% chance of losing the set and 87.12% chance of winning it.

Figure 1, Graph 2, shows how the probabilities of winning a set change with the *OL* and *SETp* variables during the *1st period*.

- Victory achieved 100% probability by winning both periods of the set (Win/Win) against an opponent two levels lower (Low level-).
- Winning both periods (Win/Win) and against a lower level opponent (Mid-level-), gives a high probability of 94.70% of winning the set.
- Losing the first period, but winning the second (Lost/Win), against Mid-level- opponents, generates a winning probability of 88.73%, while against Low-level- opponents it is 84.62%.

In Graph 3 of Figure 1, the probabilities of winning a set are shown based on different values of the *OL* and *SETp* variables during the second period.

- The highest probability of losing a set (92.40%) is found when losing both periods of the set (Lost/Lost) and losing the previous set (*SETp*/Lost).
- The greatest probability of winning the set (90.22%) is given by winning both periods of the set (Win/Win) and the previous set (*SETp*/Won).



Note. Note. OL: Opposition level variable; SETp: Result previous set; Lost vs Lost: defeat in both periods of the set; Lost vs Win: defeat in the 1st period of the set and victory in the 2nd period; Win vs Win: victory in both periods of the set; Win vs Lost: victory in the 1st period of the set and defeat in the 2nd period; Low Level-:Opponent two levels lower; Mid-level-:Opponent one level lower; High level: Equal level opponent; Low level+:Opponent two levels higher; Mid-level+:Opponent one level higher; SETp-Lost: previous set lost; SETp-Tied: previous set won, SETp-Tied: no previous set.

Figure 1. Heat maps from the Markov chain transition matrix about the different states.

Table 2 displays the average OL and SETp for both set periods. Competing against higher-level opponents offers merely a 26.52% chance of winning a set, in contrast to a 65.68% probability when facing lower-level adversaries. Against opponents of an equal level (Equal), the chances of victory are balanced. In addition, winning the previous set increases the probability of victory to 53.28%, while losing it reduces it to 45.45%. Therefore, these results show that winning the previous set increases the probability of winning the current set by 7.83% compared to losing it.

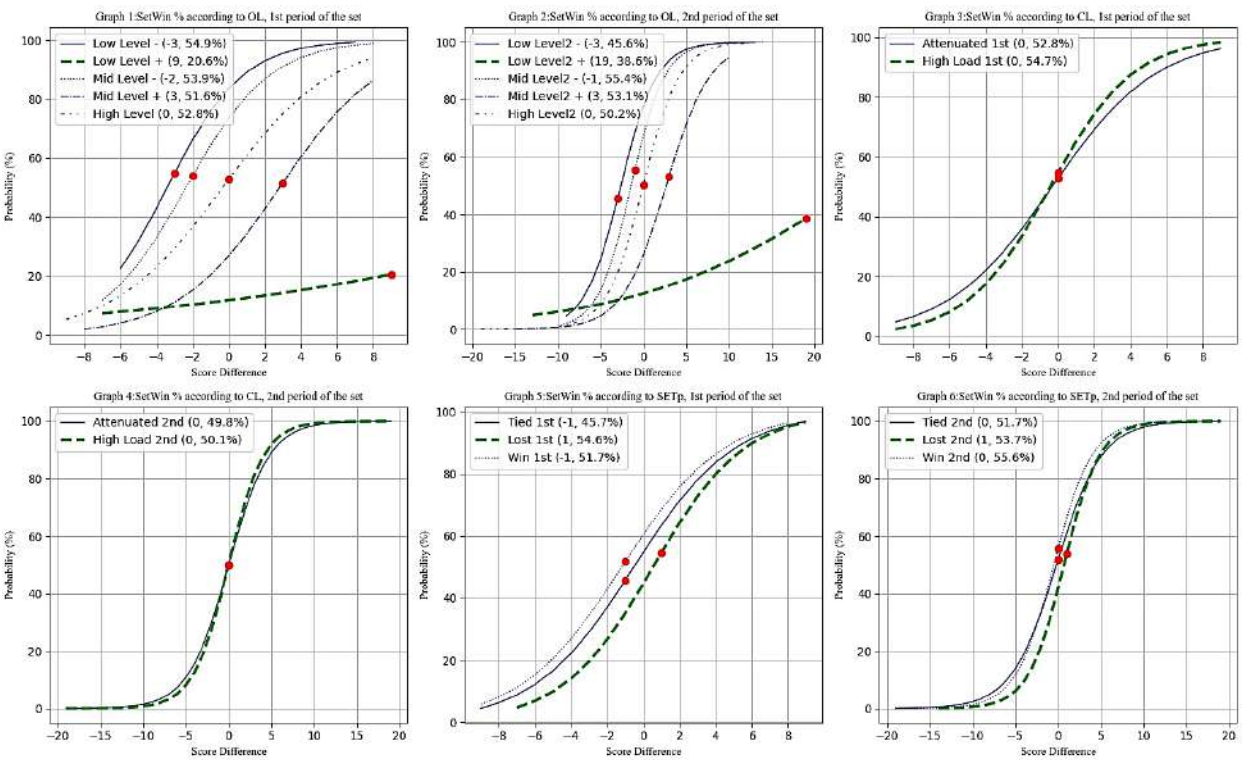
Table 2. Set win probability averages as a function of the outcome in each set period, OL and SETp.

Averages	Lost Set	Win Set
	Gathering by opponent level	
Low Level-	31.62%	68.38%
Mid-level-	37.02%	62.98%
High Level	49.85%	50.15%
Low Level+	80.11%	19.89%
Mid-level+	66.85%	33.15%
	Opponent level grouping	
Lower	34.32%	65.68%
Higher	73.48%	26.52%
Equal	49.85%	50.15%
	Gathering by SETp	
Lost	54.55%	45.45%
Won	46.72%	53.28%
Tied	48.07%	51.93%

Note. Lower - Includes Low Level- and Mid-Level ; Higher - Includes Low Level+ and Mid-Level+ ; Equal: Includes High Level.

Probability curves

In Figure 2, we complement the heat maps in Figure 1 with curves representing the evolution of the probabilities of winning the set as a function of the score differences in both periods, regarding *OL* level, *CL* and *SETp*. In addition, the values and slopes of these curves for all *score differences*, expressed as a percentage, are presented in Table 3.



Note. OL - Opposition Level; High level: same opposition level; Low level-:opponent two levels lower; Low level+; opponent two levels higher; Mid-level-: opponent one level lower; Mid-level+: opponent one level higher; CL: Competitive Load; Attenuated: Non-decisive sets; High Load - Decisive Sets - SETp - result of the previous sets; Tied - start 0-0 ; Lost - Lost previous set; Won - Won previous set.

Figure 2. Probability curves of how the probability of winning the set varies as a function of the differences in the score in the 1st and 2nd period of the set, opposition level, competitive load and SETp.

Below are the differences in the evolution of the variables across the two periods of the set:

- With regard to the *OL*, the curve indicating competition against significantly weaker opponents (*Low Level-*) shows a marked increase in the likelihood of winning the set based on the score difference. The most significant change in the inflexion points occurs at -3 points. Therefore, reducing the disadvantage to -2 would maximise our possibility of victory. Against weaker teams, starting the *1st period* with a -3 point disadvantage gives a 54.9% chance of winning. However, against *high-level* opponents, achieving a draw (0 points difference) on the scoreboard becomes crucial, maximising the chances of victory, which rise to 45.6% in the *2nd period*.
- During the second period, the curves have a greater slope around the inflexion points, indicating a stronger sensitivity to changes at this point difference. All curves show an inflexion point at a point difference of 0, either in non-decisive (*Attenuated*) or decisive (*High Load*) sets. Under high-load conditions, the likelihood of winning the set marginally increases compared to under attenuated load (52.8% vs. 54.7% in the first period). In short, breaks in the scoreboard maximise the probability of winning in *High Load*.

- Compared to the *SETp*, both curves show a steeper slope in the *2nd period* than in the *1st period*. The inflexion points indicate that a one-point lead in the first period, after losing the previous set, corresponds to a 54.6% probability of winning. This probability decreases to 53.7% in the *2nd period* (Lost 2nd . Holding a 0-point lead (Win 2nd - 0) shows a high 55.6% winning probability, indicating a greater chance of success in keeping the score balanced at the end of the set.

Table 3a. Victory probabilities and slopes by point difference (first period) and opponent level.

	1st set period											
Points	**DifP1ºP**		**Low Level -**		**Low Level +**		**Mid Level -**		**Mid Level +**		**High Level**	
	%	Slope	%	Slope	%	Slope	%	Slope	%	Slope	%	Slope
-19												
-18												
-17												
-16												
-15												
-14												
-13												
-12												
-11												
-10												
-9	3.78%										5.42%	
-8	5.41%	1.95							2.08%		7.39%	2.28
-7	7.68%	2.7			7.49%		11.83%		2.95%	1.04	9.99%	2.99
-6	10.80%	3.65	22.52%		8.01%	0.54	17.15%	6.18	4.15%	1.44	13.37%	3.85
-5	14.98%	4.8	31.90%	10.25	8.56%	0.57	24.20%	7.92	5.83%	1.98	17.68%	4.82
-4	20.41%	6.1	43.02%	11.5	9.15%	0.61	32.99%	9.48	8.11%	2.68	23.01%	5.84
-3	27.18%	7.39	54.89%	**11.61**	9.78%	0.64	43.16%	10.48	11.20%	3.57	29.36%	6.82
-2	35.19%	8.48	66.24%	10.54	10.44%	0.68	53.95%	**10.6**	15.25%	4.62	36.64%	7.61
-1	44.14%	9.15	75.97%	8.68	11.14%	0.72	64.37%	9.82	20.44%	5.79	44.58%	8.09
0	53.49%	**9.23**	83.60%	6.59	11.88%	0.76	73.59%	8.38	26.83%	6.96	52.81%	**8.15**
1	62.60%	8.7	89.15%	4.69	12.67%	0.81	81.12%	6.65	34.36%	7.97	60.89%	7.8
2	70.89%	7.7	92.98%	3.19	13.50%	0.85	86.89%	4.98	42.77%	8.63	68.42%	7.1
3	78.00%	6.43	95.52%	2.1	14.38%	0.9	91.09%	3.57	51.61%	**8.8**	75.08%	6.16
4	83.76%	5.12	97.18%	1.35	15.30%	0.95	94.04%	2.48	60.36%	8.44	80.74%	5.14
5	88.24%	3.93	98.23%	.86	16.27%	0.99	96.05%	1.68	68.49%	7.63	85.36%	4.14
6	91.61%	2.92	98.89%	.54	17.29%	1.04	97.40%	1.13	75.62%	6.55	89.03%	3.25
7	94.08%	2.12	99.31%		18.36%	1.09	98.30%	.74	81.58%	5.36	91.86%	2.49
8	95.86%	1.52			19.47%	**1.14**	98.89%		86.34%		94.01%	
9	97.12%				20.65%							
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												

Note. SD1ºP – Point difference between opponents in the 1st period; SD2ºP - Point difference between rivals in the 2nd period; Equal 1ºP– Point difference in 1st period between opponents of the same level; One Level 1ºP- Point differential in 1st period between opponents with one level of difference; Two Level 1ºP- Point differential in 1st period between rivals with two levels of difference; Equal 2ºP – Point differential in 2nd period between rivals of the same level; One Level 2ºP- Point difference in 2nd period between opponents with one level of difference; Two Level 2ºP- Point differential in 2nd period between opponents with two levels of difference.

Table 3b. Victory probabilities and slopes by point difference (second period) and opponent level.

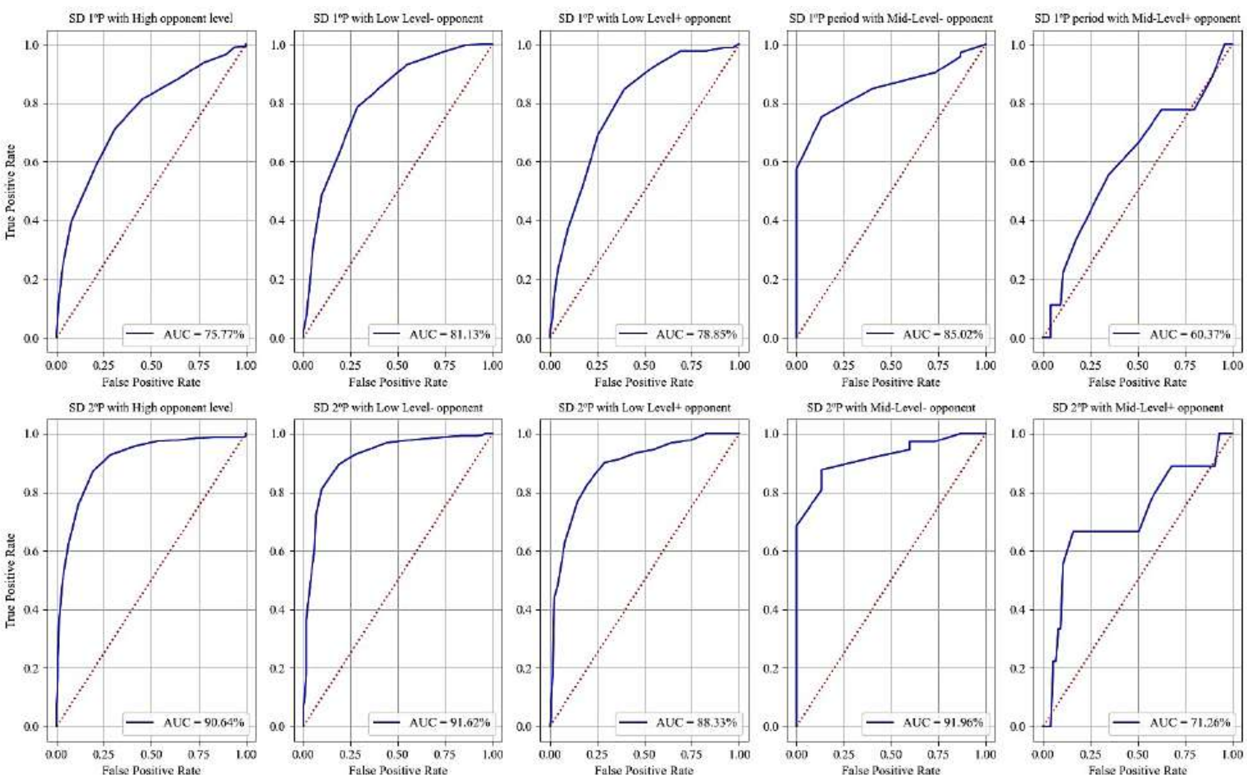
	2nd set period											
Points	**DifP2ºP**		**Low Level -**		**Low Level +**		**Mid Level -**		**Mid Level +**		**High Level**	
	%	Slope	%	Slope	%	Slope	%	Slope	%	Slope	%	Slope
-19	.02%	.01									.01%	.01
-18	.03%	.02									.02%	.01
-17	.05%	.02									.03%	.02
-16	.08%	.04									.05%	.03
-15	.13%	.06							.10%		.08%	.04
-14	.20%	.09							.14%	.06	.014%	.07
-13	.031%	.14			4.89%				.21%	.08	.022%	.11
-12	.049%	.22			5.27%	.39			.31%	.13	.35%	.17
-11	.075%	.34			5.68%	.42			.46%	.19	.56%	.27
-10	1.17%	.53			6.11%	.45	1.19%		.68%	.27	.89%	.43
-9	1.81%	.81	4.61%		6.57%	.48	1.97%	1.03	1.01%	.4	1.42%	.68
-8	2.79%	1.24	7.22%	3.25	7.07%	.51	3.25%	1.68	1.49%	.59	2.25%	1.07
-7	4.29%	1.86	11.12%	4.77	7.60%	.55	5.33%	2.68	2.18%	.86	3.56%	1.67
-6	6.52%	2.76	16.75%	6.67	8.17%	.59	8.61%	4.15	3.20%	1.24	5.59%	2.56
-5	9.81%	3.98	24.45%	8.74	8.78%	.63	13.63%	6.14	4.67%	1.78	8.68%	3.82
-4	14.49%	5.54	34.23%	10.56	9.42%	.67	20.90%	8.52	6.76%	2.51	13.23%	5.48
-3	20.89%	7.33	45.57%	**11.58**	10.11%	.71	30.67%	10.83	9.70%	3.48	19.64%	7.47
-2	29.15%	9.09	57.38%	11.42	10.84%	.76	42.56%	12.35	13.72%	4.68	28.16%	9.48
-1	39.06%	10.41	68.41%	10.16	11.62%	.8	55.37%	**12.47**	19.06%	6.07	38.61%	11.02
0	49.97%	**10.91**	77.70%	8.22	12.45%	.85	67.50%	11.15	25.85%	7.5	50.21%	**11.6**
1	60.88%	10.42	84.86%	6.16	13.33%	.9	77.67%	8.92	34.05%	8.74	61.80%	10.98
2	70.80%	9.1	90.01%	4.35	14.26%	.96	85.34%	6.52	43.33%	9.53	72.18%	9.41
3	79.07%	7.34	93.55%	2.94	15.24%	1.01	90.70%	4.44	53.10%	**9.66**	80.62%	7.39
4	85.48%	5.55	95.89%	1.93	16.28%	1.07	94.23%	2.89	62.64%	9.09	86.97%	5.42
5	90.17%	3.99	97.40%	1.24	17.37%	1.12	96.47%	1.82	71.29%	7.99	91.46%	3.76
6	93.46%	2.77	98.37%	.79	18.52%	1.18	97.86%	1.12	78.62%	6.6	94.50%	2.52
7	95.70%	1.87	98.98%	.5	19.73%	1.24	98.71%	.68	84.48%	5.17	96.50%	1.65
8	97.20%	1.24	99.36%	.31	21.00%	1.3	99.23%	.41	88.97%	3.89	97.79%	1.06
9	98.18%	.81	99.60%	.19	22.32%	1.36	99.54%	.25	92.27%	2.84	98.61%	.67
10	98.83%	.53	99.75%	.12	23.71%	1.41	99.72%	.15	94.65%		99.13%	.42
11	99.24%	.34	99.85%	.08	25.15%	1.47	99.83%	.09			99.45%	.27
12	99.51%	.22	99.90%	.05	26.65%	1.53	99.90%	.05			99.66%	
13	99.69%	.14	99.94%		28.21%	1.58	99.94%	.03				
14	99.80%	.09			29.82%	1.64	99.96%					
15	99.87%	.06			31.48%	1.69						
16	99.92%	.04			33.19%	1.73						
17	99.95%	.02			34.94%	1.78						
18	99.97%	.02			36.74%	1.82						
19	99.98%	.01			38.58%	**1.84**						

Note. SD1ºP – Point difference between opponents in the 1st period; SD2ºP - Point difference between rivals in the 2nd period; Equal 1ºP– Point difference in 1st period between opponents of the same level; One Level 1ºP- Point differential in 1st period between opponents with one level of difference; Two Level 1ºP- Point differential in 1st period between rivals with two levels of difference; Equal 2ºP – Point differential in 2nd period between rivals of the same level; One Level 2ºP- Point difference in 2nd period between opponents with one level of difference; Two Level 2ºP- Point differential in 2nd period between opponents with two levels of difference.

Effectiveness of models

The ROC curves in Figure 3 evaluate the predictive ability of winning a set, taking into consideration the score difference and the *OL* in the two periods of the set. The area under the curve (AUC), expressed as a percentage, assesses the model's ability to distinguish between wins and losses. The observed results indicate:

- Predictive ability improved significantly in the *2nd period*, reaching an AUC of 90.64%, compared to 75.77% in the first period, both with high-*OL*.
- Influence of the *OL* variable: The predictive ability significantly increases when competing against *low-level-* opponents, with an AUC of 81.13% and 91.62% in the *1st* and *2nd period*, respectively. However, this ability decreases against *mid-level+* opponents, with an AUC of 60.37% and 71.26%, and against *high-level* opponents, with an AUC of 75.77% and 90.64%.
- A significant reduction in probability is observed in the *1st period* when playing against higher-level opponents, from 90.64% to 75.77%.
- The lowest predictability is observed at (*mid-level+*; AUC = 60.37%) when the opponent is ahead in the *1st period*, leading to difficulty in predicting wins in such situations.



Note. AUC - Area under the ROC curve; SD 1°P - Score differences between the teams in the 1st set period; SD 2°P - Score differences between the teams in the 2nd set period.

Figure 3. ROC curves to evaluate predictive capacity for set victory in each period, according to opponent level.

DISCUSSION AND CONCLUSIONS

This study investigates the influence of competitive contextual variables, considered relevant by coaches, on winning sets and matches in high-level competitions.

The study showed that disparity in competitive levels significantly affects the probability of winning a set, especially when teams differ in two competitive levels, explaining 21.6% of the observed variability. A study using data from the European Men's Championship accurately classified set outcomes, won or lost, based on technical performance indicators in 91.1% of cases (Drikos et al., 2021). Several studies have indicated that higher-ranked teams in elite competitions tend to show superior performance in certain technical skills of the game. Thus, Ciemiński (2018) found that the top-ranked teams of both genders at the 2017 European Championships were more effective in serve, set, attack, and block; these outcomes were similar to those presented by Marcelino et al. (2010a) when analysing men's 2007 World Cup matches, reporting higher effectiveness in serve, attack, and block, while Drikos et al. (2021) reported a higher effectiveness of attack after reception and defence, and a higher success rate of break point complex at the 2019 European Men's Championships. Stutzig et al. (2015) found that in men's volleyball at the Olympic Games and in the World League, counterattacks were significantly more successful after defensive plays. This effect was amplified when attacks were carried out at medium and slow speeds. At the Women's Volleyball Club World Championship in 2016, it was observed that winning teams scored more from spikes, blocks, and serves, with fewer errors in reception and defence.

As regards tactical indicators, previous studies rejected the idea that the patterns of play among high-level teams influence their rankings and, consequently, their success in sets (Martins et al., 2021, 2022), while in a study of the Men's World Cup, it was found that teams adapted their tactics based on the level of their opponents (Marcelino et al., 2011).

Another variable that showed an association with set victory was winning the previous set. Although the effect size found was low, it increases the chances of winning the next set by 7.83% (53.28% vs 45.45%). This result does not match the independence between sets found by Marcelino et al. (2009) when analysing men's World League matches in 2005. Thus, based on the results presented in this article, a volleyball match could not be understood as a set of independent microcycles as other studies have suggested (García-de-Alcaraz et al., 2019; Marcelino et al., 2010b).

In relation to match status, winning the set periods established in this study significantly increased the likelihood of winning the set. The model indicates, via R^2_N, that the second period significantly influences the final outcome of the set (1st period R^2_N = 26.9%; 2nd period R^2_N = 54.2%). This phenomenon is often attributed in various sports to a possible psychological advantage, known as "*momentum*" (Den Hartigh & Gernigon, 2018), which seems to enhance the confidence and energy of the leading team (Morgulev et al., 2019). Winning both periods is associated with an 87.12% probability of winning the set. In addition, the level of the opponent influenced the probabilities of winning the set when an advantage was obtained in the periods; the model used showed a 100% probability of victory when a team faced an opponent two levels lower and finished the two established periods of the set with an advantage on the scoreboard.

On the other hand, the results show the relevance of recovery during matches: for instance, a team that rebounds from a loss in the first period and wins the second increases its chances of winning the entire set to 75.42%. Moreover, when the opponent was of a lower level, the likelihood of winning the set increased to 88.73%. In basketball, Martínez (2014) reported that winning the first quarter positively correlates with victory in NBA matches, though the teams' level had a more significant effect on the end result. However, in investigating Spanish men's professional basketball games, Sampaio et al. (2010) noted that teams with larger score deficits at the start of each quarter were more likely to regain points. In women's basketball, a similar effect seemed to occur, with the recovery of points being attributed to changes in the teams' intensity of play, although it was noted that a significant score disparity could lead to a decrease in the trailing team's level of performance (Gomez et al., 2013).

The results showed that larger point differences at the end of each set period, especially at the end of the second period of a set, significantly enhanced the likelihood of winning the set (R^2N *1st period* = 31.8%; R^2N

2nd period = 58.4%). Each additional point increased the likelihood of winning by 1.42% after the 1st period and by 1.54% after the 2nd period. The R^2N values showed higher indicators in both periods for the score difference variable than for the set period variable. This difference indicates that the score difference has greater discriminating power over the set victory. These results could be associated with the findings of Marcelino et al. (2012), who observed that players tended to take more risks at the beginning of a set, aiming to lead the score and widen their advantage quickly.

In conclusion, this research reveals that the variables *opposition level*, *result previous set*, and performance in the *1st* and *2nd period* of the set, together with the *score differences* in the *1st* and *2nd period*, showed an association with victory in volleyball sets. In contrast, *competition*, and the *round* and *competitive load* variables showed no relationship. These findings represent a significant advance in the understanding of the contextual variables associated with winning in high-level competitive sets. Additionally, this study supports the validity of the opinions of expert volleyball coaches on variables that obtained significance (López-Serrano et al., 2022).

A limitation of this research is that the impact of the studied variables on the performance of individual game actions has not been evaluated, which could represent a future area of research. It might be particularly interesting to examine how the variables of this study influence success in sets across training and elite categories.

AUTHOR CONTRIBUTIONS

Conceived investigation idea: López-Serrano, C. & Molina, J.J. Conceived and planned the observation: López-Serrano, C., Molina, J.J, Sánchez Morillas, P. & Hernández González, C. Performed the observation: Sánchez Morillas, P. & Hernández González, C. Interpretation of the results: López-Serrano, C., López, E. Wrote the manuscript: López-Serrano, C., López, E., Molina, J.J.

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REFERENCES

Araújo, C. R., Tosini, L., Freire, A. B., Costa, G. de C., & Meira, C. M. (2020). Reception-attack relation in men's and women's volleyball during the rio 2016 Olympics. Journal of Physical Education and Sport, 20(3), 2008-2012. https://doi.org/10.7752/jpes.2020.s3271

Bar-Eli, M., & Tractinsky, N. (2000). Criticality of game situations and decision making in basketball: An application of performance crisis perspective. Psychology of Sport and Exercise, 1(1), 27-39. https://doi.org/10.1016/S1469-0292(00)00005-4

Ciemiński, K. (2018). The efficiency of executing technical actions in volleyball and the teams' gender and sports level. Trends in Sport Sciences, 25(3), 159-165.

Den Hartigh, R. J., & Gernigon, C. (2018). Time-out! How psychological momentum builds up and breaks down in table tennis. Journal of Sports Sciences, 36(23), 2732-2737. https://doi.org/10.1080/02640414.2018.1477419

Drikos, S., Barzouka, K., Nikolaidou, M. E., & Sotiropoulos, K. (2021). Game variables that predict success and performance level in elite men's volleyball. International Journal of Performance Analysis in Sport, 21(5), 767-779. https://doi.org/10.1080/24748668.2021.1945879

Drikos, S., & Vagenas, G. (2011). Multivariate assessment of selected performance indicators in relation to the type and result of a typical set in men's elite volleyball. International Journal of Performance Analysis in Sport, 11(1), 85-95. https://doi.org/10.1080/24748668.2011.11868531

Fernández-Echeverria, C., Gil, A., García-González, L., Soares, F. C., Claver, F., & Del Villar, F. (2013). Employment time-out in volleyball formative stages. Journal of Human Sport and Exercise, 8(3), 591-600. https://doi.org/10.4100/jhse.2013.8.Proc3.04

Fernández-Echeverría, C., González-Silva, J., Castro, I. T., & Moreno, M. P. (2019). The timeout in sports: A study of its effect on volleyball. Frontiers in Psychology, 10(OCT), 1-7. https://doi.org/10.3389/fpsyg.2019.02437

Garciá-de-Alcaraz, A., Gómez-Ruano, M. A., & Papadopoulou, S. D. (2019). In Search for Volleyball Entertainment: Impact of New Game Rules on Score and Time-Related Variables. Journal of Human Kinetics, 70(1), 275-285. https://doi.org/10.2478/hukin-2019-0046

Garciá-De-Alcaraz, A., & Usero, L. (2019). Influence of Contextual Variables on Performance of the Libero Player in Top-Level Women's Volleyball. Journal of Human Kinetics, 70(3), 199-207. https://doi.org/10.2478/hukin-2019-0032

Giatsis, G., Drikos, S., & Lola, A. (2022). Analysis of match report indicators in men's volleyball olympics and world championships (2014-2021) depending on the type of final score. International Journal of Sports Science and Coaching. https://doi.org/10.1177/17479541221086779

Gomez, M. A. C., Ernesto, M., Carlos, L., & Jaime, S. (2013). Effects of Starting Quarter Score, Game Location, and Quality of Opposition in Quarter Score in Elite Women's Basketball. Kinesiology, 45(1), 48-54. Retrieved from [Accessed 2024, July 09]: https://www.academia.edu/80197081/Effects_of_Starting_Quarter_Score_Game_Location_and_Quality_of_Opposition_in_Quarter_Score_in_Elite_Women_s_Basketball

Hill, D. M., Hanton, S., Matthews, N., & Fleming, S. (2010). Choking in sport: A review. International Review of Sport and Exercise Psychology, 3(1), 24-39. https://doi.org/10.1080/17509840903301199

Lisi, F., Grigoletto, M., & Canesso, T. (2019). Winning tennis matches with fewer points or games than the opponent. Journal of Sports Analytics, 5(4), 313-324. https://doi.org/10.3233/JSA-190328

López-Serrano, C., Moreno, M. P., Mon-López, D., & Molina, J. J. (2022). In the Opinion of Elite Volleyball Coaches, How Do Contextual Variables Influence Individual Volleyball Performance in Competitions? Sports, 10(156), 1-16. https://doi.org/10.3390/sports

López, E., Gea-García, M. G., & Molina-Martín, J. J. (2023). Quantification of the competition load of the sets in high-level volleyball in the year 2021. Journal of Physical Education and Sport, 23(1), 134-142. https://doi.org/10.7752/jpes.2023.01017

Marcelino, R., Mesquita, I., Palao, J. M., & Sampaio, J. (2009). Home advantage in high-level volleyball varies according to set number. Journal of Sports Science and Medicine, 8(3), 352-356.

Marcelino, R., Mesquita, I., & Sampaio, J. (2010a). Efficacy of the Volleyball Game Actions Related to the Quality of Opposition. The Open Sports Sciences Journal, 3(1), 34-35. https://doi.org/10.2174/1875399X010030100034

Marcelino, R., Mesquita, I., & Sampaio, J. (2010b). Study of performance indicators in male volleyball according to the set number. Revista Brasileira de Educação Física e Esporte, 24(1), 69-78. https://doi.org/10.1590/S1807-55092010000100007

Marcelino, R., Mesquita, I., & Sampaio, J. (2011). Effects of quality of opposition and match status on technical and tactical performances in elite volleyball. Journal of Sports Sciences, 29(7), 733-741. https://doi.org/10.1080/02640414.2011.552516

Marcelino, R., Sampaio, J., & Mesquita, I. M. (2012). Attack and serve performances acording the match period and quality of opposition in elite volleyball matches. Journal of Strength and Conditioning Research, 26(12), 3385-3391. https://doi.org/10.1519/JSC.0b013e3182474269

Martínez, J. A. (2014). The influence of the first quarter on the final result in basketball. Revista Internacional De Medicina Y Ciencias De La Actividad Fisica Y Del Deporte, 14(56), 755-769.

Martins, J. B., Afonso, J., Mendes, A., Santos, L., & Mesquita, I. (2022). Inter-team variability in game play under critical game scenarios: A study in high-level men's volleyball using social network analysis. Retos. Nuevas Tendencias En Educación Física, Deporte y Recreación, 43(1), 1095-1105. https://doi.org/10.47197/retos.v43i0.90505

Martins, J. B., Mesquita, I., Mendes, A., Santos, L., & Afonso, J. (2021). Inter-team variability in high-level women's volleyball from the perspective of Social Network Analysis: an analysis in critical game scenarios. International Journal of Performance Analysis in Sport, 21(4), 564-578. https://doi.org/10.1080/24748668.2021.1924524

Morgulev, E., Azar, O. H., & Bar-Eli, M. (2019). Does a "comeback" create momentum in overtime? Journal Of Economic Psychology, 75(102126). https://doi.org/10.1016/j.joep.2018.11.005

Mulazimoglu, O., Ayfon, A. A., & Girgin, S. (2021). The effects of technical and tactical criterua on success in 2016 FIVB women's volleyball world club championship. International Journal of Life Science and Pharma Research, 14(1), 200-203.

Palao, J. M., Santos, J. A., & Ureña, A. (2004). Effect of team level on performance of skills in volleyball. International Journal of Performance Analysis in Sport, 4(2), 50-60. https://doi.org/10.1080/24748668.2004.11868304

Raab, M., Gula, B., & Gigerenzer, G. (2012). The hot hand exists in volleyball and is used for allocation decisions. Journal of Experimental Psychology: Applied, 18(1), 81-94. https://doi.org/10.1037/a0025951

Ramos, A., Coutinho, P., Silva, P., Davids, K., Guimarães, E., & Mesquita, I. (2017). Entropy measures reveal collective tactical behaviours in volleyball teams : how variability and regularity in game actions influence competitive rankings and match status. International Journal of Performance Analysis in Sport, 17(6), 848-862. https://doi.org/10.1080/24748668.2017.1405611

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

Sampaio, J., Lago, C., Casais, L., & Leite, N. (2010). Effects of starting score-line, game location, and quality of opposition in basketball quarter score. European Journal of Sport Science, 10(6), 391-396. https://doi.org/10.1080/17461391003699104

Sánchez-Moreno, J., Mesquita, I., Afonso, J., Millán-Sánchez, A., & Ureña, A. (2018). Effect of the rally length on performance according to the final action and the playing level in high-level men's volleyball. RICYDE: Revista Internacional de Ciencias Del Deporte, 14(52), 136-147. https://doi.org/10.5232/ricyde2018.05204

Stutzig, N., Zimmermann, B., Büsch, D., & Siebert, T. (2015). Analysis of game variables to predict scoring and performance levels in elite men's volleyball. International Journal of Performance Analysis in Sport, 15(3), 816-829. https://doi.org/10.1080/24748668.2015.11868833

Zetou, E., Kourtesis, T., Giazitzi, K., & Michalopoulou, M. (2008). Management and Content Analysis of Timeout during Volleyball Games. International Journal of Performance Analysis in Sport, 8(1), 44-55. https://doi.org/10.1080/24748668.2008.11868421

ORIGINAL ARTICLE

Change of health-related fitness with respect to age for adolescent boys

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ABSTRACT

Adolescence marks a crucial period for the establishment of physical health and fitness, shaping future adult health trajectories. This study aimed to investigate the changes in health-related fitness concerning age among adolescent boys. A sample of 80 students aged 13-16 from Upashahar Maddhamic Viddalay, Jashore, was selected at random to assess health-related fitness components including low back and hamstring flexibility, abdominal muscle strength endurance, upper-body strength (chin-ups), and body composition. Fitness was assessed by measuring the components of Health-Related Physical Fitness as prescribed by AAHPERD (1984). In addition to these fitness components the body composition of the subjects was assessed by measuring triceps and subscapular skin folds, all their parameters were the criteria for measurement in the present study. Statistical analyses, including mean values, standard deviation, and 't' tests (where table value at .05 levels for of 38 was 2.02), were conducted to determine significant differences across age groups. The results indicate that abdominal muscle strength endurance, as measured by sit-ups, showed significant differences at .05 level between age groups, with class VII and IX exhibiting higher mean values compared to class VIII and X. This suggests that factors such as academic pressure and lifestyle choices may impact physical fitness levels among adolescent boys. However, when considering upper-body strength, flexibility, and body fat percentage, the study did not find significant differences between age groups. This indicates that these aspects of health-related fitness may be less influenced by age alone and more by individual factors or environmental influences.

Keywords: Physical education, Adolescent boys, Health-related fitness, Flexibility, Muscle strength, Body composition.

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INTRODUCTION

Adolescence is a critical period in which physical health and fitness are established, laying the foundation for future patterns of adult health (Mitchell, 2019). During this stage of development, there are significant changes that occur in terms of biological and social factors, such as puberty and the attainment of social roles (Barendse & Pfeifer, 2021; Frank, 1945). These changes, along with various social determinants and risk and protective factors, can greatly impact the uptake of health-related behaviours among adolescent boys (Adelmann, 2005; Reingle et al., 2013). One important aspect of health during adolescence is health-related fitness. Health-related fitness refers to the overall physical well-being and ability of individuals to perform daily activities and tasks (Solera Sánchez, 2022). It encompasses various components, including cardiovascular endurance, muscular strength and endurance, flexibility, and body composition (Gopal, 2014). Understanding the changes in health-related fitness with respect to age is crucial for promoting and maintaining optimal health among adolescent boys (Maciulevičienė et al., 2018). There is a growing body of research that suggests that health-related fitness levels can vary significantly during adolescence (García-Hermoso, 2023). Regular physical exercise during adolescence has been associated with numerous health benefits including improved muscle and bone health, increased strength and endurance, reduced risk of chronic diseases such as overweight and diabetes, improved self-esteem and psychological well-being, and reduced stress, anxiety, and depression (Archer, 2014; Harold W. Kohl et al., 2013; Jančiauskas, 2018; Warburton, 2006; Wolf, 2001). Given the importance of physical fitness for adolescent boys, it becomes essential to understand how health-related fitness changes with respect to age in this population.

Multiple factors contribute to the changing landscape of health in adolescence. These factors include prenatal and early childhood development, the specific biological and social changes that occur during puberty, and social determinants and risk and protective factors that influence adolescents' health-related behaviours (Jimenez et al., 2023; Sawyer et al., 2012; Viner et al., 2017). The shape of adolescence is rapidly evolving, with the age of onset of puberty decreasing and the age at which mature social roles are achieved increasing (Viner et al., 2017). Previous studies have shown that there is a positive correlation between age and health-related fitness components, such as agility, speed, vertical jump, and broad jump (Binishi & Skenderi, 2024; Boby & Shara, 2023; Doğru, 2019; Emeljanovas et al., n.d.; Gisladottir et al., 2024).

A remarkable lack of research has been done on Bangladeshi children, whose cultural background may influence the relationship between age and fitness differently. Cultural norms may limit an individual's degree of fitness, for example, by placing a higher value on education than on physical activity. Examining the relationship between age and physical fitness could help shape policy in the field of education by assisting in the development of curriculum that support physical education while promoting learning. Development of health-related physical fitness is a natural consequence of the development of the physique in the process of growth and development (Utesch et al., 2018). The status of fitness depends on many factors like age, sex, nutrition, life style, participation in physical activities etc (Harold W. Kohl et al., 2013). Study of class VII to class X difference has become an important focus for the researcher from different fields. It is understood that in the life style, cultural pattern, food habit, living condition, attitude and many other aspects of human living there are difference between the classes (Jeong & Lee, 2021; Nemec, 2020). Same is the case for physical fitness and physique for schoolboys from class VII- X. The only difference is their age and lifestyle. In our country the school has to face two board exams in the class of VIII & X. It may put an impact in their body composition also. The food habit and health related fitness is different from one class from other. Thus the present study was planned to analyse the change of health-related fitness with respect to age for adolescent boys of Bangladesh.

METHODOLOGY

Present study was conducted to know the status of Health Related Physical Fitness of Adolescent boys. A total of 80 students within the age group of 13-16 years were selected as subjects for the present study where 20 of them were from class VII, 20 from class VIII, 20 from IX and 20 from X selected from Upashahar Maddhamic Viddalay, Jashore. Fitness was assessed by measuring the components of Health-Related Physical Fitness as prescribed by AAHPERD (1984). The measured fitness components were, low back and hamstring flexibility (measured by sit and reach test), abdominal muscle strength endurance (measured by bent knee sit ups test for one min) in addition to these fitness components the body composition of the subjects was assessed by measuring triceps and subscapular skin folds, all their parameters were the criteria for measurement in the present study. Before conducting the tests, subjects were assembled in a room and took consent of the subjects. The purpose of the tests were explained and told to exert as best as possible in the tests for achieving their best performance. For collecting data, the tests were conducted in the following order. At first the skin folds for different sites of the body were measured. Thereafter the subjects were tested for low back and hamstring flexibility by sit and reach test. Then the subjects were tested for abdominal muscle strength endurance by Bent knee sit ups test.

Statistical analysis

For statistical analysis, mean, standard deviation (SD), and 't' test were calculated by the below mention formulae:

$\bar{X} = \frac{\sum X}{N}$ (Where, $\bar{X}$denotes the mean, "$\sum X$" denote the sum total of scores and N denotes the number of scores)

S.D $(o) = \sqrt{\frac{(X-\bar{X})^2}{N}}$ (where o denotes the standard deviation, $\sum(X-\bar{X})^2$denote the total of square of the deviation and N denotes the number of scores)

't' test (t)= $\frac{\bar{X}1-\bar{X}2}{d\sqrt{[(01)/N1+(02)^2/N2]x}}$

RESULTS

The Mean Values and SD of sit ups, chin up, sit and reach and body fat % are given in the Table 1.

Table 1. Mean values of sit ups, chin-up, sit and reach and body fat %.

Class	Sit Ups	Chin ups	Sit and reach	Body fat %
VII	29.45 ± 3.904	3.4 ± 1.392	6.65 ± 6.234	12.856 ± 3.934
VIII	24.45 ± 5.97	3.45 ± 2.290	6.5 ± 4.60	15.046 ± 5.923
IX	30.55 ± 6.806	4.6 ± 2.177	8.7 ± 5.588	15.749 ± 5.694
X	27 ± 5.932	5.8 ± 3.627	29.45 ± 7.083	16.092 ± 5.399

It is seen from the Table 1, both the groups were within the age group of 13-16 years. Further, it is seen that the mean sit ups of class VII is 29.45 and SD is ±3.904. For class VIII the Mean of sit ups is 24.45 and SD is

±5.97. For class IX the Mean of sit up is 30.56 and SD is ±6.806 and for class X the mean is 27 and SD is ±5.932.

The mean values of chin up of class VII, VIII, IX and X are 3.40, 3.45, 4.6 and 5.9 and the SD are ±1.392, ±2.290, ±2.177 and ±3.627. The mean values of sit and reach of class VII, VIII, IX and X are 6.65, 6.5, 8.7 and 5.375. The SD of sit and reach of class VII, VIII, IX and X are ±6.234, ±4.60, ±5.588 and ± 7.83.

The mean values of body fat % of class VII, VIII, IX and X are 12.856, 15.046, 15.749 and 16. 092. The SD of The SD body fat of class VII, VIII, and X are ±3.934, ±5.923, ±5.694 and ±5.399. It is noted that, the boys from class VII and IX has greater mean value then class VIII and maybe it is because of the board exam or something else. Or the eating habit may be a cause. The formula to measuring % body fat is 1.35(sum of 2 SK)-.012(sum of 2 SK) 2-4.4.

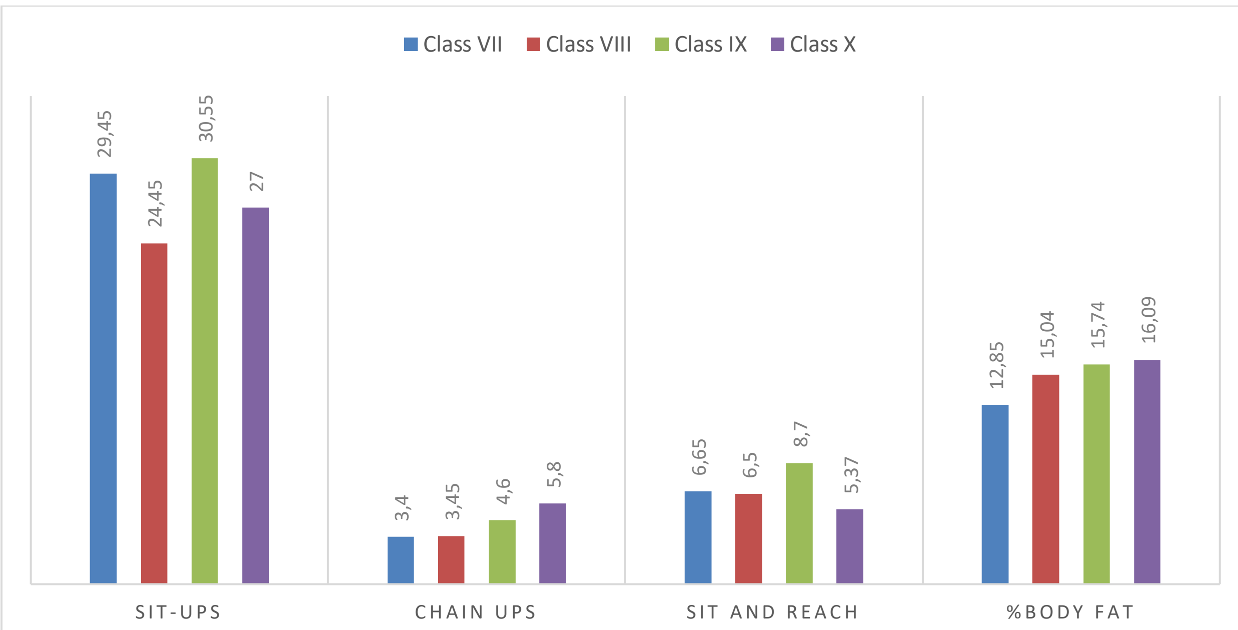

Figure 1. The bar graph on Mean values of sit ups, chin-up, sit and reach and body fat %.

Table 2. Testing statistical significance of mean difference in sit-ups.

Mean value				Mean Difference	Degrees of freedom	"*t*"	Remark
VII	VIII	IX	X		N1+N2-2		
29.45	24.45			5	38	3.134	Significant
	24.45	30.55		-6.1	38	3.038	Significant
		30.55	27	3.55	38	1.759	Not Significant

Note. Table value at .05 levels for df 38 is 2.02.

It is noted that, the boys from class VII and IX has greater mean value then class VIII and X. Maybe it is because of the board exam or something else. In class VIII and X the parent's and the students give much importance to education then playing games and sports. And the boys from class VII and IX gets much playing time then class VIII and X. But the 't' value (Table 2) indicates that the mean difference in abdominal strength endurance between the groups was statistically significant at .05 level except for IX and X.

Next component for Health-related Physical fitness was chin-up (upper-body strength). The mean values and corresponding's' value have been presented in Table 3.

Table 3. Testing statistical significance of mean difference in chin-up.

Mean value				Mean Difference	Degrees of freedom	"*t*"	Remark
VII	VIII	IX	X		N1+N2-2		
3.40	3.45			-0.05	38	0.0836	Not Significant
	3.45	4.6		-1.15	38	1.628	Not Significant
		4.6	5.8	-0.12	38	1.269	Not Significant

Note. Table value at .05 levels for df 38 is 2.02.

It is noted that, the boys from class VII and IX has greater mean value then class VIII and X. Maybe it is because of the board exam or something else. In class VIII and X, the parent's and the students give much importance to education then playing games and sports and physical exercise. And the boys from class VII and IX gets much playing time then class VIII and X. But the 't' value (Table 4) indicates that the mean difference in upper-body strength between the groups was statistically not significant at .05 level.

Next component for Health-related Physical fitness was sat and reach. The mean values and corresponding's' value have been presented in Table 4.

Table 4. Testing statistical significance of mean difference in sit and reach.

Mean value				Mean Difference	Degrees of freedom	"*t*"	Remark
VII	VIII	IX	X		N1+N2-2		
6.65	6.5			0.15	38	0.086	Not Significant
	6.5	8.7		-2.2	38	1.359	Not Significant
		8.7	5.375	3.325	38	1.648	Not Significant

Note. Table value at .05 levels for df 38 is 2.02.

It is noted that, the boys from class VII and IX has greater mean value then class VIII and X in sit and reach test. Maybe it is because of the board exam or something else. In class VIII and X, the parent's and the students give much importance to education then playing games and sports. And the boys from class VII and IX gets much playing time then class VIII and X. But the 't' value (Table 4) indicates that the mean difference in Low-back and hamstring flexibility between the groups was statistically not significant at .05 level.
Next component for Health-related Physical fitness was % body fat. The mean values and corresponding's' value have been presented in Table 5.

Table 5. Testing statistical significance of Mean Difference in body fat %.

Mean value				Mean Difference	Degrees of freedom	"*t*"	Remark
VII	VIII	IX	X		N1+N2-2		
12.856	15.046			-2.19	38	1.378	Not Significant
	15.046	15.749		-0.703	38	0.382	Not Significant
		15.749	16.092	-0.343	38	0.195	Not Significant

Note. Table value at .05 levels for df 38 is 2.02.

It is noted that, the boys from class VII and IX has greater mean value then class VIII and X. Maybe it is because of the board exam or something else. In class VIII and X, the parent's and the students give much importance to education then playing games and sports and physical exercise. And the boys from class VII and IX gets much playing time then class VIII and X. But the 't' value indicates that the mean difference in body fat % between the groups was statistically not significant at .05 level.

DISCUSSION

This study offers critical insights into the patterns of health-related fitness of adolescent boys. The research revealed variations in physically fitness components between age groups. These results may be informative regarding the influence of age on the components of health-related fitness critical to this demographic.

The results of the study show that the differences in abdominal muscle strength endurance were significant between several age groups. The most noticeable discrepancies were between class VII to VIII, and VIII to IX. These results indicate that adolescent boys undergo distinguishable changes in abdominal muscle strength endurance as they pass through different stages of adolescence. Academic pressure, varying lifestyle changes, and social influence could be responsible for some of these variations. It is, however, worthwhile to note that the class IX had the highest mean values of sit-ups. Adolescents at this stage may have more abdominal muscle strength endurance when compared to their counterparts at other stages. Comparing these findings with existing literature reveals both similarities and differences with previous research conducted in diverse cultural and geographic settings. Similar to studies conducted in other countries, this research identified significant differences in abdominal muscle strength endurance between certain age groups, indicating potential variations in physical fitness levels as adolescents' progress through adolescence (Dotsenko & Minniakhmetov, 2022; Hafsteinsson Östenberg et al., 2022; Nimkar et al., 2020; Vitali et al., 2019).

Moreover, the differences between these age groups were not statistically significant. These factors may not significantly affect the upper body and chin-up strength in all stages of this developmental period across age groups. Some variations in the average values have also been recorded across age groups, with none of them showing a significant statistical difference. It is necessary to conduct more research to determine the factors influencing the patterns in upper-body strength in teenage boys. However, the lack of significant differences in upper-body strength across age groups aligns with findings from some studies that suggest upper-body strength may not vary significantly during adolescence (Ervin et al., 2014; Guimarães et al., 2021; Skattebo et al., 2016; Tingelstad et al., 2023).

As with the upper-body strength, we did not identify any statistical significance surrounding the variations in low back and hamstring flexibility. Specifically, the sit-and-reach test indicated no meaningful differences across the youth culture. This means that levels of flexibility may be quite constant during the adolescent period in boys irrespective of the specific age. However, mean values showed some degree of variation across the age groups. Although the groups exhibited different mean values, these could not be confirmed as statistically significant. As such, additional moderation is required to find out precisely what affects the flexibility among adolescent boys. In terms of flexibility, the current study's findings of no significant differences between age groups contrast with some previous research indicating age-related improvements in flexibility during adolescence (Ávalos-Ramos et al., 2023; Rangul et al., 2011; Shao & Zhou, 2023; Shokrvash et al., 2013; Van Sluijs et al., 2021). This disparity may be attributed to cultural differences in physical activity habits, lifestyle factors, or methodological variations in assessing flexibility.

The results also showed that there were no statistically significant variations in body fat percentage among the various age groups. This indicates that among adolescent boys in Bangladesh, age may not have a significant impact on variances in body fat percentage. It is important to note, however, that although there was a minor variation in mean values between age groups, this difference was not statistically significant. To more precisely identify the variables influencing differences in body fat percentage among teenage boys, more research may be required. The absence of significant differences in body fat percentage across age groups in this study is consistent with findings from certain research, suggesting that body fat percentage may remain relatively stable during adolescence in some populations (De Pádua Cintra et al., 2013; Gemelli et al., 2020). However, contrasting findings from other studies have reported age-related changes in body composition, indicating potential cultural and contextual influences on body fat distribution and metabolism (Kim et al., 2013; Trang et al., 2019).

Understanding the changes in health-related fitness with respect to age among adolescent boys is crucial for developing targeted interventions and promoting optimal health outcomes. The findings of this study provide valuable insights into the physical fitness patterns among adolescent boys in Bangladesh. However, further research is needed to explore the complex interplay of factors influencing health-related fitness during adolescence, including socio-cultural influences, lifestyle behaviours, and environmental factors.

Additionally, future studies could benefit from larger sample sizes and longitudinal designs to examine the trajectory of health-related fitness across different stages of adolescence more comprehensively. Moreover, qualitative research methods such as interviews or focus groups could help elucidate the underlying factors shaping health-related fitness behaviours and outcomes among adolescent boys. By addressing these research gaps, policymakers, educators, and healthcare professionals can develop targeted interventions to promote physical activity, healthy lifestyles, and overall well-being among adolescent boys in Bangladesh and beyond.

CONCLUSION

In conclusion, our study aimed to analyse the changes in health-related fitness with respect to age among adolescent boys. We found that there are significant variations in certain components of health-related fitness across different age groups, while others remain relatively consistent. Our findings indicate that abdominal muscle strength endurance, as measured by sit-ups, showed significant differences between age groups, with class VII and IX exhibiting higher mean values compared to class VIII and X. This suggests that factors such as academic pressure and lifestyle choices may impact physical fitness levels among adolescent boys. However, when considering upper-body strength, flexibility, and body fat percentage, our study did not find significant differences between age groups. This indicates that these aspects of health-related fitness may be less influenced by age alone and more by individual factors or environmental influences.

AUTHOR CONTRIBUTIONS

The authors contributed to the study as follows: Asif Iqbal contributed to study design, data collection, statistical analysis, and funds collection. Farjana Akter Boby was involved in study design, data collection, statistical analysis, manuscript preparation, and funds collection. Dr. Mohammad Sohel participated in statistical analysis, manuscript preparation, and funds collection. Hannan Mia was responsible for manuscript preparation, and funds collection.

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No potential conflict of interest was reported by the authors.

REFERENCES

Adelmann, P. K. (2005). Social environmental factors and preteen health-related behaviors. Journal of Adolescent Health, 36(1), 36-47. https://doi.org/10.1016/j.jadohealth.2003.07.027

Archer, T. (2014). Health Benefits of Physical Exercise for Children and Adolescents. Journal of Novel Physiotherapies, 04(02). https://doi.org/10.4172/2165-7025.1000203

Ávalos-Ramos, M. A., Pascual-Galiano, M. T., Vidaci, A., & Vega-Ramírez, L. (2023). Future Intentions of Adolescents towards Physical Activity, Sports, and Leisure Practices. Healthcare, 12(1), 66. https://doi.org/10.3390/healthcare12010066

Barendse, M. E. A., & Pfeifer, J. H. (2021). Puberty and social brain development. In K. Cohen Kadosh (Ed.), The Oxford Handbook of Developmental Cognitive Neuroscience. Oxford University Press. https://doi.org/10.1093/oxfordhb/9780198827474.013.25

Binishi, N., & Skenderi, D. (2024). Assessment of speed & agility components for 10-14 years old: A review. Scientific Journal of Sport and Performance, 3(3), 357-369. https://doi.org/10.55860/JPNU7042

Boby, F. A., & Shara, S. S. (2023). Navigating Childhood Health: Unraveling the Tapestry of Anthropometric Indicators and Musculoskeletal Fitness in Elementary School Boys. International Journal of Kinanthropometry, 3(2), 9-16. https://doi.org/10.34256/ijk2332

De Pádua Cintra, I., De Moraes Ferrari, G. L., De Sousa Vieira Soares, A. C., Passos, M. A. Z., Fisberg, M., & De Souza Vitalle, M. S. (2013). Body fat percentiles of Brazilian adolescents according to age and sexual maturation: A cross-sectional study. BMC Pediatrics, 13(1), 96. https://doi.org/10.1186/1471-2431-13-96

Doğru, Y. (2019). Comparison of Agility, Vertical Jump and Speed Parameters in Children Between 6-12 Years. Turkish Journal of Sport and Exercise, 355-359. https://doi.org/10.15314/tsed.528573

Dotsenko, E. A., & Minniakhmetov, I. S. (2022). Age changes in static endurance and strength of different muscle groups in pupils. Russian Electronic Scientific Journal, 1, 131-144. https://doi.org/10.31563/2308-9644-2022-43-1-131-144

Emeljanovas, A., Valantine, I., Zaicenkoviene, K., Misigoj-Durakovic, M., Kreivyte, R., & Gómez-Ruano, M.-Á. (n.d.). Associations between physical activity and health-related physical.

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

Frank, L. K. (1945). Physical Fitness and Health Problems of the Adolescent: Physiological and Emotional Problems of Adolescence. American Journal of Public Health and the Nations Health, 35(6), 575-578. https://doi.org/10.2105/AJPH.35.6.575

García-Hermoso, A. (2023). Health-Related Fitness During Early Years, Childhood, and Adolescence. In J. L. Matson (Ed.), Handbook of Clinical Child Psychology (pp. 763-788). Springer International Publishing. https://doi.org/10.1007/978-3-031-24926-6_35

Gemelli, I. F. B., Farias, E. D. S., & Spritzer, P. M. (2020). Association of body composition and age at menarche in girls and adolescents in the Brazilian Legal Amazon. Jornal de Pediatria, 96(2), 240-246. https://doi.org/10.1016/j.jped.2018.10.012

Gisladottir, T., Petrović, M., Sinković, F., & Novak, D. (2024). The relationship between agility, linear sprinting, and vertical jumping performance in U-14 and professional senior team sports players. Frontiers in Sports and Active Living, 6, 1385721. https://doi.org/10.3389/fspor.2024.1385721

Gopal, C. S. (2014). Assessment of health related physical fitness, socio economic status and psychomotor ability of tribal school going children of west Bengal. Journal Biology of Exercise, 41-51. https://doi.org/10.4127/jbe.2014.0072

Guimarães, E., Maia, J. A. R., Williams, M., Sousa, F., Santos, E., Tavares, F., Janeira, M. A., & Baxter-Jones, A. D. G. (2021). Muscular Strength Spurts in Adolescent Male Basketball Players: The INEX Study. International Journal of Environmental Research and Public Health, 18(2), 776. https://doi.org/10.3390/ijerph18020776

Hafsteinsson Östenberg, A., Enberg, A., Pojskic, H., Gilic, B., Sekulic, D., & Alricsson, M. (2022). Association between Physical Fitness, Physical Activity Level and Sense of Coherence in Swedish Adolescents; An Analysis of Age and Sex Differences. International Journal of Environmental Research and Public Health, 19(19), 12841. https://doi.org/10.3390/ijerph191912841

Harold W. Kohl, I. I. I., Cook, H. D., Environment, C. on P. A. and P. E. in the S., Board, F. and N., & Medicine, I. of. (2013). Physical Activity and Physical Education: Relationship to Growth, Development, and Health. In Educating the Student Body: Taking Physical Activity and Physical Education to School. National Academies Press (US).

Jančiauskas, R. (2018). Characteristics of Young Learners' Psychological Well-Being and Self-Esteem in Physical Education Lessons. Baltic Journal of Sport and Health Sciences, 2(85). https://doi.org/10.33607/bjshs.v2i85.279

Jeong, S., & Lee, J. (2021). Effects of cultural background on consumer perception and acceptability of foods and drinks: A review of latest cross-cultural studies. Current Opinion in Food Science, 42, 248-256. https://doi.org/10.1016/j.cofs.2021.07.004

Jimenez, A. L., Banaag, C. G., Arcenas, A. M. A., & Hugo, L. V. (2023). Adolescent Development. In A. Tasman, M. B. Riba, R. D. Alarcón, C. A. Alfonso, S. Kanba, D. M. Ndetei, C. H. Ng, T. G. Schulze, & D. Lecic-Tosevski (Eds.), Tasman's Psychiatry (pp. 1-43). Springer International Publishing. https://doi.org/10.1007/978-3-030-42825-9_106-1

Kim, K., Yun, S. H., Jang, M. J., & Oh, K. W. (2013). Body Fat Percentile Curves for Korean Children and Adolescents: A Data from the Korea National Health and Nutrition Examination Survey. Journal of Korean Medical Science, 28(3), 443. https://doi.org/10.3346/jkms.2013.28.3.443

Maciulevičienė, E., Sadzevičienė, R., & Rutkauskaitė, R. (2018). Objectively Measured Weekly Physical Activity among Adolescent Boys and its Relation to Health-Related Physical Fitness. Baltic Journal of Sport and Health Sciences, 4(91). https://doi.org/10.33607/bjshs.v4i91.175

Mitchell, J. A. (2019). Physical inactivity in childhood from preschool to adolescence. ACSM'S Health & Fitness Journal, 23(5), 21-25. https://doi.org/10.1249/FIT.0000000000000507

Nemec, K. (2020). Cultural Awareness of Eating Patterns in the Health Care Setting. Clinical Liver Disease, 16(5), 204-207. https://doi.org/10.1002/cld.1019

Nimkar, N., Bera, T. K., Bagchi, A., & Narnolia, R. (2020). Abdominal Muscular Strength Endurance: Normative Reference Values for Children 11 to 15 Years of Age. Indian Journal of Public Health Research & Development, 11(2), 692. https://doi.org/10.37506/v11/i2/2020/ijphrd/194889

Rangul, V., Holmen, T. L., Bauman, A., Bratberg, G. H., Kurtze, N., & Midthjell, K. (2011). Factors Predicting Changes in Physical Activity Through Adolescence: The Young-HUNT Study, Norway. Journal of Adolescent Health, 48(6), 616-624. https://doi.org/10.1016/j.jadohealth.2010.09.013

Reingle, J. M., Jennings, W. G., Lynne-Landsman, S. D., Cottler, L. B., & Maldonado-Molina, M. M. (2013). Toward an Understanding of Risk and Protective Factors for Violence Among Adolescent Boys and Men: A Longitudinal Analysis. Journal of Adolescent Health, 52(4), 493-498. https://doi.org/10.1016/j.jadohealth.2012.08.006
Sawyer, S. M., Afifi, R. A., Bearinger, L. H., Blakemore, S.-J., Dick, B., Ezeh, A. C., & Patton, G. C. (2012). Adolescence: A foundation for future health. The Lancet, 379(9826), 1630-1640. https://doi.org/10.1016/S0140-6736(12)60072-5
Shao, T., & Zhou, X. (2023). Correlates of physical activity habits in adolescents: A systematic review. Frontiers in Physiology, 14, 1131195. https://doi.org/10.3389/fphys.2023.1131195
Shokrvash, B., Majlessi, F., Montazeri, A., Nedjat, S., Rahimi, A., Djazayeri, A., & Shojaeezadeh, D. (2013). Correlates of physical activity in adolescence: A study from a developing country. Global Health Action, 6(1), 20327. https://doi.org/10.3402/gha.v6i0.20327
Skattebo, Ø., Hallén, J., Rønnestad, B. R., & Losnegard, T. (2016). Upper body heavy strength training does not affect performance in junior female cross-country skiers. Scandinavian Journal of Medicine & Science in Sports, 26(9), 1007-1016. https://doi.org/10.1111/sms.12517
Solera Sánchez, A. (2022). Health-related behaviors, physical fitness, and health-related quality of life in children and adolescents [PhD, Universitat Jaume I]. https://doi.org/10.6035/14112.2022.806228
Tingelstad, L. M., Raastad, T., Till, K., & Luteberget, L. S. (2023). The development of physical characteristics in adolescent team sport athletes: A systematic review. PLOS ONE, 18(12), e0296181. https://doi.org/10.1371/journal.pone.0296181
Trang, L. T., Trung, N. N., Chu, D.-T., & Hanh, N. T. H. (2019). Percentage Body Fat is As a Good Indicator for Determining Adolescents Who Are Overweight or Obese: A Cross-Sectional Study in Vietnam. Osong Public Health and Research Perspectives, 10(2), 108-114. https://doi.org/10.24171/j.phrp.2019.10.2.10
Utesch, T., Dreiskämper, D., Strauss, B., & Naul, R. (2018). The development of the physical fitness construct across childhood. Scandinavian Journal of Medicine & Science in Sports, 28(1), 212-219. https://doi.org/10.1111/sms.12889
Van Sluijs, E. M. F., Ekelund, U., Crochemore-Silva, I., Guthold, R., Ha, A., Lubans, D., Oyeyemi, A. L., Ding, D., & Katzmarzyk, P. T. (2021). Physical activity behaviours in adolescence: Current evidence and opportunities for intervention. The Lancet, 398(10298), 429-442. https://doi.org/10.1016/S0140-6736(21)01259-9
Viner, R. M., Allen, N. B., & Patton, G. C. (2017). Puberty, Developmental Processes, and Health Interventions. In D. A. P. Bundy, N. de Silva, S. Horton, D. T. Jamison, & G. C. Patton (Eds.), Child and Adolescent Health and Development (3rd ed.). The International Bank for Reconstruction and Development / The World Bank. https://doi.org/10.1596/978-1-4648-0423-6_ch9
Vitali, F., Robazza, C., Bortoli, L., Bertinato, L., Schena, F., & Lanza, M. (2019). Enhancing fitness, enjoyment, and physical self-efficacy in primary school children: A DEDIPAC naturalistic study. PeerJ, 7, e6436. https://doi.org/10.7717/peerj.6436
Warburton, D. E. R. (2006). Health benefits of physical activity: The evidence. Canadian Medical Association Journal, 174(6), 801-809. https://doi.org/10.1503/cmaj.051351
Wolf, T. (2001). To Your Health: Achieving Well-Being during Medical School. SAGE Publications, Inc. https://doi.org/10.4135/9781452232744

ORIGINAL ARTICLE

A comparative study on attitude towards physical education program between urban and rural higher secondary girls

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ABSTRACT

Physical education is the fundamental aspects of human life, which is included games and sports, physical fitness. The study has shown the importance of physical education and their implication in schools. It has also discussed about the National Education policy on physical education. This study based on Higher secondary girls' students' attitude towards physical education program between Urban and Rural areas from selected three districts of Tripura i.e. North district, Sepahijala district and Unakoti District. The researcher has been selected 140 higher secondary girls students in random basis for the study as a subject and 70/70 girls in urban and rural higher secondary. The data has been collected with Opinionnaire by Raut's Attitude Opinionnaire (2007) towards physical education program and the responses were employed by Likert scale method. For analysing the data and 't' test was used. It has found out that the girls' students of Urban areas have more positive attitude towards physical education program than the rural girls and there was significant difference between urban and rural girls of selected districts of Tripura. The study has found the low attitude on rural girls' than the urban.

Keywords: Physical education, Physical fitness, Physical activity, Games and sports, National education policy.

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INTRODUCTION

Teaching should not be based only on improving or expanding the use of textual materials, visual aids, and technology tools and apparatus. During this phase, pupils engage in cognitive, interpersonal, and physical activities. However, because they directly and indirectly affect students' social, mental, emotional, and physical development, sports and physical education are highly valued within the context of educational activities. Given that the core values of athletics are perseverance in the face of adversity and an unwavering desire for achievement.

Since physical activity is essential to human survival, physical education has existed for the same amount of time as people. Regardless of whether it is organised or not, physical education has always been an essential part of human life, dating back to prehistoric times.

Physical education is widely recognised as an essential element of education. Fundamentally, humanity is a physical species. One of the earliest lessons given to a human child is physical education. No education, no matter how flawless and aspirational its objectives, is complete if motor exercise is not prioritised. The human body is a precious gift from nature. Much of its development, growth, and efficiency are determined by its ability to engage in both high-quality and high-volume motor activity.

According to C.I Brownell, "*Physical education is the accumulation of wholesome experience through participation in large muscle activities that promote optimum growth and development*" (Singh, et al., 2003).

There has been a link between physical activity and longevity since prehistoric times. Since a multitude of coexisting factors influence physical activity, this topic has attracted the attention of many scholars. Even though young people are the most active group, there have been questions about how much they actually exercise. A review of studies on children's and adolescents' participation in physical activity conducted globally reveals that girls are less active than boys and that at least 50% of kids and teenagers do not engage in enough physical activity for their health. In spite of differences in measurement and methods, as well as a notable decline during the adolescent years, these results are robust and appear to be true worldwide (Mutrie and Biddle 2008).

Children's dispositions towards various courses in the educational curriculum are bound to change with time, impacting their physical and cognitive development.

Within the educational system, physical education has a significant role, as outlined in the National Policy on Education (1986). The government plans to build sports facilities that support sports practice in order to encourage physical exercise among pupils. The policy additionally attempts to include studies pertaining to sports in the curriculum. Hiring coaches and sports instructors is another option being explored in order to provide specialised care and improve chances going forward. The user's material cannot be rewritten in an academic way because it is too brief.

The government has put in place a number of initiatives to support and encourage athletes, ranging from the Education Policy of 1986 to the National Education Policy (NEP) 2020. The construction of sports facilities, the supply of gear, and the hiring of trainers and coaches to offer direction and instruction are some of these actions. The importance of physical education, games, and sports in promoting students' holistic development—which includes both their mental and physical well-being—is being increasingly recognised, according to the National Education Policy (NEP). To guarantee the active engagement and comprehensive development of students, the government has required that physical education, games, and sports be included in the curricula of all educational institutions.

There has been a great deal of research in the subject on attitudes around physical activity and fitness.

However, most studies examine children's attitudes towards physical education, instructors' behaviours, and physical exercise by using variables such as age, gender, and grade level.

According to Morgan et al. (2003), school physical education curricula are ideally situated to offer opportunities for physical activity and to foster the knowledge and abilities necessary for leading an active lifestyle.

Physical education programs must meet the needs of youth within a changing environment while discovering ways to motivate them to develop life-long exercise habits. The physical education programme encompasses various components such as physical activity, physical fitness, exercise, games, and sports. Additionally, a comprehensive understanding of physical education enables individuals to gain knowledge about their health, nutrition, body organs, bones and muscles, wellness, lifestyle, sports psychology, and biomechanics. Consequently, it can be argued that physical education contributes to the holistic development of individuals. Physical education is a discipline that use scientific principles to facilitate the systematic movement of the human body. Engaging in physical activities, games, and sports serves as a means to achieve this objective.

According to contemporary theories, an attitude is a concise evaluation of the information related to the attitude object, which in this case is physical education. An individual's behaviours are directed towards the attitude object by it (Fazio, 2007).

The importance of students' attitudes towards physical education comes from the fact that coaches, teachers, and other professionals must consider attitude on a daily basis while evaluating and analysing the potential of others (Ryan et al., 2003).

Every area of our lives is influenced by the notion of attitude, which is shaped by both our current views towards a particular subject and our past experiences with it. For example, our attitudes impact how we develop and react to our preferences for particular cuisines, clothing items, political candidates, television shows, and even romantic partners (Silverman). Students also have opinions about the physical environment in which they receive their education, their classrooms, and their instructors. These viewpoints could be positive or negative (Albarracín, 2019).

An urban area, also known as a built-up area or an urban agglomeration, is a human settlement that is distinguished by a sizable population concentration and a sophisticated built environment infrastructure.

As per the guidelines devised for the 2011 Indian Census, an urban area is characterised as a place where there is a minimum population of 5,000 people and a population density of at least 4,000 people per square kilometre, or 1,000 people per square mile. Furthermore, the minimum percentage of male workers in an urban region who are employed in non-agricultural activities is 75%. Areas under the control of a notified town area committee, cantonment board, or municipal corporation are referred to as urban areas.

In India, the term "*countryside*" or "*village*" is frequently used to describe rural areas where there is a notably low population density. Agriculture is the main source of income in rural areas, with fishing, cottage industries, pottery, and other related pursuits rounding out the list. Generally speaking, a rural area or countryside is any geographic area that is not inside of a municipality or an urban area. Examining the effect of a focused intervention on a certain population is the main goal of this study. Rural areas are characterised by the presence of tiny villages and a relatively low population density. Generally speaking, rural areas are defined as those where forestry and agriculture are the main industries. Different countries exhibit unique perspectives on rural areas, which are employed for administrative and statistical functions.

MATERIALS AND METHOD

Statement of the problem

This study aims to compare the attitudes of higher secondary girls towards the physical education programme in a few selected Tripura districts, with a focus on urban and rural areas.

Purpose of the study

The primary goal of the research is to compare the attitudes of upper secondary students towards physical education programmes in a few selected Tripura districts, with a focus on urban and rural areas.

Objectives of the study

To compare the higher secondary girls' students' attitudes towards Physical Education program in selected districts of Tripura with special reference to Urban and Rural.

Hypotheses

It was hypothesised that there will be no significant difference in the mean scores of Higher Secondary Girls Students Attitude towards Physical Education between Urban and Rural.

Scope of the study

- i) Both boys and girls in high school may participate in the study.
- ii) College students can also be the subject of it.
- iii) Postgraduate students can likewise be subjected to it.
- iv) It can be carried out in additional Tripura districts.
- v) It is also possible to carry out in other states.

Sources of data

For the study 140 higher secondary girls (70 from urban areas from North, Sepahijala and Unakoti district and 70 from the rural areas from North), Sepahijala and Unakoti district were chosen as participants.

Sampling procedure

To gather the data simple random sampling was used for the selection of subjects.

Selection of the test and scoring procedure

To collect the data Opinionnaire by Raut (2007) attitude towards physical education program were used and the responses were employing by Likert Method.

Positive and Negative items were recorded separately for each dimension. Items measuring particular dimension positively and as "*Very strongly agree*" "*strongly agree*", "*Agree*", "*Disagree*", "*Strongly disagree*", and "*very strongly disagree*" were given the scores for positive statement 6,5,4,3,2,1 and for negative statement 1,2,3,4,5,6 respectively.

Statistical tools
To analyse and draw the conclusion the percentile, Mean, Standard Deviation and t-test technique were used.

RESULTS AND DISCUSSION

According to the questionnaire, there are two possible scores: 390 and 65. The high number indicates a positive attitude towards the physical education programme, while the low score indicates a negative attitude.

Table 1 shows that the mean value of the Urban and Rural are 271.54 and 257.56 and SD is ± 25.304 and ± 27.720 respectively. It is also shows that calculated ‘t’ value is 3.118 and tabulated ‘t’ value is 1.984 at .05 level of significance for 138 df. Where calculated value is greater than tabulated value. It was discovered that there is a notable distinction between the two groups and that urban students have more favourable sentiments than rural pupils. The alternative hypothesis is therefore accepted and the null hypothesis is rejected. The reason behind this could be the school's physical education programme, teachers, facilities, or students' awareness of it. Figure 1 representing the mean difference.

Table 1. Mean, SD & t-Value of the attitude of urban and rural higher secondary girls.

Group	N	Mean ± SD	df	t- Value
Urban	70	271.54 ± 25.304	138	3.118
Rural	70	257.56 ± 27.720		

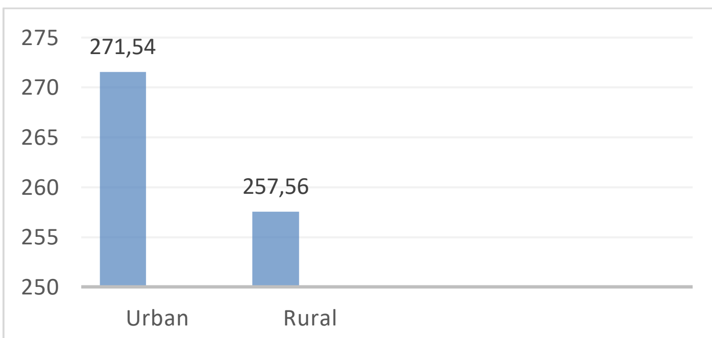

Figure 1. Attitude of the urban and rural students.

Findings
Based on the analysis and interpretation, the null hypothesis was rejected and the alternative hypothesis was accepted. It was found that there is a significant difference in the attitudes of urban and rural higher secondary girls’ students towards physical education in a particular Tripura district, where there is also a difference in their mean and "*t*" value.

Based on the aforementioned conversation, the researcher discovered that, in contrast to their rural counterparts, the students who attend urban schools have a more positive outlook. It is due to a number of factors, including the students' lack of knowledge about physical education, the inadequate infrastructure for games and sports, misconceptions held by students, parents, and even teachers about physical education, a lack of motivation, and possibly even their socioeconomic status, which may be the cause of their negative attitudes towards physical education.

Suggestion

i) Comparable research can be conducted on a variety of students, including those in elementary, middle, high school, graduate, and post-graduate programmes.
ii) Instructors ought to encourage their pupils to participate in physical education lessons and exercises.
iii) Parents ought to be better knowledgeable about the advantages of sports, games, and physical education programmes.
iv) Every day's curriculum should include a mandatory physical education session as well as games.
v) Every school should have a physical education teacher hired by the government.
vi) More parent and student education programmes should raise awareness of the value of physical education.
vii) Enough equipment should be available so that students can play the games of their choice.
viii) Every school should announce a prize and a reward at the outset for taking part in and winning a competition.

CONCLUSION

This study looks into the attitudes of female students in higher secondary school with regard to physical education. Following statistical analysis, the researcher discovered that urban students exhibit a more optimistic outlook than those of rural girls. The outcome shows that there is a notable change in how they feel about the physical education programme. For urban kids compared to rural students, the attitude score is noticeably higher.

AUTHOR CONTRIBUTIONS

Corresponding author of the study, Suparna Debbarma led the study's design, data collection, manuscript preparation, statistical analysis, and fund collection. Laishram Shila Devi, contributed to the study design, manuscript preparation and statistical analysis. The combined efforts of the authors ensured comprehensive approach to the advancing scientific knowledge in the field of physical education.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

REFERENCES

Arıkan. G. (2020) Analysis of Secondary School Students' Attitudes and Self-Efficacy Perceptions towards Physical Education and The Sports Course. World Journal of Education Vol. 10, No.6, 14-19. https://doi.org/10.5430/wje.v10n6p14

Agbuga. B., Xiang. P., McBride. R. (2012) Students' attitudes toward an after-school physical activity programme. European Physical Education Review. 19(1) 92-105. https://doi.org/10.1177/1356336X12465511

Acharya. A., Nrusingha. P., & Mishra. A., Students' sports activity preference and their attitudes towards physical education. International journal of Modern Trends in Engineering and Research. Vol 03(3), 328-332.

Ajzen, I. (2005) "The Influence of Attitudes on Behavior." In The Handbook of Attitudes, edited by D. Albarracin, B. T. Johnson, and M. P. Zanna, 173-221. Mahwah, NJ: Lawrence Erlbaum Associates.

Albarracín, D., Sunderrajan, A., Lohmann, S., Chan, M. P. S., & Jiang, D. (2019). The psychology of attitudes, motivation, and persuasion. The handbook of attitudes, volume 1: Basic principles, 3-44.

Albarracin, D., Johnson, B, T., & Zanna, M, P (Eds.), Handbook of attitudes and attitude change: Basic principles (pp. 79-125). Mahwah, NJ: Erlbaum.

Biddle, S. J. H., & Mutrie, N. (2008) American College of Sports Medicine (1988), Opinion statement on physical fitness in children and youth. Medicine and Science in Sports and Exercise, 20, 422-3. In Psychology of Physical Activity: Determinants, Wellbeing and Interventions. (2nd ed.) London: Routledge. https://doi.org/10.1249/00005768-198808000-00022

Biddle, S. J. H., & Mutrie, N. (2008) Psychology of Physical Activity: Determinants, Wellbeing and Interventions. (2nd ed.) London: Routledge. p.27.

Fazio, R. H. (2007). Attitudes as object-evaluation associations of varying strength. Social Cognition, 25(5), 603-637. https://doi.org/10.1521/soco.2007.25.5.603

Morgan, C., Beighle, A., & Pangrazi, R. (2007). What are the contributory and compensatory relationships between physical education and physical activity in children? Research Quarterly for Exercise and Sport, 78, 407-412. https://doi.org/10.1080/02701367.2007.10599440

Morgan, C., Pangrazi RP and Beighle A (2003) Using pedometers to promote physical activity in physical education. Journal of Physical Education, Recreation and Dance 74: 33-38. https://doi.org/10.1080/07303084.2003.10609235

Mondal. R. (2018) Attitude of secondary school students towards physical education in West Bengal. 8(VIII) 1812-1813.

Mutlu. O. T., Halil Erdem Akoglu. E. H., Cetinkaya. A. (2021) The analysis of high school students' attitudes towards physical education and sports class. Journal on Educational Psychology. 14(3) 55-58. https://doi.org/10.26634/jpsy.14.3.17663

Pethkar. V., Naik. Shraddha. (2012) Relationship between students' and teachers' attitude towards physical activity and physical and physical fitness. Journal Of Physical Education and Sport. 12(3), 385-390.

Rawat, S. (2019). History, principles and Foundation of Physical Education, sports publication. Pp-6,8,10.

Ryan, S., Fleming, D. & Maina, M. (2003). Attitudes of middle school students towards their physical education teachers and classes. The Physical Educator, 60, 28-42.

Simonton. L.k., Mercier. K., Garn. C.A. (2019) Do fitness test performances predict students' attitudes and emotions toward physical education? Physical Education and Sport Pedagogy. https://doi.org/10.1080/17408989.2019.1628932

Singh, A., Bains, J., Gill, S.J., & Singh, R. (2003). Essential of Physical Education, Kalyani Publisher, pp 37, 309 Singh, A., Bains, J., Gill, S.J., & Singh, R. (2003). Essential of Physical Education, Kalyani Publisher, pp 14-15, 215.

Togo, O. T., Caz, C., & Kayhan, R. F. (2018). The relationship between resilience and constant hope in students studying science. European Journal of Educational Research. volume: 7 Issue:(3) 583 - 589. https://doi.org/10.12973/eu-jer.7.3.583

ORIGINAL ARTICLE

Muscular activity differences and mechanisms for backhand straight and backhand cross in squash

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ABSTRACT

The purpose of the current study was to identify the differences of the upper extremity muscle activations around three joints of the dominant arm during two patterns of backhand strokes. Ten elite female right-handed squash players participated (age: 18.4 ± 0.8 years; mass: 60.8 ± 1.8 kg; height: 165.2 ± 1.6 cm). EMG data from six muscles around the shoulder, elbow, and wrist joints were recorded. The AD muscle activity of the backhand straight was greater throughout the execution and follow-through phases than the backhand cross ($p < .001$). In contrast, muscular activity in the PD muscle was greater during the three phases of backhand cross than backhand straight ($p < .001$). Elbow muscles showed no significant differences except in the follow-through phase, where the TB muscle demonstrated increased activity in the backhand straight. The WF and WE muscles had similar patterns in both strokes. This study provides novel insights into arm muscle activation during two patterns of backhand stroke in squash. Understanding the muscle activity mechanisms of these patterns can inform training strategies, optimize performance, and prevent injury risks to the shoulder, elbow, and wrist during the phases of the two patterns of backhand stroke in squash.

Keywords: Biomechanics, Wearable, Electromyography, Physical activity, Backhand cross, Backhand straight.

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INTRODUCTION

Muscular activity is essential in the game of squash due to its fast-paced nature, dynamic motions, and forceful strokes. Players must possess exceptional muscular strength, endurance, and control. Consequently, muscle activity plays a crucial role in squash. It helps with strength, speed, endurance, injury avoidance, and movement efficiency. Players may improve their performance, reduce their risk of injury, and eventually raise their game on the squash court by working on physical strength, endurance, and control (Akl, Hassan, Elgizawy, Tilp, & health, 2021; Karess et al., 1991; Kim, Min, Subramaniyam, & Kim; Locke et al., 1997; Tapie, Gil, Thoreux, & Making, 2020).

Therefore, the interaction and complementarity of motor abilities and needs in terms such as physiological, kinetics, and cognition variables are crucial for performance success (Finch & Eime, 2001; Horobeanu, Johnson, & Pullinger, 2019; Lees, 2002; Mohammed, 2015; Okhovatian & Ezatolahi, 2009).

However, scientific research into the acquisition of EMG data to record the activity of muscles, particularly in squash strokes, is quite required (Safikhani, Kamalden, Amri, & Ahmad, 2015). To date, no research has exclusively focused on comparing the kinetic, kinematic, and muscular activity of backhand cross and backhand straight in squash, simultaneously (Akl, Hassan, Elgizawy, & Tilp, 2021; Cho & Kim, 2007). Specifically, there's a gap in understanding the movement and muscle activity in the upper limb during forehand and backhand stroke patterns in squash (Akl, Hassan, Elgizawy, & Tilp, 2021; Yaghoubi, Moghadam, Khalilzadeh, & Shultz, 2014).

The frequency of backhand strokes (63.1 percent) surpassing forehand strokes (36.9 percent) highlights the importance of the backhand stroke in squash, Nevertheless, there are noticeable differences in the abilities utilized throughout a squash game (Hong, Chang, & Chan, 1996). Previous studies have investigated the relationship between racket speed and upper extremity circular motion (Elliott, Marshall, & Noffal, 1996), kinematic analysis of forehand stroke (Hong et al., 1996), and the upper extremity segment's kinematics during backhand strokes (An, Ryu, Ryu, Soo, & Lim, 2007).

The backhand cross is an important stroke in squash because it allows players to change the direction of the rally and put pressure on their opponent. With its ability to create angles and open up the court, the goal is to hit the ball diagonally across the court, aiming for the opposing front corner, which is often the opponent's weaker side (Fernández Pérez, García Hernández, & Díaz Miranda, 2020; Ghani, Zainuddin, & Ibrahim, 2018). In many game situations, the backhand straight stroke may be employed tactically.

Offensively, it enables players to exert pressure by hitting the ball with speed and precision, forcing the opponent to respond fast and perhaps opening up for further strokes. Defensively, it may be used to reset the rally and retake control by returning the ball deep and near to the side wall, limiting the attacking possibilities of the opponent (Carboch, Dušek, & Sport, 2023; Ghani, 2013; Pérez, Hernández, & Miranda, 2020).

To summarize, the backhand cross is a fundamental squash stroke that provides players with a vital option for shifting the direction of the rally and applying pressure to their opponents (Fernández Pérez et al., 2020; Ghani et al., 2018). The backhand straight stroke, another fundamental skill, enables players to strike the ball with power and precision along the side wall (Carboch et al., 2023; Ghani, 2013; Pérez et al., 2020). Additionally, incorporating specific drills and workouts that promote muscular coordination, timing, and sequencing. This involves a focus on controlled motions to develop improved technique during various squash-related activities (Girard, Micallef, Noual, & Millet, 2010; Masu & Otsuka, 2021).

Thus, understanding the nature of backhand pattern performance, the differences between the two patterns, and the relationship between training volume or intensity and the types and grades of injuries helps coaches and players acquire the proper technique and practice, addressing coordination issues and optimizing performance, and players can effectively use this stroke to gain an advantage on the court and improve their overall game (Akyol, 2012; Drew & Finch, 2016; Leeder, Horsley, & Leeder, 2016; Vanrenterghem, Nedergaard, Robinson, & Drust, 2017).

Therefore, it appears critical to research the mechanism of muscle activation during backhand stroke patterns. This study may provide further information regarding the significance of muscle activation in squash for joint support and stability, maintaining optimal body alignment, absorbing impact pressures, and reducing the risk of injury (Pallis, McNitt-Gray, & Hung, 2019).

Surprisingly, no study has yet explored the differences and processes of muscle activation during both of the backhand strokes (backhand cross and backhand straight). Therefore, the purpose of the current study is to identify the differences of the upper extremity muscle activations around three joints of the dominant arm during two patterns of backhand strokes. We hypothesized that muscular activation in the upper extremity muscles would differ across the two backhand stroke patterns as well as within each pattern's backhand stroke phases, particularly during the execution phase.

MATERIALS AND METHODS

Subjects and study design

We recruited ten healthy volunteers, all elite female squash players (age: 18.4 ± 0.8 years; mass: 60.8 ± 1.8 kg; height: 165.2 ± 1.6 cm). The subjects participated in professional squash tournaments and had official Egyptian squash federation rankings ranging from 4 to 20 (national and international). The study was authorized by the institution's studies and research ethics committee after the subjects gave written informed consent.

We utilized a cross-sectional design with repeated measures, in which all participants conducted three successful trials while recording EMG measurements for electrical muscle activity. of six upper extremity muscles: anterior deltoid (AD), posterior deltoid (PD), biceps brachii (BB), triceps brachii (TB), wrist flexor (WF), and wrist extensor (WE).

Experiment protocol

Following a 15-minute warm-up that comprised general, elbow, and shoulder mobility exercises, stretching, and protocol familiarization, participants performed squash backhand straight and crosscourt strokes. Each participant provided multiple successful tries, with a one-minute break in between. The backhand cross and straight squash abilities were subdivided into three phases: preparation, execution, and follow-through. From the start of the movement until the end of the elbow flexion, the preparation phase was defined; from the start of the elbow extension to the shot, the execution phase was defined; and from the moment of the shot to the conclusion of the movement, the follow-through phase was defined, see Figure 1. Video analysis employing 3D simi motion capture, synchronized with EMG, characterized the phases.

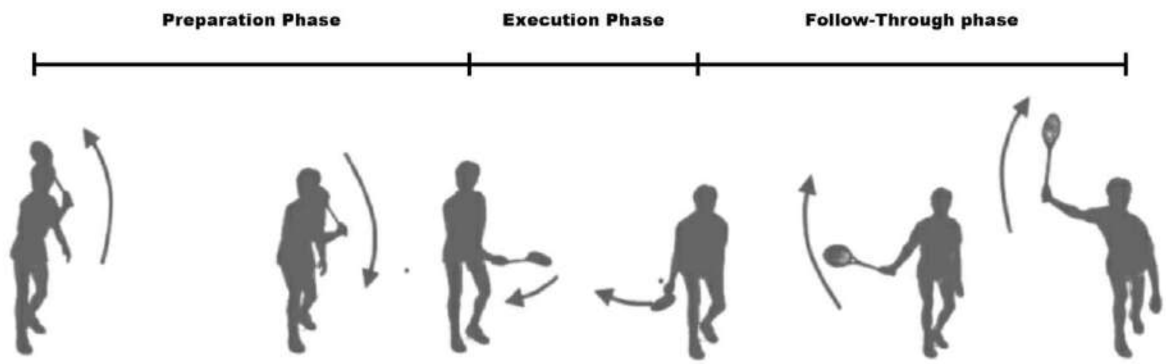


Figure 1. Backhand stroke phases (preparation phase, execution phase, follow-through phase).

sEMG activity recording and analysis

Surface EMG (Myon m320RX; Myon, Switzerland) was used to record the selected muscles of the dominant arm. The upper extremity muscles' skin was shaved and cleaned with alcohol before bipolar, circular 10 mm diameter silver chloride surface electrodes (SKINTACT FS-RG1/10, Leonhard Lang GmbH, Austria) were placed to the chosen muscles (Figure 2). Following the SENIAM recommendations, electrodes were placed over each muscle (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). The EMG signals were sampled at 1000 Hz and processed using a 16-bit analogue-to-digital (A/D) converter.

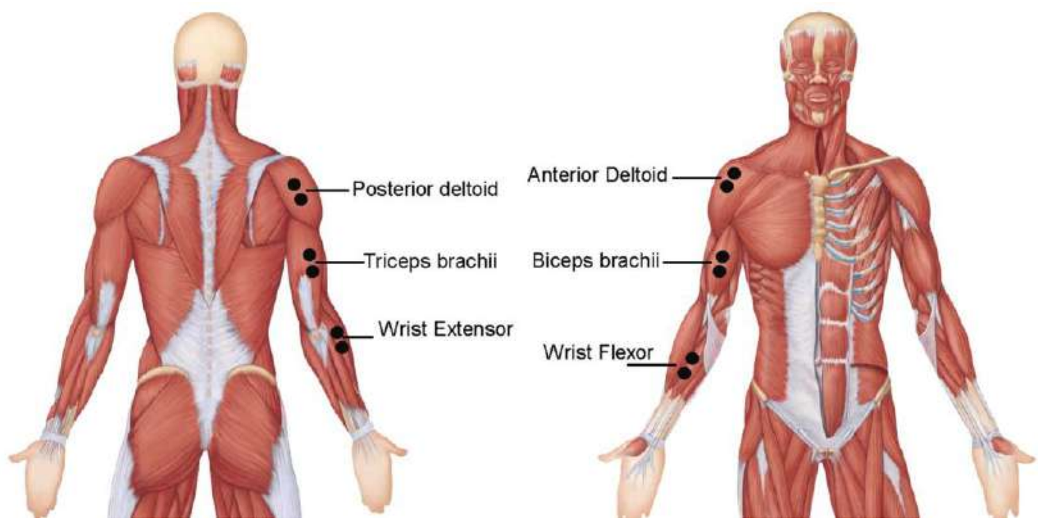


Figure 2. Electrode placements of the selected muscles (Black dots).

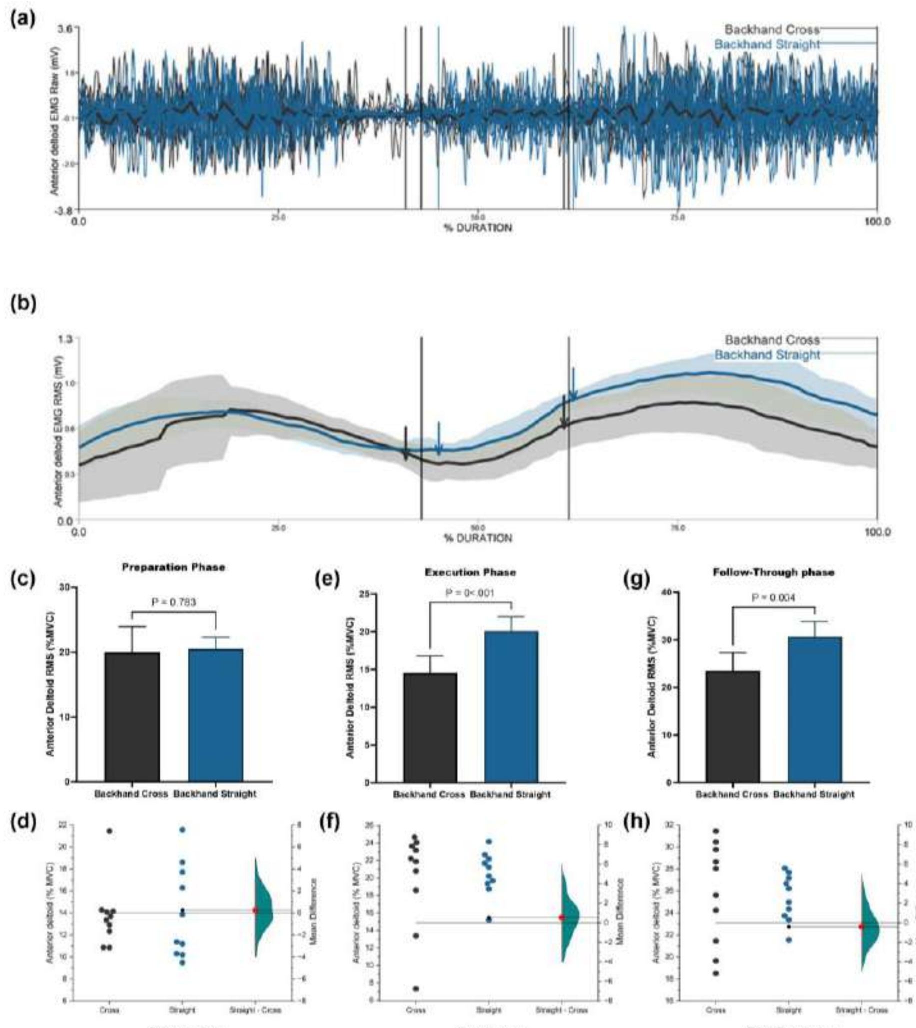
Visual 3D software was used to analyse EMG data (C-Motion, MD, USA). A Butterworth filter was used to band-pass filter raw EMG data (20 Hz-450 Hz). The signals were pre-processed using a full-wave rectifier and a linear envelope created using the root mean square (RMS) technique with a window size of 100 ms. After each individual completed the experimental activities, the data were normalized to an isometric maximal voluntary contraction (MVC). To get the MVC values, subjects performed three 5 s repeats with a 60 s rest interval while sitting in a comfortable and stable chair with forearm resistance. The MVC value was calculated by averaging peak muscular activity across three repetitions for each muscle.

Statistical analysis

Means and confidence intervals (mean CI) were used to report descriptive statistics. The Shapiro-Wilk test was utilized to investigate the normality of the data, and all data were found to be appropriate for parametric analysis. A paired T-test and Gardner-Altman estimate plots were used to identify significant differences and compare the mean of each variable across the two backhand stroke patterns (Cross and Straight) in squash. The IBM SPSS Statistics v21 software was used for statistical analysis.

RESULTS

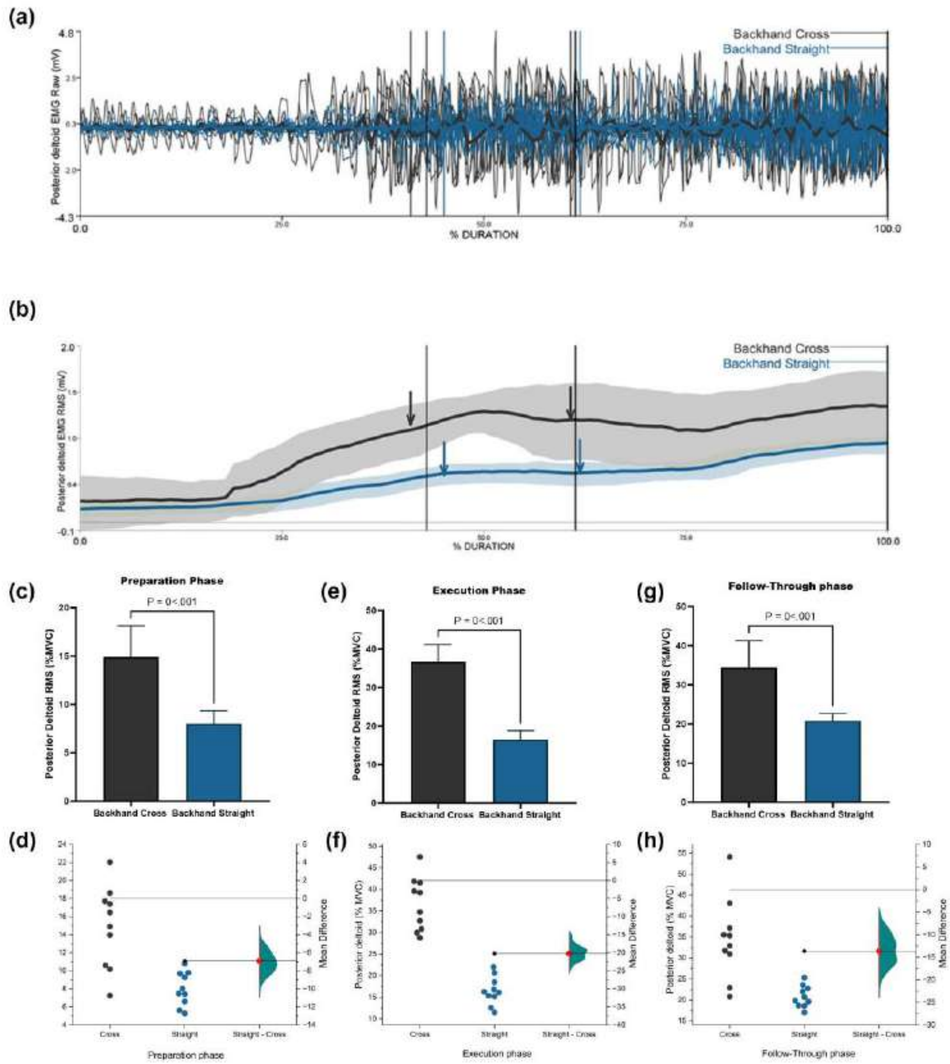
EMG raw data (a), EMG RMS (b), and average values, coefficient interval, and paired T-test for the normalized EMG (%MVC) are presented for the preparation (c), execution (e), and follow-through (g) phases. The Gardner-Altman estimation plots showing the paired mean differences between the cross and the straight for Squash backhand stroke related to muscle activity present the effect size as a confidence interval (95% CI) on separate but aligned axes, where the confidence interval of the mean difference is displayed to the right of the data during the three analysed of backhand phases.



Note. (a) raw data, and (b) RMS data. Average values and coefficient interval for the normalized EMG (%MVC) and Gardner-Altman estimation plot of AD per skill of the muscles during the three phases of performance (c, d; e, f; and g, h, respectively.

Figure 3. Backhand Cross and Backhand Straight muscle activity of AD muscle activity.

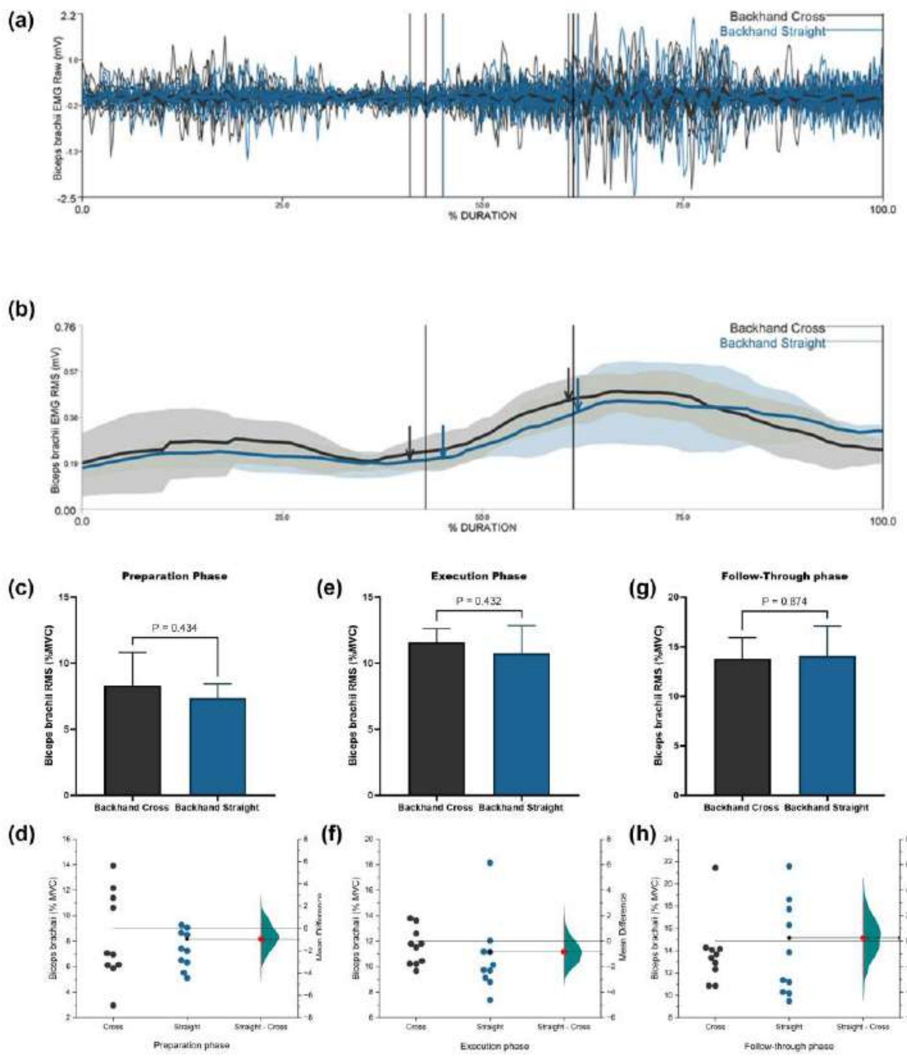
Figure 3 shows the average values and coefficient intervals for the AD muscle. The paired T-test demonstrated significant main effects for backhand strokes for AD muscle activity during the preparation (Figure 3c), execution (Figure 3e), and follow-through phase (Figure 3g). During preparation, there was no significant difference in AD muscle activity during the backhand cross compared to the backhand straight (p = .783, Figure 3c). However, there was a significant difference during execution (p < .001, Figure 3e) and follow-through (p < .001, Figure 3g). And the estimation plots demonstrated the differences between backhand cross and backhand straight during the three analysed phases: the preparation = 0.263 (Figure 3d), the execution = 0.541 (Figure 3f), and the follow-through phase = -0.4 (Figure 3h).



Note. (a) raw data, and (b) RMS data. Average values and coefficient interval for the normalized EMG (%MVC) and Gardner-Altman estimation plot of PD per skill of the muscles during the three phases of performance (c, d; e, f; and g, h, respectively.

Figure 4. Backhand Cross and Backhand Straight muscle activity of PD muscle activity.

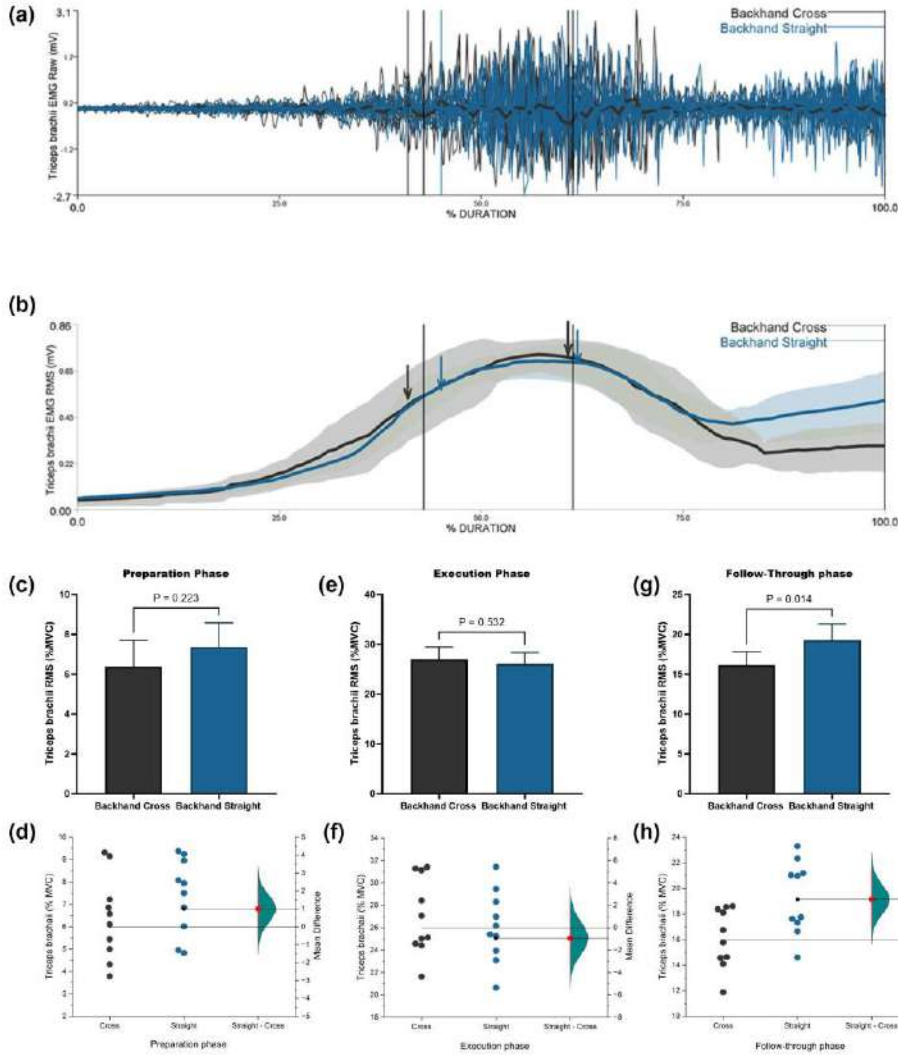
Figure 4 shows the average values and coefficient intervals for the PD muscle. The paired T-test demonstrated significant main effects for backhand strokes for PD muscle activity during the preparation (Figure 4c), execution (Figure 4e), and follow-through phase (Figure 4g). There was a significant difference between PD muscle activity during the backhand cross compared to that present during the backhand straight during the three analysed phases: the preparation (*p* < .001, Figure 4c), the execution (*p* < .001, Figure 4e), and the follow-through phase (*p* < .001, Figure 4g). And the estimation plots demonstrated the differences between backhand cross and backhand straight during the three analysed phases: the preparation = -6.907 (Figure 4d), the execution = -20.211 (Figure 4f), and the follow-through phase = -13.646 (Figure 4h).



Note. (a) raw data, and (b) RMS data. Average values and coefficient interval for the normalized EMG (%MVC) and Gardner-Altman estimation plot of BB per skill of the muscles during the three phases of performance (c, d; e, f; and g, h, respectively.

Figure 5. Backhand Cross and Backhand Straight muscle activity of BB muscle activity.

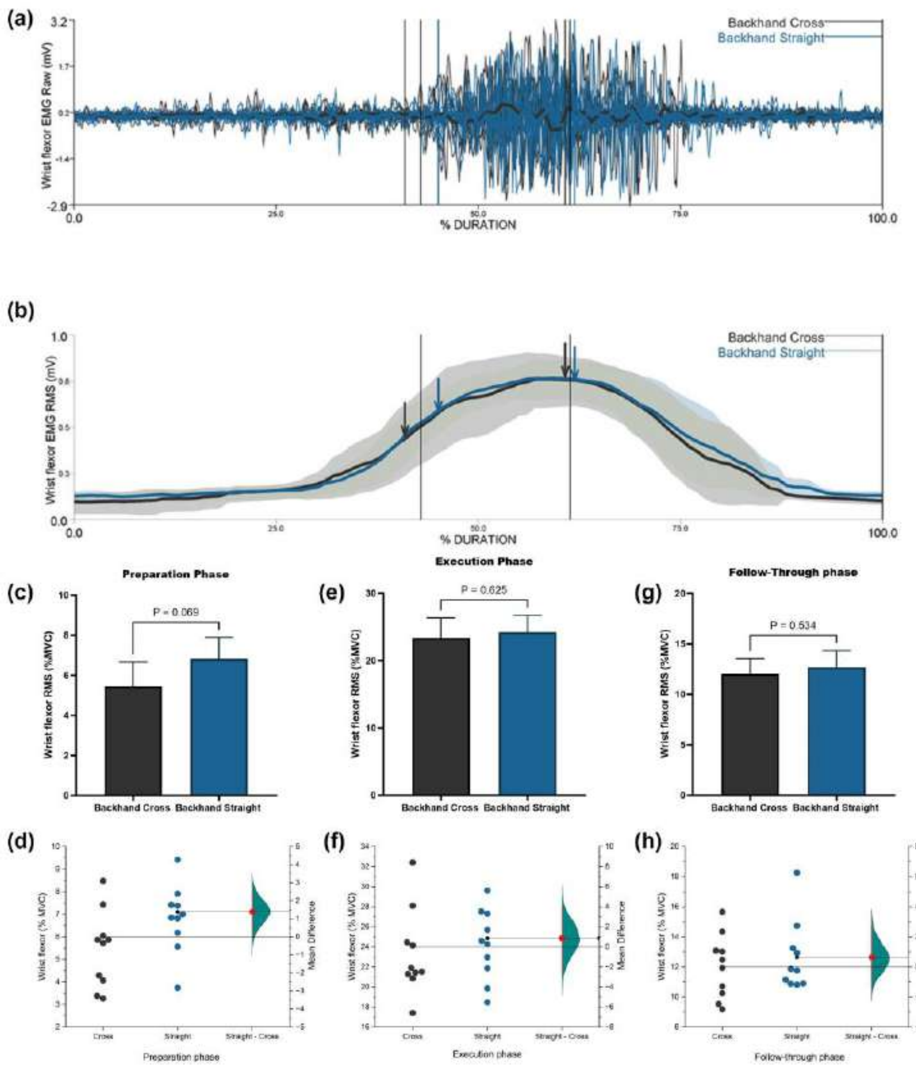
Figure 5 shows the average values and coefficient intervals for the BB muscle. The paired T-test demonstrated significant main effects for backhand strokes for BB muscle activity during the preparation (Figure 5c), execution (Figure 5e), and follow-through phase (Figure 5g). There was a non-significant difference between BB muscle activity during the backhand cross compared to that present during the backhand straight during the three analysed phases: the preparation (*p* = .434, Figure 5c), the execution (*p* = .432, Figure 5e), and the follow-through phase (*p* = .874, Figure 5g). And the estimation plots demonstrated the differences between backhand cross and backhand straight during the three analysed phases: the preparation = -0.957 (Figure 5d), the execution = -0.829 (Figure 5f), and the follow-through phase = 0.263 (Figure 5h).



Note. (a) raw data, and (b) RMS data. Average values and coefficient interval for the normalized EMG (%MVC) and Gardner-Altman estimation plot of TB per skill of the muscles during the three phases of performance (c, d; e, f; and g, h, respectively.

Figure 6. Backhand Cross and Backhand Straight muscle activity of TB muscle activity.

Figure 6 shows the average values and coefficient intervals for the TB muscle. The paired T-test demonstrated significant main effects for backhand strokes for TB muscle activity during the preparation (Figure 6c), execution (Figure 6e), and follow-through phase (Figure 6g). There was a non-significant difference between TB muscle activity during the backhand cross compared to that present during the backhand straight during the preparation phase (*p* = .223, Figure 6c) and the execution phase (*p* = .532, Figure 6e). And a significant difference was observed during the follow-through phase ($p < .05$, Figure 6g). And the estimation plots demonstrated the differences between backhand cross and backhand straight during the three analysed phases: the preparation = 1.00 (Figure 6d), the execution = -0.939 (Figure 6f), and the follow-through phase = 3.144 (Figure 6h).

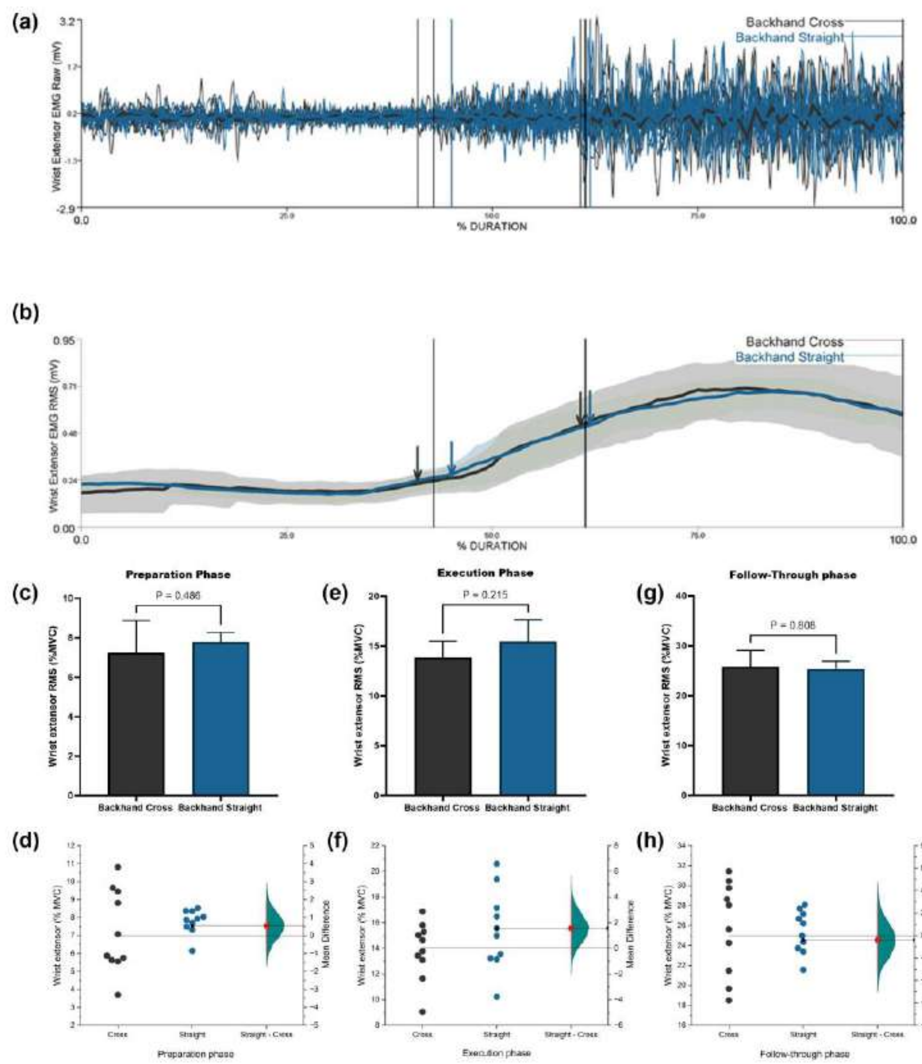


Note. (a) raw data, and (b) RMS data. Average values and coefficient interval for the normalized EMG (%MVC) and Gardner-Altman estimation plot of WF per skill of the muscles during the three phases of performance (c, d; e, f; and g, h, respectively.

Figure 7. Backhand Cross and Backhand Straight muscle activity of WF muscle activity.

Figure 7 shows the average values and coefficient intervals for the WF muscle. The paired T-test demonstrated significant main effects for backhand strokes for WF muscle activity during the preparation (Figure 7c), execution (Figure 7e), and follow-through phase (Figure 7g). There was a non-significant difference between WF muscle activity during the backhand cross compared to that present during the backhand straight during the three analysed phases: the preparation (p = .069, Figure 7c), the execution (p = .625, Figure 7e), and the follow-through phase (p = .534, Figure 7g). And the estimation plots demonstrated the differences between backhand cross and backhand straight during the three analysed phases: the preparation = 1.386 (Figure 7d), the execution = 0.865 (Figure 7f), and the follow-through phase = 0.633 (Figure 7h).

Figure 8 shows the average values and coefficient intervals for the WE muscle. The paired T-test demonstrated significant main effects for backhand strokes for WE muscle activity during the preparation (Figure 8c), execution (Figure 8e), and follow-through phase (Figure 8g). There was a non-significant difference between WE muscle activity during the backhand cross compared to that present during the backhand straight during the three analysed phases: the preparation (*p* = .486, Figure 8c), the execution (*p* = .215, Figure 8e), and the follow-through phase (*p* = .808, Figure 8g). And the estimation plots demonstrated the differences between backhand cross and backhand straight during the three analysed phases: the preparation = 0.543 (Figure 8d), the execution = 1.564 (Figure 8f), and the follow-through phase = -0.400 (Figure 8h).



Note. (a) raw data, and (b) RMS data. Average values and coefficient interval for the normalized EMG (%MVC) and Gardner-Altman estimation plot of WE per skill of the muscles during the three phases of performance (c, d; e, f; and g, h, respectively.

Figure 8. Backhand Cross and Backhand Straight muscle activity of WE muscle activity.

DISCUSSION

The purpose of the current study was to explore the arm muscle activations regarding performance and injury prevention during different patterns of backhand stroke in squash. To our knowledge, this is the first paper to demonstrate the importance of determining the muscle activity during the cross and straight squash backhand strokes using electromyographic analysis, which may help to increase the information about the muscular mechanisms of each pattern of backhand stroke, focus on the most appropriate exercises and training methods, and improve the quality of performance to prevent injury.

The muscle activity of AD, PD, BB, TB, WF, and WE were examined during the three phases of performance, when they activated as prime movers' muscles of the arm during backhand strokes in squash. The muscles being evaluated work around three upper-extremity joints. They control adduction and abduction at the shoulder, flexion and extension at the elbow, and radial deviation at the wrist.

Shoulder muscles

The muscles around the shoulder play a different role during backhand cross than in backhand straight strokes. During both backhand strokes, we can assess muscle activity based on its function and the role of muscle in performance. At the shoulder, AD muscle showed high activity of the backhand cross and backhand straight during the preparation phase, then decreased during the execution phase and increased again during the follow-through phase, as it provided power by abducting the shoulder. Its action appeared to be a deceleration of the backhand cross during the execution phase. In context, the action continues to keep the level of activity of the backhand straight during the execution phase, and then both patterns of strokes increase during the follow-through phase (Morris, Jobe, Perry, Pink, & Healy, 1989). Overall, the AD muscle is more active during backhand straight than backhand cross. There were no significant differences observed in the amplitude of the AD muscle activation during the preparation phase of the backhand cross and backhand straight. Subsequently, the AD muscle demonstrated significant differences in muscle activity during the execution phase and follow-throw phase of the backhand cross and backhand straight strokes, this finding is in agreement with Yaghoubi et al. (2014) (Yaghoubi et al., 2014).

In addition, the PD muscle showed high activity of the backhand cross during the execution phase and the follow-through phase, with less activity during the preparation phase. Nevertheless, the PD muscle activity is higher on the backhand cross than the backhand straight during the three phases of performance. In context, the PD muscle activity increased during the backhand straight, from the preparation phase to the follow-through phase. In contrast, the PD muscle is more active during the backhand cross than the backhand straight when compared to the AD muscle activity. This result is clearly demonstrated by the high significant differences in the amplitude of the PD muscle activation between both patterns of the backhand strokes (backhand cross and backhand straight) during the three phases of performance, and it is supported by the Gardner-Altman estimation plot method. During backhand strokes, the shoulder and trunk rotate, and as the body weight shifts, energy is transmitted to the dominant arm, requiring considerable horizontal abduction to place the upper limb posterior to the trunk (Morris et al., 1989; Yaghoubi et al., 2014). Thus, the AD and PD muscles act to stabilize the arm as a rigid extension of the racket by interactions, as they are the agonist and antagonist muscles around the shoulder during both patterns of the backhand strokes, as both utilize a forward action of the upper extremity (Yaghoubi et al., 2014). The backhand strokes required greater activity of the PD to maintain the abducted shoulder position necessary in the backhand performance, this finding agrees with Yaghoubi et al. (2014) (Yaghoubi et al., 2014).

Elbow muscles

Two of the muscles examined (BB and TB) work on the elbow hinge. The BB and TB are only responsible for controlling elbow flexion and extension. The BB showed lower activity during the backhand strokes, and in addition to performing elbow flexion, they also controlled forearm rotation. This means that the muscles have a positioning role, and that the elbow joint's inherent stability maintains position against the forces of both patterns of backhand strokes and a flexed position during the preparation phase. Except for an increase in activity during the execution and follow-through phases, the BB muscle showed reduced activity during the preparation phase of both patterns of backhand strokes, resulting in prolonged durations of the preparation phase (Akl, Hassan, Elgizawy, & Tilp, 2021; Yaghoubi et al., 2014). This means that, in addition to putting the elbow in flexion, the BB muscle was stabilizing the elbow flexion and contributing to the forearm's stability against rotation (Akl, Hassan, Elgizawy, & Tilp, 2021; Morris et al., 1989). The BB muscle showed no significant differences in the muscle activation between both patterns of the backhand strokes (backhand cross and backhand straight) during the three phases of performance. At the elbow, the TB muscle showed high activity only during the execution phase and the early of the follow-through phase, as they provided power by extending the elbow (Akl, Hassan, Elgizawy, & Tilp, 2021). At the forearm, again, the BB and TB muscles showed an increase in activity in the early of the follow-through phase, and in the late of the follow-through phase, the TB increased during the backhand straight rather than backhand cross. Because both the backhand straight and the backhand cross require the elbow to extend across a wide range of motion and against resistance, the TB is engaged for lengthier periods of time throughout both patterns of backhand strokes, particularly during the execution phase. This result was clearly demonstrated by the moderately significant differences in the amplitude of the TB muscle activation between both patterns of the backhand strokes (backhand cross and backhand straight) during the follow-through phase (p = .014), and it is supported by the Gardner-Altman estimation plot method. Furthermore, no significant variations in BB and TB amplitude were identified throughout other phases of performance. This finding is in agreement with previous research in other activities (Werner, Fleisig, Dillman, & Andrews, 1993; Yaghoubi et al., 2014). Backhand strokes generate substantial trunk rotation and horizontal abduction of the shoulder, resulting in a strong centrifugal force at the elbow joint. Because the forces generated at the proximal joint were higher than those produced at the elbow (Sisto, Jobe, Moynes, & Antonelli, 1987; Yaghoubi et al., 2014), both the BB and TB muscles performed a similar role of transmitting energy during the backhand strokes. Thus, no differences in the BB and TB muscles amplitude were found between both patterns of the backhand strokes (backhand cross and backhand straight) (Yaghoubi et al., 2014).

Wrist muscles

The wrist was the third joint involved in muscular activity. Flexion and extension motions demonstrate wrist and grip stability. During both patterns of backhand strokes, the WF and WE were examined. They worked cooperatively to support the wrist during both patterns. The WF muscle was highly active during both patterns when flexor moment resistance was necessary due to execution and ball contact (Morris et al., 1989). While hitting the single-handed backhand stroke, the WE muscle activity increased as the impact time approaches, which is likely necessary for wrist function throughout the racket swing (Furuya et al., 2021; Charles E. Giangarra, Betty Conroy, Frank W. Jobe, Marilyn Pink, & Jacquelin Perry, 1993). This is most likely because the WF and WE muscles act as stabilizers during forehand and backhand strokes, respectively (Furuya et al., 2021).

The amplitude of the WF was higher during the execution phase at the most distal joint because the ball is cupped between the forearm and hand during the backhand stroke, requiring a greater amplitude of the WF muscle (Yaghoubi et al., 2014). This is most likely because both the backhand cross and backhand straight rely on a pushing movement incorporating elbow extension. Thus, for the backhand strokes, the WE muscle activity was higher during the execution and follow-through phases during both patterns as compared to the WF muscle activity, which was higher during the execution phase only. This finding is in agreement with Furuya et al. (2021) (Furuya et al., 2021). Furthermore, WE muscle activation was common throughout both backhand stroke patterns. A previous study of EMG activity during tennis strokes showed a similar trend. Clearly, the high level of activity in the WE muscle during the backhand stroke helps to keep grip stability in an extension and radial deviation wrist position throughout execution and early follow-through. This is interesting because the wrist extensors are the most commonly injured muscle among racket players

(Charles E Giangarra, Betty Conroy, Frank W Jobe, Marilyn Pink, & Jacquelin Perry, 1993). The WF and WE muscles showed no significant changes between the two backhand stroke patterns. Thus, this finding demonstrates that these muscles had a comparable function in terms of muscular and temporal activity in the backhand cross and backhand straight strokes (Yaghoubi et al., 2014).

CONCLUSIONS

In conclusion, it was exploring the muscular activation of the shoulder, elbow, and wrist muscles as they changed during the different phases of the various squash backhand stroke patterns. Particularly, the backhand straight had more AD muscle activation throughout the execution and follow-through phases than the backhand cross ($p < .001$). In contrast, muscular activity in the PD muscle was greater during the three phases of backhand cross than backhand straight ($p < .001$). There were no differences in the BB and TB muscles between the backhand cross and backhand straight in the muscles of the elbow. Furthermore, being the agonist muscle for the two types of backhand stroke, the TB muscle demonstrated the highest levels of activity during the execution phase. In this context, the wrist muscles perform in concert during the two patterns of backhand stroke phases by increasing the muscle activity of the WF muscle during the execution phase and transferring the load of activity to the WE muscle during the follow-through phase for control and more stability in the wrist joint. This knowledge of using electromyographic analysis on the main arm muscles may be useful in understanding muscular activation, optimizing performance, and preventing injury risks to the shoulder, elbow, and wrist during the phases of the two patterns of backhand stroke in squash.

AUTHOR CONTRIBUTIONS

Conceptualization, K.A., and A.-R.A.; methodology, K.A., and A.-R.A.; software, A.-R.A.; validation, K.A., A.A., and A.-R.A.; formal analysis, A.-R.A.; investigation, K.A., A.A., and A.-R.A.; resources, A.-R.A.; data curation, A.-R.A.; writing—original draft preparation, K.A., A.A., and A.-R.A.; writing—review and editing, K.A., A.A., and A.-R.A.; visualization, A.A., and A.-R.A.; supervision, A.-R.A.; project administration, A.-R.A. All authors have read and agreed to the published version of the manuscript.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

INSTITUTIONAL REVIEW BOARD STATEMENT

The study was conducted according to the guidelines of the Declaration of Helsinki.

INFORMED CONSENT STATEMENT

Informed consent was freely obtained, and the study was approved by the institutional ethics committee of studies and research.

DATA AVAILABILITY STATEMENT

The data presented in this study are available on request from the Corresponding author.

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REFERENCES

Akl, A.-R., Hassan, A., Elgizawy, H., & Tilp, M. (2021). Quantifying Coordination between Agonist and Antagonist Elbow Muscles during Backhand Crosscourt Shots in Adult Female Squash Players. Int J Environ Res Public Health, 18(18). https://doi.org/10.3390/ijerph18189825

Akyol, M. (2012). Squash For Beginners: Squash Basics: Mehmet Akyol.

An, Y.-H., Ryu, J.-S., Ryu, H.-Y., Soo, J.-M., & Lim, Y.-T. (2007). The kinematic analysis of the upper extremity during backhand stroke in squash. Korean Journal of Sport Biomechanics, 17(2), 145-156. https://doi.org/10.5103/KJSB.2007.17.2.145

Carboch, J., Dušek, P. J. J. o. P. E., & Sport. (2023). Gender differences in squash performance and strategy at the elite level: a notational analysis. 23(4), 1010-1015.

Cho, K.-K., & Kim, Y.-S. (2007). The kinematic analysis and the study of muscle activities during backhand drive in squash. Korean Journal of Sport Biomechanics, 17(3), 11-21. https://doi.org/10.5103/KJSB.2007.17.3.011

Drew, M. K., & Finch, C. F. (2016). The Relationship Between Training Load and Injury, Illness and Soreness: A Systematic and Literature Review. Sports Med, 46(6), 861-883. https://doi.org/10.1007/s40279-015-0459-8

Elliott, B., Marshall, R., & Noffal, G. (1996). The role of upper limb segment rotations in the development of racket-head speed in the squash forehand. J Sports Sci, 14(2), 159-165. https://doi.org/10.1080/02640419608727697

Fernández Pérez, O., García Hernández, T. R., & Díaz Miranda, M. J. P.-R. d. C. y. T. e. l. C. F. (2020). Actions for the top-spin technique of backhand, in school table tennis athletes. 15(3).

Finch, C. F., & Eime, R. M. (2001). The epidemiology of squash injuries. International SportMed Journal, 2(2), 1-11.

Furuya, R., Yokoyama, H., Dimic, M., Yanai, T., Vogt, T., & Kanosue, K. (2021). Difference in racket head trajectory and muscle activity between the standard volley and the drop volley in tennis. PLoS One, 16(9), e0257295. https://doi.org/10.1371/journal.pone.0257295

Ghani, D. Z. A. (2013). Analysis of Stroke Distribution Between Professional, Intermediate and Novice Squash Players. Universiti Teknologi Malaysia,

Ghani, D. Z. A., Zainuddin, Z. A., & Ibrahim, H. (2018). Squash Backhand Stroke Analyses for Three Different Playing Levels in Malaysia. Paper presented at the Proceedings of the 3rd International Colloquium on Sports Science, Exercise, Engineering and Technology: ICoSSEET 2016, 20-22 November 2016, Kota Kinabalu, Malaysia.

Giangarra, C. E., Conroy, B., Jobe, F. W., Pink, M., & Perry, J. (1993). Electromyographic and cinematographic analysis of elbow function in tennis players using single- and double-handed backhand strokes. Am J Sports Med, 21(3), 394-399. https://doi.org/10.1177/036354659302100312

Giangarra, C. E., Conroy, B., Jobe, F. W., Pink, M., & Perry, J. (1993). Electromyographic and cinematographic analysis of elbow function in tennis players using single-and double-handed backhand strokes. Am J Sports Med, 21(3), 394-399. https://doi.org/10.1177/036354659302100312

Girard, O., Micallef, J. P., Noual, J., & Millet, G. P. (2010). Alteration of neuromuscular function in squash. J Sci Med Sport, 13(1), 172-177. https://doi.org/10.1016/j.jsams.2008.11.002

Hermens, H. J., Freriks, B., Disselhorst-Klug, C., & Rau, G. (2000). Development of recommendations for SEMG sensors and sensor placement procedures. J Electromyogr Kinesiol, 10(5), 361-374. https://doi.org/10.1016/S1050-6411(00)00027-4

Hong, Y., Chang, T. C.-M., & Chan, D. (1996). A comparison of the game strategies employed by national and international squash players in competitive situation by notational analysis. Journal of Human Movement Studies, 31(2), 89-104.

Horobeanu, C., Johnson, A., & Pullinger, S. A. (2019). The prevalence of musculoskeletal injuries in junior elite squash players. Asian Journal of Sports Medicine, 10(1). https://doi.org/10.5812/asjsm.84495

Karess, R. E., Chang, X.-j., Edwards, K. A., Kulkarni, S., Aguilera, I., & Kiehart, D. P. J. C. (1991). The regulatory light chain of nonmuscle myosin is encoded by spaghetti-squash, a gene required for cytokinesis in Drosophila. 65(7), 1177-1189. https://doi.org/10.1016/0092-8674(91)90013-O

Kim, S. E., Min, S. N., Subramaniyam, M., & Kim, S. K. Effects of correction program on back muscle functional asymmetry among squash players.

Leeder, J., Horsley, I., & Leeder, J. (2016). Physiotherapy in Squash. Science of Sport: Squash.

Lees, A. (2002). Technique analysis in sports: a critical review. J Sports Sci, 20(10), 813-828. https://doi.org/10.1080/026404102320675657

Locke, S., Colquhoun, D., Briner, M., Ellis, L., O'Brien, M., Wollstein, J., & Allen, G. J. S. m. (1997). Squash racquets: A review of physiology and medicine. 23, 130-138. https://doi.org/10.2165/00007256-199723020-00005

Masu, Y., & Otsuka, A. (2021). Comparison of electromyogram reaction time at the onset of motion in badminton players at different competitive levels. Journal of Human Sport and Exercise, 17(4). https://doi.org/10.14198/jhse.2022.174.12

Mohammed, M. H. H. (2015). Effect of squash training program on health related physical fitness variables of male college students. Journal of Human Sport and Exercise, 10(Special Issue 2). https://doi.org/10.14198/jhse.2015.10.Proc2.07

Morris, M., Jobe, F. W., Perry, J., Pink, M., & Healy, B. S. J. T. A. j. o. s. m. (1989). Electromyographic analysis of elbow function in tennis players. 17(2), 241-247. https://doi.org/10.1177/036354658901700215

Okhovatian, F., & Ezatolahi, A. (2009). Sport injuries in squash. Pakistan Journal of Medical Sciences, 25, 413-417.

Pallis, J. M., McNitt-Gray, J. L., & Hung, G. K. (2019). Biomechanical Principles and Applications in Sports: Springer. https://doi.org/10.1007/978-3-030-13467-9

Pérez, O. F., Hernández, T. R. G., & Miranda, M. D. J. R. P. (2020). Actions for the top-spin technique of backhand, in school table tennis athletes. 15(3), 1-15.

Safikhani, H., Kamalden, T. F. T., Amri, S. B., & Ahmad, M. (2015). The effect of different systems of carrying backpacks on muscle activity. Journal of Human Sport and Exercise, 10(Special Issue 2). https://doi.org/10.14198/jhse.2015.10.Proc2.08

Sisto, D. J., Jobe, F. W., Moynes, D. R., & Antonelli, D. J. (1987). An electromyographic analysis of the elbow in pitching. Am J Sports Med, 15(3), 260-263. https://doi.org/10.1177/036354658701500314

Tapie, B., Gil, C., Thoreux, P. J. I., & Making, H. R. M. i. S. A. G. t. D. (2020). Squash. 677-681. https://doi.org/10.1007/978-3-662-60752-7_102

Vanrenterghem, J., Nedergaard, N. J., Robinson, M. A., & Drust, B. (2017). Training Load Monitoring in Team Sports: A Novel Framework Separating Physiological and Biomechanical Load-Adaptation Pathways. Sports Med, 47(11), 2135-2142. https://doi.org/10.1007/s40279-017-0714-2

Werner, S. L., Fleisig, G. S., Dillman, C. J., & Andrews, J. R. (1993). Biomechanics of the elbow during baseball pitching. Journal of Orthopaedic & Sports Physical Therapy, 17(6), 274-278. https://doi.org/10.2519/jospt.1993.17.6.274

Yaghoubi, M., Moghadam, A., Khalilzadeh, M. A., & Shultz, S. P. (2014). Electromyographic analysis of the upper extremity in water polo players during water polo shots. International Biomechanics, 1(1), 15-20. https://doi.org/10.1080/23335432.2014.976591

ORIGINAL ARTICLE

A pilot study for detecting release instant using a single inertia measurement unit in shot put

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ABSTRACT

Evaluating and understanding the release parameters is crucial in the throwing events of athletics, however, calculating the release parameters is time-consuming for data collection and can be expensive. The present study aimed to investigate a method for detecting the release instant from data collected using a single inertia measurement unit (IMU) in shot put. Two male shot putters participated in the study. Each participant performed six competitive throws with a 9-axis IMU (100 Hz) attached to the back of the participant's throwing hand. Three different methods were examined from IMU data: threshold values of resultant acceleration, waveform of resultant acceleration, and waveform of the angular velocity around the radio-ulnar axis of the hand. The release instant as a true value was obtained from the video recorded in sync with the IMU, and the error of the release instant detected from the IMU was calculated. The final number of trials analysed was four for participant A and six for participant B. As results, there were various cases where the threshold value of acceleration did not exceed the value depending on the participant and trial, and the release instant could not be detected. The release instant detected from the moment the acceleration decreased based on the acceleration waveform had a large error (4.00 ± 2.26 frames). The release instant, which was detected from the moment when the angular velocity became negative based on the angular velocity waveform, was detected in all trials for both participants, and the error was low (1.20 ± 0.92 frame).It was found that utilizing the detection of dorsiflexion timing of the wrist joint, with the angular velocity around the rotational axis parallel to the radio-ulnar axis of the hand as a cue, proved to be a highly accurate approach for determining the release instant.

Keywords: Biomechanics, Dorsiflexion, Throwing, Event detection.

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INTRODUCTION

In the throwing events of athletics, throwers compete for distance by throwing objects. This throwing distance is determined by variables called release parameters, such as the velocity of the object (initial velocity), angle of release, and location of release (release height) at the instance of release (Hay, 1993). Aerodynamic factors influence the throwing distance in discus and javelin throws (Bartlett & Best, 1988; Hay & Yu, 1995; Hubbard & Cheng, 2007), whereas, in shot put and hammer throw, these factors have minimal effect due to the density of the objects being thrown (Hay, 1993). Therefore, evaluating and understanding these release parameters is crucial, particularly for shot put and hammer throw events. Release parameters have traditionally been calculated using 3-D motion analysis methods such as video-based DLT method or optical motion capture systems (Dinsdale, Thomas, Bissas, & Merlino, 2017; Kato, Kintaka, Urita, & Maeda, 2017; Kato, Maeda, Mizushima, & Maeda, 2022; Kumar, Murali, & MR, 2016; Landolsi et al., 2018; Liu & Yu, 2021; Thomas, Dinsdale, Bissas, & Merlino, 2019; Van Biesen, McCulloch, & Vanlandewijck, 2018). Although these methods provide accurate data on release parameters, the video-based DLT method is time-consuming for data collection, and optical motion capture systems can be expensive (Lee & Yoo, 2017). Consequently, these methods make it challenging to readily use data for training and coaching purposes.

Wearable devices are now being used for immediate data collection and feedback. In particular, the inertial measurement unit (IMU) is becoming smaller and less expensive. Recent research has explored the use of IMUs to evaluate athletes' posture (Brice, Hurley, & Phillips, 2018; Wada et al., 2020), behaviour of sports equipment (Gao et al., 2009; Wada, B. Shepherd, D. Rowlands, & A. James, 2016), joint power (Jiang, Gholami, Khoshnam, Eng, & Menon, 2019; Nagahara & Murata, 2020), and ground reaction force (Karatsidis et al., 2017; Shahabpoor & Pavic, 2018) across various sports. In the context of throwing events, IMUs have been employed to estimate the throwing velocity in team handball by attaching them to the wrist or arm segments and using machine learning (Gençoğlu & Gümüş, 2020; van den Tillaar, Bhandurge, & Stewart, 2021). Furthermore, the throwing velocity in team handball can be estimated from the acceleration measured by a wrist-mounted accelerometer without the need for machine learning, yielding unbiased results with minimal errors (Skejø, Bencke, Møller, & Sørensen, 2020). Based on previous research, it is feasible to estimate release parameters in throwing events using a single IMU attached to the hand or wrist.

Determining the release instant is essential for obtaining accurate release parameters, which have been traditionally determined visually using video images (Dinsdale et al., 2017; Kato et al., 2017; Kato et al., 2022; Thomas et al., 2019). For example, in shot put, the acceleration of the shot had calculated using an accelerometer embedded inside the shot without relying on video images (Gao et al., 2009). Another study has also evaluated the kinematics of throwing motion using multiple IMUs (Saračević, Atiković, Štuhec, & Čuk, 2018). However, these research efforts have not specifically investigated the release parameters and the detection of release instant moment from the sensors. Therefore, in order to estimate release parameters using the IMU, it is necessary to first establish a method for detecting the release moment solely based on the IMU data.

The aim of this research was to investigate methods for detecting the release instant from data collected through the use of the IMU.

MATERIAL AND METHODS

Participants

Two well-trained male shot putters (personal best of shot put, 18.29 m and 17.35 m) volunteered to participate in the study after providing informed consent. Both participants were right-handed throwers and competed at the national level in Japan. The study protocol was approved by the research ethics committee.

Measures and procedures

Following a self-selected warm-up, which included warm-up throws, each participant performed six competitive throws. A 9-axis wireless IMU with an accelerometers range of 200 G and gyro sensors range of 6000 deg/s was used at a sampling rate of 100 Hz (SS-MS-HMA5G3, SPORTS SENSING Co., Japan). After static calibration, the IMU was attached to the dorsum of the participant's right hand, and the shot put motion was recorded by two high-speed cameras (Ex-F1, Casio, Japan) at a frame rate of 300 fps with a shutter speed of 1/2000 s. The IMU was attached such that its X, Y, and Z-axes of the IMU were parallel to the long axis of the right hand, the left-right axis (parallel to the dorsiflexion axis of the wrist joint), and the axis perpendicular to the long axis and the left-right axis, respectively. The angular velocity was positive in the direction of palm flexion and negative in the direction of dorsiflexion.

The IMU was controlled using a dedicated application (SPORTS SENSING Co., Japan) on a wirelessly connected computer. LED lights (SS-WSYLT1, SPORTS SENSING Co., Japan) were synchronized with the IMU measurement using a synchronization unit (SS-WSY12, SPORTS SENSING Co., Japan) and placed within the cameras' field of view to synchronize the time axis of the video images and IMU data.

The captured video was converted to 100 fps using video editing software (Adobe Premier Pro 14.2, Adobe, Inc.) based on the frame when the LED light began to emit light. The converted video was then played back frame by frame at 100 Hz using video playback software (Quicks time 7.79, Apple, Inc.), and the number of frames was obtained as the true value of the release time, representing the instance when the shot was completely released from the fingertips in both videos. The study protocol was approved by the research ethics committee at the Shonan Institute of Technology.

Three different methods for detecting release instant using the IMU were examined, based on accelerometer and gyro sensor data. In sprint acceleration, the touchdown and take-off of the foot were detected using an accelerometer attached to the calf or heel, employing either acceleration threshold or waveform analysis (Purcell, Channells, James, & Barrett, 2006; Schmidt et al., 2016). In the shot put, the shot's acceleration was measured using an accelerometer integrated into the shot itself, and its acceleration exhibited a peak followed by a decrease during the release, with a maximum value exceeding 15 G (Gao et al., 2009). Considering that the IMU was affixed to the hand in this study, it is expected that the acceleration values would be different from those of the shot. Following a kinetic chain perspective (Blazevich, 2017), it can be inferred that hand acceleration reaches its peak before the release and gradually decreases toward release, albeit to a lower level than the shot's acceleration.

The first method for detecting the release instant involved setting four threshold values (10.0 G, 7.5 G, 5.0 G, and 2.5 G), and the release instant was determined as the point when the resultant acceleration fell below each threshold (BT 10.0 G, BT 7.5 G, BT 5.0 G, and BT 2.5 G).

The second method utilized the waveform of the resultant acceleration. For all trials of both participants, waveforms were observed in which the resultant acceleration increased before release and then started to decrease just before release. Therefore, the instant when the resultant acceleration began to decrease was extracted as DRA (Decrease of Resultant Acceleration).

Regarding the gyro sensors, the focus was on the angular degrees of freedom of the hand joints, which influence hand motion. The wrist joint encompasses two types of motion—palmar and dorsal flexion, as well as radial and ulnar flexion. However, evaluating flexion and ulnar flexion requires a relative positional relationship with the forearm. On the other hand, the release is characterized by a snap of the wrist (palm flexion) in shot put motion (Fok & Bain, 2022). Hence, the behaviour of the hand enables the observation of palm flexion and dorsiflexion of the wrist joint, particularly before and after the release. Consequently, the angular velocity waveforms around the left-right axis of the IMU attached to the hand were employed as the third method for detecting the release instant. Across all participants and trials, the angular velocity around the radio-ulnar axis of the hand exhibited a negative increase immediately before and after the release instant, followed by a positive increase.

Therefore, the instant at which the angular velocity became negative was detected as NAV (Negative Angular Velocity).

Statistical analysis
The mean value, standard deviation, and error range were calculated for the release moments obtained from the acceleration and angular velocity of the IMU, in comparison to the release instants determined from the video images. The error range, presented as absolute values, was analysed using a student t-test with a significant level set at 5% for comparison.

RESULTS

Trials in which the IMU lost contact from the hand before the release of the shot were excluded from the analysis. The final number of trials analysed was four for participant A and six for participant B. Figure 1 and 2 shows the resultant acceleration and Figure 3 and 4 shows the waveforms of the angular velocity around the radio-ulnar axis of the hand before and after the release instant, identified as 0 s, as detected from the video for each participant and trial. In participant A's first trial, the waveform was interrupted due to the removal of the IMU from the hand after release.

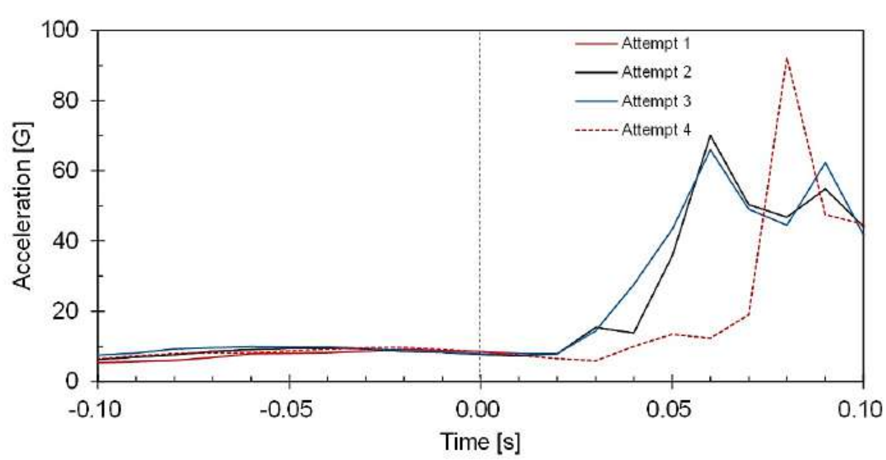

Figure 1. The resultant acceleration of the hand around the release instant for participant A. 0 s shows the release instant detected from the video image.

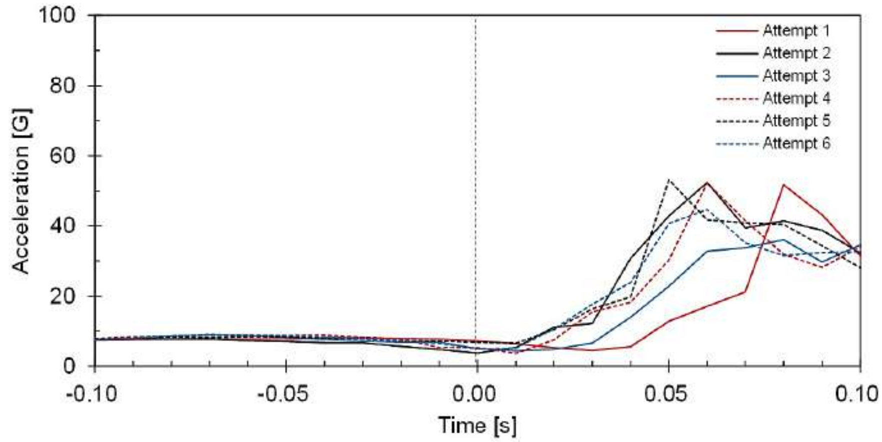

Figure 2. The resultant acceleration of the hand around the release instant for participant B. 0 s shows the release instant detected from the video image.

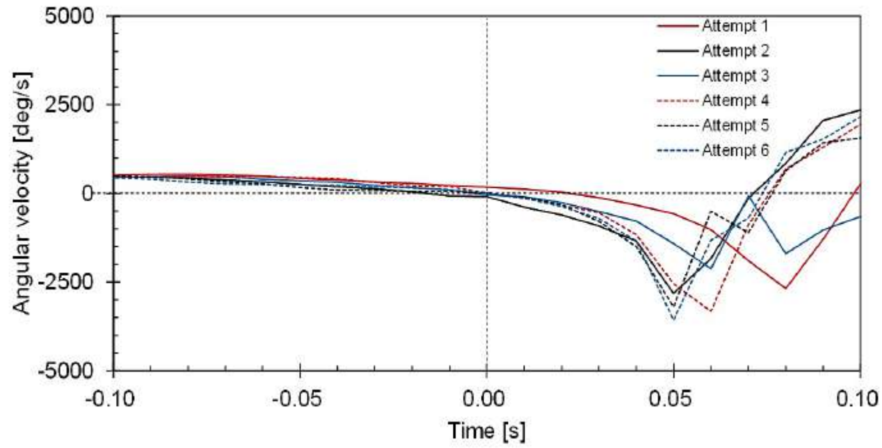

Figure 3. Angular velocity around the radio-ulnar axis of the hand of participant A around the release instant. 0 s shows the release instant detected from the video image.

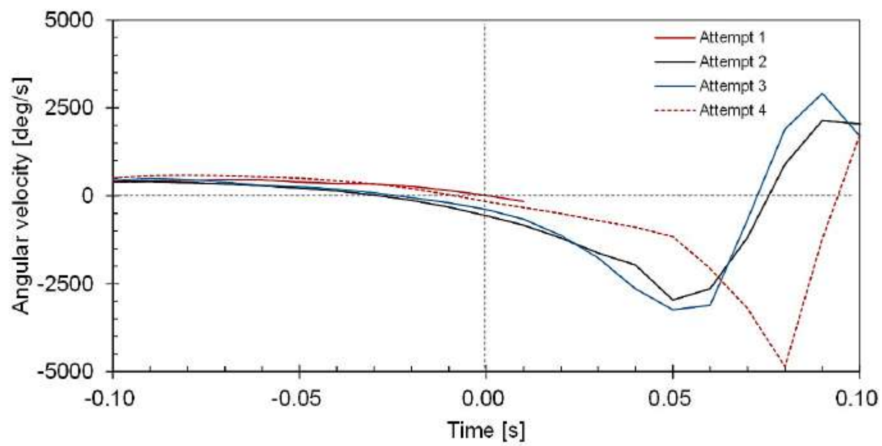

Figure 4. Angular velocity around the radio-ulnar axis of the hand of participant B around the release instant. 0 s shows the release instant detected from the video image.

Table 1. Means and absolute means of errors in detecting release instant for each method. Negative values mean that estimated release instant preceded true (by video) instant.

Participant		Acceleration [frame]					Angular velocity [frame]
		BT 10.0 G	BT 7.5 G	BT 5.0 G	BT 2.5 G	DRA	NAV
A	Attempt 1	-	-	-	-	-1	1
	Attempt 2	-	1	-	-	-3	-2
	Attempt 3	-	-	-	-	-5	-2
	Attempt 4	-	1	-	-	-1	0
B	Attempt 1	-	0	3	-	-3	3
	Attempt 2	-	-6	-1	-	-8	-1
	Attempt 3	-	-3	0	-	-6	0
	Attempt 4	-	-1	1	-	-3	1
	Attempt 5	-	-2	-	-	-4	1
	Attempt 6	-	-2	0	-	-6	1
Mean ± SD			-1.50 ± 2.33	0.60 ± 1.52		-4.00 ± 2.26	0.20 ± 1.55
Absolute mean ± SD			2.00 ± 1.85	1.00 ± 1.22		4.00 ± 2.26	1.20 ± 0.92

Table 1 shows the mean value, standard deviation, and error range of the error and absolute error in the release instant detected from the acceleration and angular velocity, in comparison to the release instant determined from the video. No trials were observed with accelerations above 10.0 G or below 2.5 G for both participants. BT 7.5 G was detected in two out of four trials for participant A and in all trials for participant B. BT 5.0 G was not detected in any of participants A's trials; in contrast, it was detected in all trials for participant B. DRA and NAV were detected in all trials for both participants. The results of student t-tests, as shown in Figure 5, indicate that DRA (4.00 ± 2.26 frames) had a significantly larger absolute error than BT 7.5 G (2.00 ± 1.85 frame), BT 5.0 G (1.00 ± 1.22 frame) and NAV (1.20 ± 0.92 frame). There was no significant difference between BT 7.5 G, BT 5.0 G, and NAV.

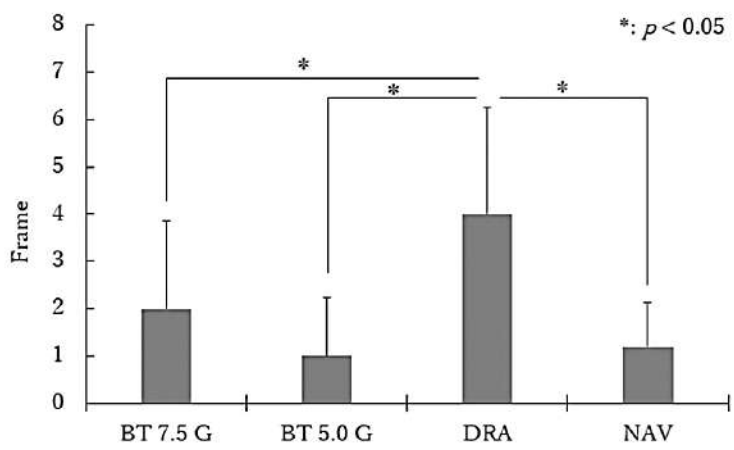

Figure 5. Comparison in absolute errors in detecting release instant for each method. BT 10.0 G and BT 2.5 G were removed from the comparison, as no trial was observed for both participants.

DISCUSSION

This study aimed to investigate methods for detecting the release instant in shot put using the IMU. Two participants threw the shot with the IMU attached to their hand. The primary focus of the study was to assess the errors in detecting the release instant detected from acceleration and angular velocity compared to the true value detected from video images. The results of the study confirmed that using a threshold for resultant acceleration and analysing the waveform of angular velocity around the axis paralleled to parm flexion and dorsiflexion of the wrist joint can effectively detect the release instant with minimal errors.

Regarding the threshold of resultant acceleration, BT 7.5 G showed small errors in detecting the release instant for participant A, but exhibited errors of up to six frames (0.06 s) for participant B. BT 5.0 G had small errors in participant B, which was not detected in any trials in participant A. Furthermore, BT 10.0 G and BT 2.5 G were never detected in any of the trials. Additionally, the method of DRA showed significantly higher errors compared to other methods. In the throwing motion, the kinetic chain perspective suggests that the body moves from the centre to the extremities in sequence and with acceleration (Blazevich, 2017). In addition, the initial velocity of the shot is a critical factor affecting on the throwing distance (Hay, 1993). Therefore, it is assumed that the hand velocity around the release instant also varies between the trials, depending on the participant's skill level and the differences in throwing distance among trials. Consequently, the resultant acceleration of the hand may differ not only between participants but also between trials. Based on the results of this study, it can be stated that BT 7.5 G and BT 5.0 G can be used to detect the release instant with relatively high accuracy for participant A and participant B, respectively. However, given that both methods failed to detect the release instant in some trials for each participant, further verification is required to determine whether hand acceleration depends on the characteristics of the participants and the throwing distance to detect the release instant using the threshold of resultant acceleration.

NAV was detected within 3 frames (0.03 s) of the true value in all trials for both participants. This indicates that the hand's behaviour near the release instant resembled dorsiflexion of the wrist joint. In terms of hand behaviour, in baseball pitching, the angular velocity of flexion-extension in the proximal and the middle finger joints increases in the extension direction just before the release instant, followed by a rapid increase in the flexion direction, which has been suggested to be due to high joint stiffness of the fingers (Matsuo et al., 2018). Therefore, in shot put, it is plausible that the interphalangeal joints rapidly extend and then flex near the release instant, and the hand joints are dorsiflexed by the reaction. The IMU attached to the hand may measure the angular velocity of rotation in the direction of extension (dorsiflexion) around the hand's right and left axes. The rotation behaviour of the hand around the radio-ulnar axis near the release instant, as shown in the present results, is a distinctive characteristic of shot put. It is considered the most accurate method for detecting the release instant examined in the present study.

There are several limitations to the study's design. Since there were two participants, and their competition level was sub-elite, it cannot be assured that similar results would be obtained in athletes of different competition levels. As mentioned earlier, the optimal threshold values for hand acceleration may vary for different athletes. Therefore, it is necessary to verify the results with a large number of participants and a wider range of competition levels. In addition, the behaviour of the hand and wrist joints inferred from the angular velocity waveforms in this study needs to be verified through detailed analysis using an optical motion capture system.

CONCLUSIONS

The present study aimed to investigate three different methods for detecting the release instant in shot put using data obtained from a single IMU. The release instant determined from synchronized video images was considered as the reference value, and a comparison was made based on the absolute error in relation to this reference. Among the methods examined, it was found that utilizing the detection of dorsiflexion timing of the wrist joint, with the angular velocity around the rotational axis parallel to the radio-ulnar axis of the hand as a cue, proved to be a highly accurate approach for determining the release instant.

AUTHOR CONTRIBUTIONS

TK conceived the study, participated in its design and coordination, performed the experiment and the statistical analyses, and drafted the original version of the manuscript. KM and KO participated in its design and coordination, performed the experiment, and heled in participants' recruitment. JM, TA and JF conceived the study and participated in its design and coordination. All authors have read and approved the final version of the manuscript and agree with the order of presentation of the authors.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

REFERENCES

Bartlett, R. M., & Best, R. J. (1988). The biomechanics of javelin throwing: a review. Journal of Sports Sciences, 6(1), 1-38. https://doi.org/10.1080/02640418808729791

Blazevich, A. J. (2017). Sports biomechanics: the basics optimising human performance. London: Bloomsbury Publishing.

Brice, S. M., Hurley, M., & Phillips, E. J. (2018). Use of inertial measurement units for measuring torso and pelvis orientation, and shoulder-pelvis separation angle in the discus throw. International Journal of Sports Science & Coaching, 13(6), 985-992. https://doi.org/10.1177/1747954118778664

Dinsdale, A., Thomas, A., Bissas, A., & Merlino, S. (2017). Biomechanical Report for the IAAF World Championships London 2017: Shot put men's. Retrieved from [Accessed 2024, July 11]: https://www.worldathletics.org/about-iaaf/documents/research-centre

Fok, M. W. M., & Bain, G. I. (2022). Wrist Injuries in Throwers. Management of Track and Field Injures, 105-110. https://doi.org/10.1007/978-3-030-60216-1_11

Gao, Z., Song, B., Liu, M., Song, G., Sun, W., & Ge, Y. (2009). Design and application of a multidimensional acceleration sensor for coaching of shot-put athletes. Sensors and Actuators A: Physical, 149(2), 213-220. https://doi.org/10.1016/j.sna.2008.11.029

Gençoğlu, C., & Gümüş, H. (2020). Standing handball throwing velocity estimation with a single wrist-mounted inertial sensor. Annals of Applied Sport Science, 8. https://doi.org/10.29252/aassjournal.893

Hay, J. G. (1993). The Biomechanics of Sports Techniques (4th ed.). Englewood Cliffs, NJ: Prentice-Hall.

Hay, J. G., & Yu, B. (1995). Critical characteristics of technique in throwing the discus. J Sports Sci, 13(2), 125-140. https://doi.org/10.1080/02640419508732220

Hubbard, M., & Cheng, K. B. (2007). Optimal discus trajectories. J Biomech, 40(16), 3650-3659. https://doi.org/10.1016/j.jbiomech.2007.06.010

Jiang, X., Gholami, M., Khoshnam, M., Eng, J. J., & Menon, C. (2019). Estimation of Ankle Joint Power during Walking Using Two Inertial Sensors. Sensors, 19(12), 2796. https://doi.org/10.3390/s19122796

Karatsidis, A., Bellusci, G., Schepers, H. M., De Zee, M., Andersen, M. S., & Veltink, P. H. (2017). Estimation of Ground Reaction Forces and Moments During Gait Using Only Inertial Motion Capture. Sensors, 17(1), 75. https://doi.org/10.3390/s17010075

Kato, T., Kintaka, H., Urita, Y., & Maeda, A. (2017). Kinematic and Technical factors for acceleration of whole body in rotational shot put technique. ISBS-Conference Proceedings Archive, 35(1). Retrieved from [Accessed 2024, July 11]: https://commons.nmu.edu/isbs/vol35/iss1/149

Kato, T., Maeda, K., Mizushima, J., & Maeda, A. (2022). Investigation of a theoretical model for the rotational shot put technique. ISBS Proceedings Archive, 40(1), 327.

Kumar, M., Murali, M., & MR, D. D. (2016). Kinematic analysis of shot release of intercollegiate athletes. International Journal of Physical Education, Sports and Health, 3(5), 131-134.

Landolsi, M., Labiadh, L., Zarrouk, F., Maaref, K., Ghannouchi, S., Tabka, Z., & Lacouture, P. (2018). Kinematic analysis of the shot-put: A method of assessing the mechanical work of the hand action force. Eur J Sport Sci, 18(9), 1208-1216. https://doi.org/10.1080/17461391.2018.1478449

Lee, Y., & Yoo, H. (2017). Low-cost 3D motion capture system using passive optical markers and monocular vision. Optik, 130, 1397-1407. https://doi.org/10.1016/j.ijleo.2016.11.174

Liu, H., & Yu, B. (2021). Rotation of the thrower-discus system and performance in discus throwing. Sports Biomech, 1-16. https://doi.org/10.1080/14763141.2021.1880619

Matsuo, T., Jinji, T., Hirayama, D., Nasu, D., Ozaki, H., & Kumagawa, D. (2018). Middle finger and ball movements around ball release during baseball fastball pitching. Sports Biomechanics, 17(2), 180-191. https://doi.org/10.1080/14763141.2016.1261932

Nagahara, R., & Murata, M. (2020). Inertial Measurement Unit Based Hip Flexion Strength-Power Test for Sprinters. Front Sports Act Living, 2, 571523. https://doi.org/10.3389/fspor.2020.571523

Purcell, B., Channells, J., James, D., & Barrett, R. (2006). Use of accelerometers for detecting foot-ground contact time during running. Microelectronics, MEMS, and Nanotechnology, 6036. https://doi.org/10.1117/12.638389

Saračević, Z., Atiković, A., Štuhec, S. S., & Čuk, I. (2018). How kinematics influences shot put results in track and field of international level athletes (a case study). Journal of Physical Education & Sport. https://doi.org/10.7752/jpes.2018.s173

Schmidt, M., Rheinländer, C., Nolte, K. F., Wille, S., Wehn, N., & Jaitner, T. (2016). IMU- based Determination of Stance Duration During Sprinting. Procedia Engineering, 147, 747-752. https://doi.org/10.1016/j.proeng.2016.06.330

Shahabpoor, E., & Pavic, A. (2018). Estimation of vertical walking ground reaction force in real-life environments using single IMU sensor. Journal of Biomechanics, 79, 181-190. https://doi.org/10.1016/j.jbiomech.2018.08.015

Skejø, S. D., Bencke, J., Møller, M., & Sørensen, H. (2020). Estimating Throwing Speed in Handball Using a Wearable Device. Sensors, 20(17), 4925. https://doi.org/10.3390/s20174925

Thomas, A., Dinsdale, A., Bissas, A., & Merlino, S. (2019). Biomechanical Report for the IAAF World Indoor Championships 2018: Shot Put Men.

Van Biesen, D., McCulloch, K., & Vanlandewijck, Y. C. (2018). Comparison of shot-put release parameters and consistency in performance between elite throwers with and without intellectual impairment. International Journal of Sports Science & Coaching, 13(1), 86-94. https://doi.org/10.1177/1747954117707483 van den Tillaar, R., Bhandurge, S., & Stewart, T. (2021). Can machine learning with IMUs be used to detect different throws and estimate ball velocity in team handball? Sensors, 21(7), 2288. https://doi.org/10.3390/s21072288

Wada, T., B. Shepherd, J., D. Rowlands, D., & A. James, D. (2016). A measurement of sport wheelchair propulsion based on AHRS. The Proceedings of the Symposium on sports and human dynamics, 2016(0). https://doi.org/10.1299/jsmeshd.2016.A-16

Wada, T., Nagahara, R., Gleadhill, S., Ishizuka, T., Ohnuma, H., & Ohgi, Y. (2020). Measurement of Pelvic Orientation Angles during Sprinting Using a Single Inertial Sensor. Paper presented at the The 13th Conference of the International Sports Engineering Association. https://doi.org/10.3390/proceedings2020049010

REVIEW ARTICLE

Sporting talent in volleyball: A scoping review

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ABSTRACT

The aim of this study was to investigate the available literature on sporting talent in volleyball, and critically analyse what else has been researched in the area, methodological approaches, knowledge gaps, and encouraging future research. The search strategy was carried out in four electronic databases (PubMed®, Scopus, SPORT Discuss and Web of Science) using the PRISMA-ScR methodology (extension for Scoping Reviews). 78 articles were included for the final analysis. Most studies analysed female athletes (56.4%), in a cross-sectional design (85.9%), with group comparison (60.3%), bivariate analysis (66.7%) and application of test batteries (91%) of anthropometric (62.8%) and physical-motor (56.4%) characteristics. There were few studies that adopted a multidimensional (20.5%) and retrospective/longitudinal approach (11.5%), evaluated psychological skills (7.7%), subjective coach analysis (25.6%), motor coordination (9%), maturation (9%) and sociocultural characteristics (5.1%). Thus, talent identification in volleyball generally uses batteries of tests to discriminate between skill levels, mainly using physical tests (anthropometric and physiological measures), but the evidence for their validity in predicting future performance and discriminating skill levels is limited. Future research should adopt multidimensional and longitudinal approaches, combining objective and subjective indicators of sporting potential of young volleyball athletes.
Keywords: Sports performance, Athlete, Expertise.

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INTRODUCTION

The field of sporting talent has aroused the interest of the academic community in recent years (Baker et al., 2020). In parallel with this increase, the number of identification and development talent programs has grown, as they aim to recognize athletes with the potential to excel within their specific sport, as well as provide a suitable systematic training environment for the development of their capabilities (Barraclough et al., 2022).

In this context, there is still no consensus in the literature on the definition of sporting talent due to the lack of methodological rigor in research (Baker et al., 2019). Despite these inconsistencies, the studies agree that sporting talent is multidimensional (Roberts et al., 2019), as it involves the interaction of individual aspects and the environment (Paula et al., 2021), and thus within the individual factors is the potential of specific sporting talent abilities of the sport modality along with the psychological capacities, physical and cognitive, which enable the attainment of high performance (Issurin, 2017). Furthermore, sporting talent is considered to be non-linear (Roberts et al., 2019), i.e., the characteristics of talented individuals change during the long-term training process.

Volleyball is a team sport with unpredictable game situations that require players to make quick decisions (Claver et al., 2016). In addition, volleyball is an intermittent sport, in which, during the match, athletes perform high and low intensity actions and rest periods. Thus, the volleyball athlete who reaches the elite level is the one who has excellent physical-motor preparation (Altavilla et al., 2022), excellent anthropometric characteristics (Tsoukos et al., 2019), as well as cognitive (Waelle et al., 2021), psychological (Rabaz et al., 2015), technical/tactical (Lopes et al., 2016) and favourable environmental aspects (Coutinho et al., 2021).

From the perspective of identifying talent in volleyball, studies demonstrated that the coach plays an important role in this process (Formenti et al., 2022; Stanovic et al., 2020). Generally, coaches use their "*instinct*" (Roberts et al., 2019) to analyse the performance of the athletes in competitions and performance in physical tests when choosing the one with the best chance of reaching high performance (Baker et al., 2019; Johnston et al., 2018). However, the use of assessments together with the opinion of the coach may constitute an excellent tool for detecting talent.

Thus, research demonstrates that the field of sports talent is highly complex, since it is characterized in a multidimensional manner and specific to each modality, considering that each sport has its own specificity, requiring different talent characteristics. Recent systematic reviews (Johnston et al., 2018) and scoping reviews (Baker et al., 2020) have analysed the literature on talent in various sports. However, there is a lack of literature reviews addressing sporting talent in volleyball.

In this way, the aim of this research review was to investigate the available literature on sporting talent in volleyball, and to critically analyse what has been most researched in the area, methodological approaches, in addition to identify knowledge gaps and encourage future research.

METHOD

This scoping review followed the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) (Liberati et al., 2009; Tricco et al., 2018). This type of review has as an objective to carry out a collection of information already available within the literature on a thematic subject in order to obtain a better understanding about the trends and shortcomings (Baker et al., 2020).

Eligibility criteria

The articles that were included for analysis, after reading the title, abstract and full text, respectively, were those that met the criteria: (1) published between January 2000 and July 2022, (2) written in English, (3) original articles (books were excluded, commentaries, theses, dissertations, notes, conference abstracts and letters to the reader), (4) contained information on volleyball athletes (studies on coaches were excluded), (5) contained relevant data on sporting talent in volleyball (studies with multiple indicators: anthropometric, physical-motor, psychological, cognitive, technical/tactical; performance prediction, athlete selection and career analysis), (6) included comparisons based on skill level of athletes and by age group (e.g. more skilled versus less skilled and under-15 versus under-17, respectively), (7) athletes under 18 years of age (except retrospective studies with athletes over 18 years of age and studies comparing age groups that included the adult category), (8) did not focus on the effect of relative age. The exclusion criteria were: (1) articles on the effect of training, (2) studies that only evaluated match performance analysis (used DataVolley software), (3) comparison between genders (female versus male), (4) comparison between modalities (for example, volleyball versus basketball), (5) health outcomes (for example, injuries, COVID-19, doping), (6) descriptive articles, (7) articles that compared non-athletes/control group or compared athletes from different playing positions (e.g. outside hitter versus central midfielder), (8) studies on paralympic athletes and (9) studies on beach volleyball athletes.

Search information

The searches were conducted in July 2022 in four databases (PubMed®, Scopus, SPORTDiscus and Web of Science) by Author and Author. All the databases have a broad scope in the field of sports science, and to identify the articles in each database separately, the search terms were applied. The external search included the bibliographic reference lists of the articles included for analysis and indication of the articles performed by a renowned researcher in the field of sporting talent.

Search strategies

The search strategy was divided into the following stages: (1) search in electronic databases; (2) secondary search using external sources. The first stage consisted of searching the four databases: PubMed®, Scopus, SPORTDiscus and Web of Science. The establishment of the terms for the search in the databases was carried out by means of a review of the existing literature in the area, in order to identify the most commonly used terms on the subject. In order to combine the terms and search for articles in the databases, we used the Boolean operators OR & AND. Thus, the search terms utilized, considering the title and abstract of the articles were:

("*talent**" OR "*expert**" OR "*gift**" OR "*ability*" OR "*aptitude*" OR "*skill**" OR "*select**" OR "*champion**" OR "*finalist*" OR "*success**" OR "*develop**" OR "*identif**" OR "*prognos**" OR "*predict**" OR "*diagnos**" OR "*career*") AND ("*volleyball**") AND ("*young**" OR "*youth*" OR "*junior*" OR "*adolescent**" OR "*athlete**" OR "*elite*")

The second stage consisted of reading the bibliographical references of the articles found in stage 1, as well as consulting a specialist in the field of sporting talent who suggested original articles that might fit the eligibility criteria.

Study selection and data collection process

The studies collected in each database were processed in EndNote X9 (Clarivate Analytics, Philadelphia, USA), and duplicate articles were removed automatically and manually. The reading of titles and abstracts was undertaken by two independent researchers (Author) and (Author) following the eligibility criteria, and in any conflicts a third reviewer (Author) decided on the inclusion or not of the study. The abstracts that lacked decisive information were selected for full-text reading. The data was recorded in an Excel spreadsheet specifically for this review.

Data items

The articles included in this review were thoroughly assessed by the Author researcher, who initially extracted general information from the studies: name of the author(s), year of publication, name of the journal, title and objective of the article, theory/concept of sporting talent, design (cross-sectional, intervention/tracking and longitudinal/retrospective), whether or not there was a division of groups (by skill level or age group) and statistical analysis of the study (bivariate, multivariate or qualitative analysis).

In addition, the results related to the sample were analysed: sample size (<20 participants, 20-50 participants, 51-100 participants, 101-200 participants, 201-500 participants or >500 participants), nationality of the sample, gender (female, male or mixed), age (adolescent - 12 to 17 years; adult - + 18 years or mixed) and skill level of the participants (expert - international level, advanced - national level, intermediate - state level, basic - regional/local level and novice - inconsistent/beginner or mixed) (Baker et al., 2015).

Moreover, the following talent/athlete results were also evaluated: anthropometric, physical/motor/physiological indicators, psychological skills, technical, tactical/cognitive, quality/quantity of practice/training, performance in competitions, motor coordination, sociocultural characteristics, biological maturation and the coach's subjective evaluation. The indicators of sporting talent were classified as: restricted to the individual, the task and the environment. Further, the studies were classified as multidimensional (those that assessed 4 or more indicators within sporting talent) or non-multidimensional.

Furthermore, when the articles were classified as group division, performance prediction and future success/career pathway, the results were classified as positive, i.e., when there was a difference between groups or if the variables analysed predicted performance or if the variables were determinant in the career of the athlete, respectively. The results of the group division were also classified as contradictory, i.e., when some variables made a significant difference and others did not. And finally, the results were also classified as negative, that is, when there was no significant difference in any variable or if the variables failed to predict performance or if the variables were not determinant for career progression, respectively.

Synthesis method

No meta-analysis was planned. A narrative synthesis of the data was performed.

RESULTS

The first phase identified 5 113 articles from the search of databases using the keywords cited. In the second phase, 29 articles were identified through external sources. 2 468 duplicated articles were removed, and after reading the titles and abstracts, 2 575 were excluded, 2 550 from the first phase and 25 from the second phase. In addition, 7 articles were not found in the entirety of the literature and were consequently excluded. This left 92 articles for the evaluation of the whole text. After a meticulous reading of the studies, 14 articles were removed, and thus a total of 78 articles remained in the final analysis of the study (see Figure 1).

Figure 2 illustrates the distribution of studies published in the defined time interval (2000-2022). It can be seen that of the 78 articles analyzed, 16.7% were published between 2000 and 2009, 26.9% between 2010 and 2014, 28.2% between 2015 and 2019 and 28.2% between 2020 and 2022.

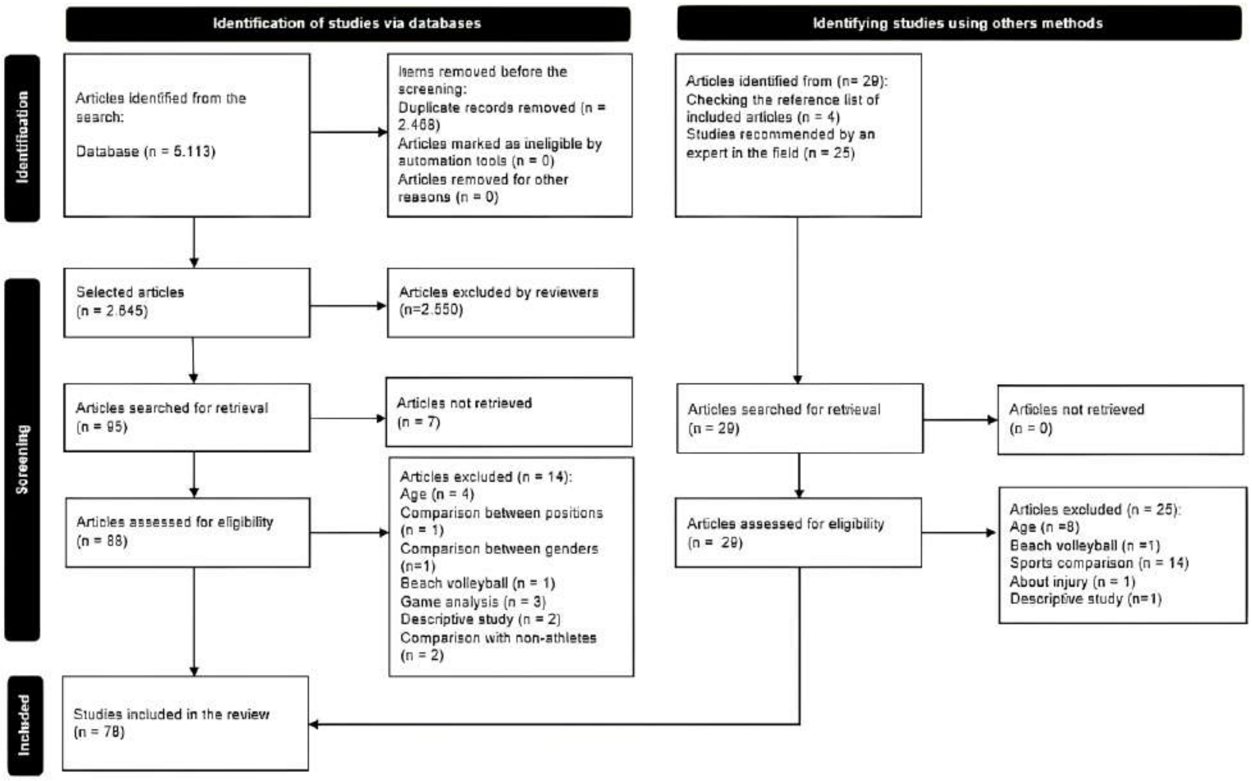

Figure 1. Flowchart: number of reports collected and the number of eligible studies after the screening process.

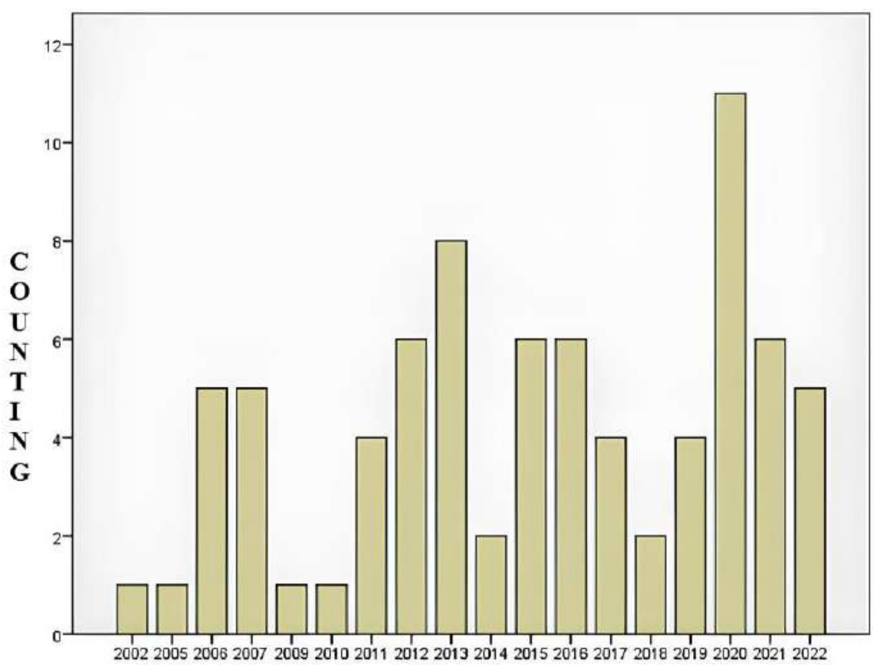

Figure 2. Number of studies by year of publication.

According to Table 1, 56.4% of the studies used samples made up of females, followed by both sexes (17.9%), and finally by males (16.7%). In relation to the age of the sample, the majority of the studies evaluated adolescent athletes - 12 to 17 years old (57.7%), followed by those that evaluated both adolescents and adults (33.3%), and just 9% evaluated only adults (these are the ones that evaluated the passage of the career/retrospective of the athlete).

In terms of skill level, some of the studies evaluated athletes of different abilities (32.1%), followed by advanced (national level, 29.5%), intermediate (state level, 12.8%), basic (regional/local level, 10.3%), and specialists and novices (international level and inconsistent level, respectively, each with 3.8%). Additionally, athletes from 22 countries were represented in the studies analysed, with Brazil, Croatia and Spain having the highest number of studies (11.5% each), followed by Portugal (10.3%). In terms of sample size, 57.7% of the studies had a sample size of 20-100 athletes.

Table 1. Descriptive statistics for gender, age, skill level and sample size for the study samples with volleyball athletes.

	N (%)
Sex	
Masculine	13 (16.7%)
Feminine	44 (56.4%)
Mixed	14 (17.9%)
Not reported	7 (9%)
Age	
Adolescent: 12-17	45 (57.7%)
Adult: +18	7 (9%)
Mixed	26 (33.3%)
Level of ability	
Specialist	3 (3.8%)
Advanced	23 (29.5%)
Intermediate	10 (12.8%)
Basic	8 (10.3%)
Novice	3 (3.8%)
Mixed	25 (32.1%)
Not reported	6 (7.7%)
Sample size	
<20	7 (9%)
20-50	26 (33.3%)
51-100	19 (24.4%)
101-200	13 (16.6%)
201-500	8 (10.3%)
501+	5 (6.4%)

In Table 2, there is a higher percentage of cross-sectional studies (85.9%), followed by retrospective/longitudinal studies (11.5%) and short-tracking studies (2.6%). In relation to the studies that compared groups, it was observed that some compared age categories (26.9%), and others compared athletes of different performance levels, covering a wide range of terms such as: elite vs sub-elite (9%), more skilled vs less skilled (7.7%), more experienced vs less experienced (6.4%). Regarding the data analysis, a significant proportion of the studies adopted the bivariate analysis (66.7%), followed by the multivariate analysis (30.8%) and few qualitative analyses (2.6%). As far as the type of data collection, most of the studies used a battery of tests (91%), followed by interviews with athletes (7.7%) and, lastly, a database/secondary source (1.3%).

Table 2. Characteristics of the study project.

	N (%)
Study design	
Cross-sectional	67 (85.9%)
Retrospective / longitudinal	9 (11.5%)
Intervention / short-tracking	2 (2.6%)
Division into groups	
Successful vs unsuccessful	6 (7.7%)
Age categories	21 (26.9%)
Technical performance	1 (1.3%)
Elite vs Sub-elite	7 (9%)
More experienced vs less experienced	5 (6.4%)
Most skilled vs least skilled	6 (7.7%)
Ranking	3 (3.8%)
National team vs other	3 (3.8%)
Selected vs not selected	4 (5.1%)
Starters reserve	1 (1.3%)
Not applicable	21 (26.9%)
Data analysis	
Bivariate analysis	52 (66.7%)
Multivariate analysis	24 (30.8%)
Qualitative analysis	2 (2.6%)
Type of data collection	
Battery of tests	71 (91%)
Secundary source database	1 (1.3%)
Interview with athletes	6 (7.7%)

Note: Bivariate analysis (T-test, X^2 test, Correlation, Intraclass Correlation, ANOVA, ANCOVA, Kruskal Wallis test, Mann-Whitney U test); Multivariate analysis (Linear Regression, Multiple Linear Regression, Canonical Correlation, Discriminant Analysis, Factor Analysis).

Table 3 demonstrates which are the indicators of sporting talent in volleyball most utilized in research. Among those restricted to the individual, anthropometric and physical-motor characteristics are the most used (62.8% and 56.4%, respectively). However, the psychological abilities were the indicator least analysed by the studies (7.7%). With regards to the indicator restricted to the task, 52.6% of the research studies used the quantity/quality of practice and/or training characteristics, and most of the time this indicator was used to characterize the sample. Lastly, those restricted to the environment, despite the subjective assessment of the coach being the most used among the research, only 20 studies out of the 78 analysed by this study utilized the perspective of the coach.

Table 3. Characteristics according to the types of variables analysed.

	N (%)
Individual restrictions	
Anthropometric characteristics	49 (62.8%)
Physical-motor characteristics	44 (56.4%)
Technical skills	17 (21.8%)
Tactical/cognitive skills	23 (29.5%)
Maturation	7 (9%)
Motor coordination	7 (9%)
Psychological abilities	6 (7.7%)
Task constraints	
Quantity/quality of practice/training	41 (52.6%)
Environmental constraints	
Socio-cultural characteristics	4 (5.1%)
Subjective evaluation by the coach	20 (25.6%)
Performance in competitions	14 (17.9%)

In addition, of the 78 articles analysed, only 16 (20.5%) adopted a multidimensional approach, i.e., they evaluated four or more indicators within sporting talent. In relation to the division of studies in terms of the approach adopted, the majority of studies utilized group comparisons (60.3%), followed by performance prediction (28.2%) and with little research into predicting the future success/progression in the career of the athlete (11.5%).

Table 4 presents the results of the articles on the group division, performance prediction and career progression, classified as positive, contradictory and negative. Regarding the group division studies, the variables of motor coordination, maturation and sociocultural characteristics were not used. There was a balance between positive, contradictory and negative results for the anthropometric indicator, while for the physical-motor, technical skill and psychological indicators the results were mainly positive and contradictory, with few negative ones.

Moreover, in the variable tactical/cognitive skills, quantity/quality of practice/training and subjective evaluation by the coach, there was a higher concentration of positive results compared to the others. Hence, for the performance in competitions, there was a balance between positive and negative results. For the performance prediction studies in almost all of the variables analysed, except quantity/quality of practice, there was an over-representation of the positive results in relation to negative ones. In relation to the career progression studies, there was a balance between positive and negative results for the anthropometric and physical-motor indicators and a greater concentration of positive results for the indicators: quantity/quality of practice/training, subjective assessment of the coach and, above all, for maturation and motor coordination, for which the results were 100% positive.

Table 4. Distribution of indicator results to group division, performance prediction and career path studies.

	Division of groups			Performance prediction		Career progression	
	Positive	Contradictory	Negative	Positive	Negative	Positive	Negative
Restricted to the individual							
Anthropometric characteristics	11 (35.6%)	10 (32.2%)	10 (32.2%)	7 (77.7%)	2 (22.3%)	1 (50%)	1 (50%)
Physical-motor characteristics	12 (41.4%)	11 (37.9%)	6 (20.7%)	14 (93.3%)	1 (6.7%)	1 (50%)	1 (50%)
Technical skills	5 (41.7%)	5 (41.7%)	2 (16.6%)	3 (75%)	1 (25%)	0 (0%)	0 (0%)
Tactical/cognitive skills	8 (57.1%)	5 (35.7%)	1 (7.2%)	8 (88.9%)	1 (11.1%)	0 (0%)	0 (0%)
Maturation	0 (0%)	0 (0%)	0 (0%)	2 (100%)	0 (0%)	1 (100%)	0 (0%)
Motor coordination	0 (0%)	0 (0%)	0 (0%)	4 (100%)	0 (0%)	2 (100%)	0 (0%)
Psychological skills	2 (40%)	3 (60%)	0 (0%)	1 (100%)	0 (0%)	0 (0%)	0 (0%)
Restricted to the task							
Quantity/quality of practice/training	7 (70%)	1 (10%)	2 (20%)	1 (50%)	1 (50%)	3 (60%)	2 (40%)
Restricted to the environment							
Socio-cultural characteristics	0 (0%)	0 (0%)	0 (0%)	1 (100%)	0 (0%)	2 (100%)	0 (0%)
Subjective evaluation of the coach	10 (83.3%)	2 (16.7%)	0 (0%)	4 (100%)	0 (0%)	2 (66.6%)	1 (33.4%)
Performance in competitions	3 (60%)	0 (0%)	2 (40%)	6 (85.7%)	1 (14.3%)	0 (0%)	0 (0%)

DISCUSSION

The objectives of this research were to investigate studies in the current literature on the area of sporting talent in volleyball, as well as to critically analyse what else has been researched on the subject, identify gaps and encourage new research. The results found demonstrate that there has been a significant increase in research publications in the field, especially in the last 10 years and with an greater emphasis in the last 2 years.

Most of the studies analysed adolescent female athletes at national level (intermediate), with samples ranging from 20 to 100 individuals, with a cross-sectional design, bivariate analysis and the application of test batteries. Among the most commonly assessed indicators were anthropometric and physical-motor characteristics, and more than half of the studies used comparisons between groups, with a large variety of terms (age categories, successful *vs.* unsuccessful, elite *vs*. sub-elite, among others). In addition, athletes from Brazil, Croatia and Spain were the most represented in this study.

Concerning the results found by the studies, the studies that compared groups had a balance between positive, contradictory and negative results for anthropometric characteristics, while for physical-motor indicators, technical and psychological skills there was a balance between positive and contradictory results, the latter being greater than the negative ones. In addition, there was a higher concentration of positive results compared to the others for the indicators tactical/cognitive skills, quantity/quality of practice/training and the subjective evaluation of the coach. Only the variable performance in competition showed a balance between positive and negative results. In regards to the performance prediction studies, there was an over-representation of positive results in relation to negative results for almost all the variables, except quantity/quality of practice/training, which showed a balance between positive and negative. The studies aimed at predicting future success/career progression that used anthropometric and physical-motor indicators had balanced positive and negative results. However, the indicators of motor coordination, sociocultural characteristics and maturation had 100% positive results. The indicators of subjective assessment of the coach and quantity/quality of practice/training had slightly more positive results than negative ones.

Regarding the gaps identified, there have been studies with samples of male athletes, international level (experts) and beginners (novices), longitudinal and retrospective studies, multivariate and qualitative analysis. Also, there has been little research evaluating psychological skills and few have used the subjective analysis of the coach. Another shortcoming are studies that adopted multidimensional analysis (those that assessed at least 4 indicators), and that took the approach of predicting future success/career progression. Furthermore, there were scarce studies both comparing groups and predicting performance that evaluated the indicators of psychological skills, motor coordination, sociocultural characteristics and maturation. And for studies predicting future success/career progression, the indicators of technical, tactical/cognitive, psychological skills and performance in competitions were the least analysed.

The present research analysed 78 articles about sports talent in volleyball between 2000 and 2022. It was found that in the first 10 years (2000 to 2009), the growth in publications was slow, and from 2010 onwards the number of studies began to grow rapidly. It is noteworthy that in the 4-year period from 2015 to 2019 there were 28.2% of studies included and in the last 2.5 years (2020 to mid-2022) there were also 28.2% of research included. This demonstrates that the area of sporting talent in volleyball has aroused the interest of the academic community, converging with the scoping review undertaken by Baker et al. (2020), in which they synthesized articles from the area of sporting talent encompassing various sports between the years 1990 to 2018.

Surprisingly, it was found that the female sex is more represented in the research on talent in volleyball, not corroborating what has been found in the literature on sporting talent. The review by Curran et al. (2019) analysed 276 articles on sporting talent and only 9.42% of them were on the female gender. Thus, although there is a certain scarcity of male studies of sporting potential in volleyball, women/girls have achieved an important prominence within volleyball. This result is probably due to the fact that female volleyball has gained worldwide prominence, which may have stimulated the development of research focused on this gender.

Furthermore, another relevant fact of this research is that, even though the inclusion criteria were only English-language articles, Brazil is among the 24 countries found that have published the most on sporting talent in volleyball, tied with Spain (11.5%) and higher than Portugal (10.3%). Probably, this result is due to the fact that Brazil is considered a world reference in volleyball, whether male or female, which may encourage Brazilian researchers to delve deeper into this area of knowledge and become a world reference in the academic world as well, when it comes to sporting talent in volleyball.

In relation to the age of the sample, more than half of the studies analysed adolescents, 33.3% both adolescents and adults (comparison by age group), and only 9% adult athletes (retrospective). This result was to be expected, given that one of the inclusion criteria is for studies involving a sample under the age of 18, with the exception of retrospective studies (which evaluated the career of the adult athlete). Therefore, it cannot be said that there is a shortage of research on athletes over 18. This is also true for studies with a short-tracking/intervention design, since one of the exclusion criteria are studies focused on the effect of training, which are mostly short-tracking.

However, a large disparity was observed between retrospective/longitudinal studies (11.5%) and cross-sectional studies (85.9%). This result is in accordance with the narrative review conducted by Barraclough et al. (2022), which assessed the reality of studies on sports talent in team sports in relation to methodological approaches. The researchers analysed that most studies on sporting talent are cross-sectional due to the ease of assessing athletes at a single point in time.

Despite, longitudinal and retrospective studies, on the other hand, are scarce because they are more labour-intensive (the former constantly dealing with dropout), since they contribute to assessing the long-term development of the athlete and the predictive value of aspects relating to performance, respectively. Unfortunately, cross-sectional studies are at odds with the fact that sporting talent is non-linear (Roberts et al., 2019), in which case, the characteristics change during the development process of the athlete. In other words, if an athlete possesses an excellent trait at a given time, this does not mean that this athlete will be successful in the future.

Regarding the type of analysis carried out by the studies, 66.7% used bivariate analysis, 30.8% multivariate analysis and only 2.6% qualitative analysis. According to Massa et al. (1999), bivariate analysis is that which relates variable by variable, however, it does not analyse the possible relationships between different variables and does not relate the importance of each variable in the period analysed. These two components are present in multivariate analysis, which can be seen as the most appropriate when analysing sports talent variables, because for an athlete to reach a high level (which is considered to be sports talent) there needs to be interaction between different factors, whether individual or environmental (Paula et al., 2021). In this way, it is recommended that future research into sporting talent be mindful of adopting multivariate analysis.

Additionally, only 20.5% (16 studies) were considered multidimensional, i.e., those that assessed at least 4 indicators of sporting talent. This reality contrasts with what is already known about sporting talent, which is considered multidimensional (Issurin, 2017), indicating a need to adjust research in this area. The systematic review by Piggott et al. (2019) analysed sports science research in the literature, including studies on sports talent, and the researchers reinforced the need for and importance of conducting research that links various sports science subdisciplines (such as physiological fitness, cognitive-motor ability, physical performance) to assess sports talent. Thus, even with research consolidating the multidimensional approach to talent, there are still few studies that have adopted this perspective.

Another important result is that the studies were divided into three categories: group comparison (60.3%), performance prediction (28.2%) and prediction of future success/career progression (11.5%). It can be seen that most of the studies focus on comparing groups, either by age group (26.9%) or by different levels of performance with distinct terminologies: elite vs sub-elite (9%), more skilled vs less skilled (7.7%), successful vs unsuccessful (7.7%), more experienced vs less experienced (6.4%), among others. Thus, although a variety of terms used in the literature is to be expected, perhaps this reality is due to the fact that there is still no clear concept of talent (Baker et al., 2019), which is influenced by its level of performance, since the experienced/expert athlete is the one who has reached the international level, therefore, he or she is the sporting talent.

In addition, in relation to the type of data collection, 91% of the studies included used batteries of tests, which are considered to be one of the best ways of identifying the determining indicators for high-level sport. Among the variables analysed by the studies, anthropometric characteristics (62.8%) and physical-motor characteristics (56.4%) were the ones that were covered most in the literature. This was to be expected, considering it has already been consolidated that high performance in volleyball requires the athlete to present, for example, high values for height and wingspan (Noori & Sadeghi, 2018), upper and lower limb strength (both important for the fundamentals of the sport and for vertical jumps) (Sarvestan et al., 2020; Tsoukos et al., 2019). The variable quality/quantity of practice/training (52.6%) was also widely utilized in the researches, since most of the studies which compared groups, compared athletes of different skill levels, in which the length of experience (quantity of practice) was employed (Castro et al., 2020; Gil et al., 2012).

Another important result of this study is that, although the importance of anthropometric indicators in the performance of volleyball athletes is well-established in the literature, there is a balance between positive, contradictory and negative results in studies comparing groups. This result may be due to the fact that the studies comparing different age groups (26.9%) were very heterogeneous in relation to the categories analysed, for example, the study by Majstorovic et al. (2020) which compared volleyball athletes from the U15, U17, U19 and U21 categories and the study by Cherouveim et al. (2020) that compared athletes born in 2006 and 2007. The first study found positive results in anthropometric indicators, given that the chronological age interval between the groups is much greater than the second study, which presented negative results. It is therefore expected that with the influence of maturation, the greater the difference in age, the greater the difference in some anthropometric indicators (Albaladejo-Saura et al., 2022). However, despite being able to construct this relationship in terms of the number of age categories that were compared, the reason for this balance between positive, contradictory and negative results for anthropometric indicators is still unclear.

The tactical/cognitive skill variable presented itself with less frequency in the literature (29.5%). This may be due to the difficulty in measuring decision-making, which has been shown to be a determining factor in volleyball performance (Afonso et al., 2012; Claver et al., 2016), which requires the athlete to choose the best decision in the shortest possible time, due to the dynamic and unpredictable nature of this modality. On the other hand, technical skills (21.8%) and performance in competitions (17.9%) were less analysed compared to the others already mentioned. Perhaps these indicators were given less prominence due to our exclusion criteria: studies that only evaluated match performance analysis. Therefore, we cannot affirm that there is a need for more research using these two indicators.

On the other hand, the subjective evaluation of the coach was used by 20 (25.6%) of the 78 articles included. This result shows that there is still little research that considers the opinion of the coach, considering that previous studies have demonstrated that the coach plays a fundamental role in the long-term training process of the athlete, as this agent is a determinant in the detection of talented athletes, since they can identify characteristics that test batteries cannot measure. This ability of the coach is based on their instinct through their professional experience (Roberts et al., 2019). One result of this research that corroborates this perspective is that 83.3% of the group comparison studies, 100% of the performance prediction studies and 66.6% of the career transition studies found positive results in the subjective evaluation of the coach, thus demonstrating that the coach has a high capacity to detect talented athletes.

Moreover, maturation (9%) and motor coordination (9%) were rarely addressed in the studies. This result needs to be analysed, since the maturation directly influences indicators such as height and muscle strength (Albaladejo-Saura et al., 2022), which are determinants in volleyball. In this way, an athlete with advanced (early) maturation can be seen as a sporting talent, while a late athlete can be "*left out*" in the talent identification process. Moreover, motor coordination, despite being trainable, has a great influence especially in the early years of long-term training, since it allows the athlete, at the beginning of their career, to master the technical fundamentals more easily (Stamm et al., 2005), in addition to already being positively related with the performance in the modality (Karalić et al., 2016).

In relation to the indicators of psychological skills (7.7%) and sociocultural characteristics (5.1%), these were the least studied. Among the psychological skills, although there is little research, it has already been consolidated in the literature that motivation, the resistance of the athlete in dealing with the pressure of training and competitions, and goal setting are determinants for performance in volleyball and maintenance of the athlete in the elite (Issurin, 2017; Milavić et al., 2013; Rabaz et al., 2015). Among the sociocultural characteristics is the support of the parents and coaches in the career trajectory of the athlete, as the retrospective study by Coutinho et al. (2021), analysed qualified and less qualified athletes, and the researchers concluded that those with higher qualification had parents with a moderate involvement in the sport and provided autonomy, and had demanding coaches who provided quality training compared to the less qualified group. Although psychological skills and sociocultural characteristics are important in athlete development, it seems that both are seen as secondary by the academic community, with anthropometric and physical-motor indicators seen as the main determinants of sporting talent in volleyball.

Another important result is that the performance prediction studies (28.2%) presented 75% or more positive results for practically all the variables (except quantity/quality of practice/training). This result demonstrates how each variable plays a fundamental and unique role in the performance of the talented volleyball athlete, thus showing that volleyball is multidimensional. In other words, in order to achieve high performance in the sport, it is necessary for indicators, whether restricted to the individual or the environment, to correlate positively with performance.

In addition, although this study brings important considerations about sporting talent in volleyball, it is subject to certain limitations, including, due to the exclusion criteria, the failure to address some important issues in the area of sporting talent in volleyball, including the effect of relative age (Rubajczyk & Rokita, 2020), and studies that interviewed and/or investigated the opinion of coaches (Milistetd et al., 2013). Another limitation is the fact that we only analysed studies in English, which made it impossible to include articles on talent from other languages, which could have contributed to our discussion. In addition, this research did not analyse the different definitions of talent provided by the studies, since according to Baker et al. (2019), there is still no complete clarity about the complexity of the definition of sporting talent. Finally, this study did not analyse the quality of the articles included, as some of them, for example, did not state the gender (9%) and skill level (7.7%) of the sample, which could provide a more accurate analysis of the current literature.

It is therefore recommended that new studies carry out a literature review in order to analyse the current definition of sporting talent. Another recommendation is for new studies to adopt a longitudinal or retrospective design, with multivariate analysis, developing relationships with various indicators (i.e., multidimensional), focusing on variables that are little studied in the literature, such as psychological skills, subjective evaluation by the coach, biological maturation, motor coordination and sociocultural characteristics, without neglecting the other indicators.

CONCLUSION

It can be concluded from the analysis of the 78 articles included that the area of volleyball sporting talent has grown in recent years and focuses on cross-sectional research, with bivariate analysis, comparison of groups, with batteries of tests and the female gender having greater relevance. However, there are only a few studies that employ a multidimensional approach, with a retrospective/longitudinal design, multivariate analysis and which used the male gender. Furthermore, the main indicators used were anthropometric and physical-motor characteristics, with psychological abilities, biological maturation, motor coordination and sociocultural characteristics as the indicators least studied in the literature. Although the subjective assessment of the coach is not the least important, it should be further developed in future research, as well as the less analysed indicators using a multidimensional approach.

AUTHOR CONTRIBUTIONS

Júlia Ribeiro de Oliveira, Francisco Zacaron Werneck and Mauricio Gattas Bara Filho designed the manuscript, actively participated in decisions related to the inclusion of studies and interpreted the results. Francisco Zacaron Werneck and Mauricio Gattas Bara Filho systematically guided Júlia Ribeiro de Oliveira during the article writing process, reviewed the manuscript and contributed technically to the quality of the manuscript. Júlia Ribeiro de Oliveira wrote the draft of the manuscript, conducted the literature search and data collection. Francisco Zacaron Werneck performed the statistical analysis and manuscript review. Mauricio Gattas Bara Filho supervised the study and review of the final version. All authors contributed to the creation of this manuscript, involved in the extensive article review, and reviewed versions of the final manuscript prior to submission.

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DISCLOSURE STATEMENT

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REFERENCES

Afonso, J., Garganta, J., McRobert, A., Williams, A. M., & Mesquita, I. (2012). The perceptual cognitive processes underpinning skilled performance in volleyball: Evidence from eye-movements and verbal reports of thinking involving an in situ representative task. Journal of Sports Science and Medicine, 11(2), 339-345.

Albaladejo-Saura, M., Vaquero-Cristobal, R., Garcia-Roca, J. A., & Esparza-Ros, F. (2022a). Influence of biological maturation status on selected anthropometric and physical fitness variables in adolescent male volleyball players. Peerj, 10, e13216. https://doi.org/10.7717/peerj.13216

Albaladejo-Saura, M., Vaquero-Cristobal, R., Garcia-Roca, J. A., & Esparza-Ros, F. (2022b). Influence of maturity status on kinanthropometric and physical fitness variables in adolescent female volleyball players. Applied Sciences, 12(9), 4400. https://doi.org/10.3390/app12094400

Altavilla, G., Esposito, G., Ceruso, R., Domenico, F., & D'Isanto, T. (2022). Profile and differences in anthropometric data and jumping ability performance between elite and amateur u16 volleyball players. Physical Education Theory and Methodology, 22(2), 237-241. https://doi.org/10.17309/tmfv.2022.2.13

Araujo, R., Afonso, J., & Mesquita, I. (2011). Procedural knowledge, decision-making and game performance analysis in female volleyball's attack according to the player's experience and competitive success. International Journal of Performance Analysis in Sport, 11(1), 1-13. https://doi.org/10.1080/24748668.2011.11868524

Arroyo, M. P. M., Dominguez, A. M., Arias, A. G., Garcia-Gonzalez, L., & Alvarez, F. D. (2016). Influence of experience in procedural knowledge in volleyball: Applications for training. International Journal of Sports Science & Coaching, 11(2), 191-199. https://doi.org/10.1177/1747954116637152

Baker, J., Wattie, N., & Schorer, J. (2015). Defining expertise: A taxonomy for researchers in skill acquisition and expertise. In Routledge handbook of sport expertise (pp. 145-155). Routledge. https://doi.org/10.4324/9781315776675-13

Baker, J., Wattie, N., & Schorer, J. (2019). A proposed conceptualization of talent in sport: The first step in a long and winding road. Psychology of Sport and Exercise, 43, 27-33. https://doi.org/10.1016/j.psychsport.2018.12.016

Baker, J., Wilson, S., Johnston, K., Dehghansai, N., Koenigsberg, A., Vegt, S., & Wattie, N. (2020). Talent research in sport 1990-2018: A scoping review. Frontiers in Psychology, 11, 607710. https://doi.org/10.3389/fpsyg.2020.607710

Barcelos, J. L., Morales, A. P., Maciel, R. N., Azevedo, M. M. dos A., & da Silva, V. F. (2009). Time of practice: A comparative study of the motor reaction time among volleybal players. Fitness & Performance Journal, 8(2), 103-109. https://doi.org/10.3900/fpj.8.2.103.e

Barraclough, S., Till, K., Kerr, A., & Emmonds, S. (2022). Methodological approaches to talent identification in team sports: A narrative review. Sports, 10(6), 81. https://doi.org/10.3390/sports10060081

Boichuk, R., Iermakov, S., Kovtsun, V., Levkiv, V., Ulizko, V., Kryzhanivskyi, V., Kovtsun, V., & Kazmiruk, A. (2020). Relation of the competitive activity effectiveness of volleyball players (girls) at the age of 16-18 with the physical development indicators. Journal of Physical Education & Sport, 20(2), 615-622. https://doi.org/10.7752/jpes.2020.02090

Boichuk, R., Iermakov, S., Nosko, M., Kovtsun, V., & Nosko, Y. (2017). Influence of motor coordination indicators on efficiency of game activity of volleyball players at the stage of specialized basic training. Journal of Physical Education & Sport, 17(4), 2632-2637. https://doi.org/10.7752/jpes.2017.04301

Boichuk, R., Iermakov, S., Vintoniak, O., Hrabchuk, A., & Bieliavskyi, I. (2020). Influence of psychophysiological factors on the effectiveness of competitive activity of volleyball players (girls) aged 16 to 18. Journal of Physical Education & Sport, 20(326), 2392-2399. https://doi.org/10.7752/jpes.2020.s4326

Bozo, D., & Lleshi, E. (2012). Comparison of Albanian female volleyball player with anthropometric, performance and haematological parameters. Journal of Human Sport & Exercise, 7(1), S41-S50. https://doi.org/10.4100/jhse.2012.7.Proc1.06

Buśko, K., Michalski, R., Mazur, J., & Gajewski, J. (2012). Jumping abilities in elite female volleyball players: Comparative analysis among age categories. Biology of Sport, 29(4), 317-319. https://doi.org/10.5604/20831862.1022654

Cabral, B. G. A. T., Cabral, S. D. A. T., Miranda, H. F., Dantas, P. M. S., & Reis, V. M. (2011). Discriminant effect of morphology and range of attack on the performance level of volleyball players. Brazilian Journal of Kineanthropometry & Human Performance, 13(3), 223-229. https://doi.org/10.5007/1980-0037.2011v13n3p223

Castro, H. O., Aguiar, S. S., Clemente, F. M., Lima, R. F., Oliveira, V., Ribas, S., Pedrosa, G. F., Laporta, L., & Costa, G. C. T. (2020). Association between motivation and decision-making in under-18 male volleyball players. Trends in Sport Sciences, 27(4), 183-189.

Cherouveim, E., Tsolakis, C., Ntozis, C., Apostolidis, N., Gkountas, K., & Koulouvaris, P. (2020). Anthropometric and physiological characteristics of 13-14-year-old female volleyball players in different playing positions. Journal of Physical Education & Sport, 20(6), 3642-3650. https://doi.org/10.7752/jpes.2020.06491

Claver, F., Jimenez, R., Garcia-Gonzalez, L., Fernandez-Echeverria, C., & Moreno, M. P. (2016). Cognitive and emotional factors as predictors of performance indicators in young volleyball players. International Journal of Performance Analysis in Sport, 16(1), 234-249. https://doi.org/10.1080/24748668.2016.11868883

Coutinho, P., Mesquita, I., Davids, K., Fonseca, A. M., & Cote, J. (2016). How structured and unstructured sport activities aid the development of expertise in volleyball players. Psychology of Sport and Exercise, 25, 51-59. https://doi.org/10.1016/j.psychsport.2016.04.004

Coutinho, P., Mesquita, I., Fonseca, A. M., & Cote, J. (2015). Expertise development in volleyball: The role of early sport activities and players' age and height. Kinesiology, 47(2), 215-225. Retrieved from [Accessed 2024, July 10]: https://hrcak.srce.hr/150549

Coutinho, P., Mesquita, I., Fonseca, A. M., & Martin-Silva, L. (2014). Patterns of sport participation in Portuguese volleyball players according to expertise level and gender. International Journal of Sports Science & Coaching, 9(4), 579-592. https://doi.org/10.1260/1747-9541.9.4.579

Coutinho, P., Ramos, A., Fonseca, A. M., Davids, K., & Mesquita, I. (2021). The nature of formative physical activities and sports in the development of senior volleyball players. International Journal of Sports Science & Coaching, 16(3), 731-740. https://doi.org/10.1177/1747954121992040

Coutinho, P., Ribeiro, J., Silva, S. M., Fonseca, A. M., & Mesquita, I. (2021). The influence of parents, coaches, and peers in the Long-term development of highly skilled and less skilled volleyball players. Frontiers in Psychology, 12, 667542. https://doi.org/10.3389/fpsyg.2021.667542

Curran, O., MacNamara, A., & Passmore, D. (2019). What about the girls? Exploring the gender data gap in talent development. Frontiers in Sports and Active Living, 1(3). https://doi.org/10.3389/fspor.2019.00003

Davila-Romero, C., Hernandez-Mocholi, M. A., & Garcia-Hermoso, A. (2015). Technical player profiles related to the physical fitness of young female volleyball players predict team performance. Journal of Sports Medicine and Physical Fitness, 55(3), 137-143.

Formenti, D., Trecroci, A., Duca, M., Vanoni, M., Ciovati, M., Rossi, A., & Alberti, G. (2022). Volleyball-specific skills and cognitive functions can discriminate players of different competitive levels. Journal of Strength and Conditioning Research, 36(3), 813-819. https://doi.org/10.1519/JSC.0000000000003519

Gabbett, T., Georgieff, B., Anderson, S., Cotton, B., Savovic, D., & Nicholson, L. (2006). Changes in skill and physical fitness following training in talent-identified volleyball players. Journal of Strength and Conditioning Research, 20(1), 29-35. https://doi.org/10.1519/00124278-200602000-00005

Gabbett, T., Georgieff, B., & Domrow, N. (2007). The use of physiological, anthropometric, and skill data to predict selection in a talent-identified junior volleyball squad. Journal of Sports Sciences, 25(12), 1337-1344. https://doi.org/10.1080/02640410601188777

Gil, A., Moreno, M. P., Garcia-Gonzalez, L., Moreno, A., & Villar, F. (2012). Analysis of declarative and procedural knowledge in volleyball according to the level of practice and players' age. Perceptual and Motor Skills, 115(2), 632-644. https://doi.org/10.2466/30.10.25.PMS.115.5.632-644

Gil, A., Moreno, M. P., Moreno, A., Garcia-Gonzalez, L., Claver, F., & Del Villar, F. (2013). Analysis of the relationship between the amount of training and cognitive expertise. A study of young volleyball players. Journal of Strength and Conditioning Research, 27(3), 698-702. https://doi.org/10.1519/JSC.0b013e31825d99c9

Grgantov, Z., Katic, R., & Jankovic, V. (2006). Morphological characteristics, technical and situation efficacy of young female volleyball players. Collegium Antropologicum, 30(1), 87-96. Retrieved from [Accessed 2024, July 10]: https://hrcak.srce.hr/8896

Grgantov, Z., Milic, M., & Katic, R. (2013). Identification af explosive power factors as predictors of player quality in young female volleyball players. Collegium Antropologicum, 37(2), 61-68. Retrieved from [Accessed 2024, July 10]: https://hrcak.srce.hr/102458

Grgantov, Z., Nedovic, D., & Katic, R. (2007). Integration of technical and situation efficacy into the morphological system in young female volleyball players. Collegium Antropologicum, 31(1), 267-273.

Hancock, D. J., Coutinho, P., Côté, J., & Mesquita, I. (2018). Influences of population size and density on birthplace effects. Journal of Sports Sciences, 36(1), 33-38. https://doi.org/10.1080/02640414.2016.1276614

Ilics, K. B., Bakk, A. B., & Suskovics, C. (2013). Researching the aptitude of young volleyball players (children and adolescents). Journal of Human Sport & Exercise, 8(2), S61-S71. https://doi.org/10.4100/jhse.2012.8.Proc2.08

Issurin, V. B. (2017). Evidence-based prerequisites and precursors of athletic talent: A review. Sports Medicine, 47(10), 1993-2010. https://doi.org/10.1007/s40279-017-0740-0

Jakubšova, Z., Vaverka, F., & Jandačka, D. (2011). Comparison of the lower extremities' explosive muscular strength via jumping tests in different performance level and age groups of women volleyball players. Acta Gymnica, 41(4), 7-15. https://doi.org/10.5507/ag.2011.021

Jandova, S., & Janura, M. (2019). Jumping performance and take-off efficiency in two different age categories of female volleyball players. Acta of Bioengineering and Biomechanics, 21(2), 55-61.

Johnston, K., Wattie, N., Schorer, J., & Baker, J. (2018). Talent identification in sport: A systematic review. Sports Medicine, 48, 97-109. https://doi.org/10.1007/s40279-017-0803-2

Karalić, T., Ljubojević, A., Gerdijan, N., & Vukić, Ž. (2016). Correlation of specific coordination by young female volleyball players and performance level of technical elements in volleyball. SportLogia, 12(1), 1-16. https://doi.org/10.5550/sgia.161201.en.KLGV

Katic, R., Grgantov, Z., & Jurko, D. (2006). Motor structures in female volleyball players aged 14-17 according to technique quality and performance. Collegium Antropologicum, 30(1), 103-112.

Kitamura, K., Pereira, L. A., Kobal, R., Abad, C. C. C., Finotti, R., Nakamura, F. Y., & Loturco, I. (2017). Loaded and unloaded jump performance of top-level volleyball players from different age categories. Biology of Sport, 34(3), 273-278. https://doi.org/10.5114/biolsport.2017.67123

Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gøtzsche, P. C., Ioannidis, J. P., Clarke, M., Devereaux, P. J., Kleijnen, J., & Moher, D. (2009). The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: Explanation and elaboration. Annals of Internal Medicine, 151(4), W-65-W-94. https://doi.org/10.7326/0003-4819-151-4-200908180-00136

Lidor, R., Arnon, M., Hershko, Y., Maayan, G. I. L., & Falk, B. (2007). Accuracy in a volleyball service test in rested and physical exertion conditions in elite and near-elite adolescent players. Journal of Strength & Conditioning Research, 21(3), 937-942. https://doi.org/10.1519/00124278-200708000-00047

Lidor, R., Hershko, Y., Bilkevitz, A., Arnon, M., & Falk, B. (2007). Measurement of talent in volleyball: 15-month follow-up of elite adolescent players. Journal of Sports Medicine and Physical Fitness, 47(2), 159-168.

Lopes, M. C., Magalhães, T., Diniz, L. B. F., Moreira, J. P. A., & Albuquerque, M. R. (2016). The influence of technical skills on decision making of novice volleyball players. Brazilian Journal of Kineanthropometry & Human Performance, 18(3), 362-370. https://doi.org/10.5007/1980-0037.2016v18n3p362

Majstorovic, N., Dopsaj, M. M., Grbic, V., Savic, Z., Vicentijevic, A., Anicic, Z., Zadraznik, M., Toskic, L., & Nesic, G. (2020). Isometric strength in volleyball players of different age: A multidimensional model. Applied Sciences, 10(12), 4107. https://doi.org/10.3390/app10124107

Mala, L., Maly, T., Zahalka, F., & Bunc, V. (2010). The profile and compartion of body composition of elite female volleyball players. Kinesiology, 42(1), 90-97.

Marinho, B., & Chagas, D. D. (2022). Can motor coordination level predict performance on volleyball skills in youth? Retos: Nuevas Tendencias En Educacion Fisica Deporte Y Recreacion, 45, 195-201. https://doi.org/10.47197/retos.v45i0.90359

Massa, M., Tanaka, N. I., Berti, A. F., Böhme, M. T. S., & Massa, I. C. M. (1999). Análises univariadas e multivariadas na classificação de atletas de voleibol masculino. Revista Paulista de Educação Física, 13(2), 131-145. https://doi.org/10.11606/issn.2594-5904.rpef.1999.137863

Matušov, M., Zapletalová, L., Duchoslav, L., & Hagara, M. (2013). Relationship between the height of jump reach and the height of ball contact at spike in two different age categories of female volleyball players. Acta Facultatis Educationis Physicae Universitatis Comenianae, 53(2), 23-32.

Melrose, D. R., Spaniol, F. J., Bohling, M. E., & Bonnette, R. A. (2007). Physiological and performance characteristics of adolescent club volleyball players. Journal of Strength & Conditioning Research, 21(2), 481-486. https://doi.org/10.1519/00124278-200705000-00034

Mendes, F. G., Nascimento, J. V., Souza, E. R., Collet, C., Milistetd, M., Cote, J., & Carvalho, H. M. (2018). Retrospective analysis of accumulated structured practice: A Bayesian multilevel analysis of elite Brazilian volleyball players. High Ability Studies, 29(2), 255-269. https://doi.org/10.1080/13598139.2018.1507901

Milavić, B., Grgantov, Z., & Milić, M. (2013). Relations between coping skills and situational efficacy in young female volleyball players. Facta Universitatis: Series Physical Education & Sport, 11(2), 165-175.

Milic, M., Grgantov, Z., Chamari, K., Ardigo, L. P., Bianco, A., & Padulo, J. (2017). Anthropometric and physical characteristics allow differentiation of young female volleyball players according to playing position and level of expertise. Biology of Sport, 34(1), 19-26. https://doi.org/10.5114/biolsport.2017.63382

Milic, M., Grgantov, Z., & Katic, R. (2013). Impact of biomotor dimensions on player quality in young female volleybal players. Collegium Antropologicum, 37(1), 93-99.

Milistetd, M., Mesquita, I., Sobrinho, S., A., Carrara, P., & Nascimento, J. (2013). Coaches representation about detection and selection of talents on the brazilian volleyball. International Journal of Sports Science, 3(5), 157-162.

Misovski, A., Milenkoski, J., Zadraznik, M., Vasileva, F., & Markovski, N. (2019). Comparative analysis of motor abilities between players of youth and junior national volleyball teams in Macedonia. Research in Physical Education, Sport & Health, 8(1), 23-26.

Mostaert, M., Pion, J., Lenoir, M., & Vansteenkiste, P. (2020). A retrospective analysis of the national youth teams in volleyball: Were they always faster, taller, and stronger? The Journal of Strength & Conditioning Research, 1-7. https://doi.org/10.1519/JSC.0000000000003847

Mroczek, D., Superlak, E., Kawczynski, A., & Chmura, J. (2017). Relationships between motor abilities and volleyball performance skills in 15-year-old talent-identified volleyball players. Baltic Journal of Health and Physical Activity, 9(1), 17-27. https://doi.org/10.29359/BJHPA.09.1.02

Nasuka, N., Setiowati, A., & Indrawati, F. (2020). Power, strength and endurance of volleyball athlete among different competition levels. Utopia y Praxis Latinoamericana, 25(10), 15-23. https://doi.org/10.5281/zenodo.4155054

Nesic, G. P., Majstorović, N., Sikimić, M. M., Marković, S., Ilić, D., Grbić, V. M., Osmankač, N., & Savić, Z. (2014). Anthropometric characteristics and motor abilities in 13-15 years old female volleyball players. Facta Universitatis, 12, 327-339.

Nikolaidis, P. T., Ziv, G., Arnon, M., & Lidor, R. (2012). Physical characteristics and physiological attributes of female volleyball players- the need for individual data. Journal of Strength and Conditioning Research, 26(9), 2547-2557. https://doi.org/10.1519/JSC.0b013e31823f8c06

Noori, M., & Sadeghi, H. (2018). Designing smart model in volleyball talent identification via fuzzy logic based on main and weighted criteria resulted from the analytic hierarchy process. Journal of Advanced Sport Technology, 2(1), 16-24.

Palao, J. M., & Valades, D. (2016). Validity of the standing and jump spike tests for monitoring female volleyball players of different levels of competition. International Journal of Performance Analysis in Sport, 16(3), 1102-1108. https://doi.org/10.1080/24748668.2016.11868951

Papadopoulou, S. D., Zorzou, A., Garcia-de-Alcaraz, A., Rosemann, T., Knechtle, B., & Nikolaidis, P. T. (2020). Subcutaneous adipose tissue in female volleyball players: Is it related with performance indices? Medicina, 56(4), 159. https://doi.org/10.3390/medicina56040159

Paula, H. L. B., Coelho, E. F., Barbosa, D. M., Matta, M. de O., Marins, J. C. B., & Werneck, F. Z. (2021). Indicadores multidimensionais do potencial esportivo de jovens futebolistas. Revista Brasileira de Futebol, 14(2), 49-68.

Piggott, B., Müller, S., Chivers, P., Papaluca, C., & Hoyne, G. (2019). Is sports science answering the call for interdisciplinary research? A systematic review. European Journal of Sport Science, 19(3), 267-286. https://doi.org/10.1080/17461391.2018.1508506

Pion, J. A., Fransen, J., Deprez, D. N., Segers, V. I., Vaeyens, R., Philippaerts, R. M., & Lenoir, M. (2015). Stature and jumping height are required in female volleyball, but motor coordination is a key factor for future elite success. Journal of Strength and Conditioning Research, 29(6), 1480-1485. https://doi.org/10.1519/JSC.0000000000000778

Rabaz, F. C., Costuera, R. J., Suarez, M. C., González, L. C., & Arroyo, M. P. M. (2015). Cognitive and motivational variables as predictors of performance in game actions in young volleyball players. European Journal of Human Movement, 35, 68-84.

Rikberg, A., & Raudsepp, L. (2011). Multidimensional performance characteristics in talented male youth volleyball players. Pediatric Exercise Science, 23(4), 537-548. https://doi.org/10.1123/pes.23.4.537

Roberts, A. H., Greenwood, D. A., Stanley, M., Humberstone, C., Iredale, F., & Raynor, A. (2019). Coach knowledge in talent identification: A systematic review and meta-synthesis. Journal of Science and Medicine in Sport, 22(10), 1163-1172. https://doi.org/10.1016/j.jsams.2019.05.008

Rubajczyk, K., & Rokita, A. (2020). The relative age effect and talent identification factors in youth volleyball in Poland. Frontiers in Psychology, 11(1445). https://doi.org/10.3389/fpsyg.2020.01445

Sarvestan, J., Svoboda, Z., & Claudino, J. G. D. (2020). Force-time curve variables of countermovement jump as predictors of volleyball spike jump height. German Journal of Exercise and Sport Research, 50(4), 470-476. https://doi.org/10.1007/s12662-020-00676-5

Schaal, M., Ransdell, L. B., Simonson, S. R., & Gao, Y. (2013). Physiologic performance test differences in female volleyball athletes by competition level and player position. Journal of Strength and Conditioning Research, 27(7), 1841-1850. https://doi.org/10.1519/JSC.0b013e31827361c4

Schorer, J., Rienhoff, R., Fischer, L., & Baker, J. (2013). Foveal and peripheral fields of vision influences perceptual skill in anticipating opponents' attacking position in volleyball. Applied Psychophysiology Biofeedback, 38(3), 185-192. https://doi.org/10.1007/s10484-013-9224-7

Serenini, A. L. P., Rueda, F. J. M., & Moreno, M. P. (2021). Attention and visuospatial reasoning in high-performance volleyball players. Ciencias Psicologicas, 15(1), e-2348. https://doi.org/10.22235/cp.v15i1.2348

Slovak, L., Zahradnik, D., Farana, R., Svoboda, Z., Alaei, F., & Sarvestan, J. (2022). Kinetic analysis of volleyball spike jump among young female volleyball players. International Journal of Performance Analysis in Sport, 22(1), 66-76. https://doi.org/10.1080/24748668.2021.1996906

Stamm, R., Stamm, M., & Koskel, S. (2002). Age, body build, physical ability, volleyball technical and psychophysiological tests and proficiency at competitions in young female volleyballers (aged 13-16 years). Papers on Anthropology, 11, 253-282.

Stamm, R., Stamm, M., & Koskel, S. (2006). Adolescent female volleyballers' (aged 13-15 years) body build classification and proficiency in competitions. Anthropologischer Anzeiger, 64(4), 423-433. https://doi.org/10.1127/anthranz/64/2006/423

Stamm, R., Stamm, M., & Thomson, K. (2005). Role of adolescent female volleyball players' psychophysiological properties and body build in performance of different elements of the game. Perceptual and Motor Skills, 101(1), 108-120. https://doi.org/10.2466/pms.101.1.108-120

Stanovic, N., Milic, M., & Grgantov, Z. (2020). Competitive state anxiety and self-esteem in youth female volleyball players of different player roles and competitive efficacy. Acta Kinesiologica, 14(1), 64-69.

Superlak, E. (2006). The structure of volleyball playing dispositions in players aged 14-15, cadidates for the polish national team. Human Movement, 7(2), 118-129.

Tessutti, L. S., da Silva Aguiar, S., De Conti Teixeira Costa, G., Clemente, F. M., Lima, R. F., Passos Neves, R. V., Moreira Praça, G., & de Oliveira Castro, H. (2019). Body composition and performance variables differences in female volleyball players by age-group and playing position. Brazilian Journal of Kineanthropometry & Human Performance, 21, e60131. https://doi.org/10.1590/1980-0037.2019v21e60131

Trecroci, A., Duca, M., Cavaggioni, L., Rossi, A., Scurati, R., Longo, S., Merati, G., Alberti, G., & Formenti, D. (2021). Relationship between cognitive functions and sport-specific physical performance in youth volleyball players. Brain Sciences, 11(227). https://doi.org/10.3390/brainsci11020227

Tricco, A. C., Lillie, E., Zarin, W., O'Brien, K. K., Colquhoun, H., Levac, D., Moher, D., Peters, M. D., Horsley, T., & Weeks, L. (2018). PRISMA extension for scoping reviews (PRISMA-ScR): Checklist and explanation. Annals of Internal Medicine, 169(7), 467-473. https://doi.org/10.7326/M18-0850

Tsoukos, A., Drikos, S., Brown, L. E., Sotiropoulos, K., Veligekas, P., & Bogdanis, G. C. (2019). Upper and lower power are strong predictors for selection of male junior national volleyball team players. Journal of Strength and Conditioning Research, 33(10), 2760-2767. https://doi.org/10.1519/JSC.0000000000002472

Vitaić, S., Erceg, M., & Milić, M. (2015). Differences in pulmonary ventilation function parameters in young volleyball players according to competitive success criterion. Research in Physical Education, Sport & Health, 4(2), 113-117.

Waelle, S., Van Bostraeten, S., Lenoir, M., Deconinck, F. J. A., & 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

Waelle, S., Warlop, G., Lenoir, M., Bennett, S. J., & Deconinck, F. J. A. (2021). The development of perceptual-cognitive skills in youth volleyball players. Journal of Sports Sciences, 39(17), 1911-1925. https://doi.org/10.1080/02640414.2021.1907903

Yavuz, S. C. (2015). Somatic and physical characteristics of adolescent female volleyball teams at different success levels. Anthropologist, 21(3), 427-438. https://doi.org/10.1080/09720073.2015.11891832

Zafirovska, A., & Daskalovski, B. (2012). Relations between some anthropometric characteristics and assess situation-motoric knowledge serve for the woman volleyball players in the age of 14-18. Activities in Physical Education & Sport, 2(2), 195-197.

ORIGINAL ARTICLE

A Tabata-based high-intensity interval training study on body composition and physical fitness in sedentary university female students

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ABSTRACT

The current investigation explored the impact of given 12-week Tabata training intervention on decreasing body composition and overall physical performance among sedentary female students. The study involved the random assignment of forty undergraduate women into two groups for the purpose of this research. The age of individuals spans from 18 to 23. The study consisted of two groups: the control group (CG N = 20) and experimental group (EG N = 20). The experimental group engaged in a 12-week Tabata training routine. Pre and post data were calculated with the dependent variables, which comprises height, weight, body mass index, waist circumference, speed, agility, endurance, abdominal strength, and leg strength. Followed by the statistical analysis of the collected data. The majority of the enhancements resulted in a decrease in BMI and waist-to-hip ratio. In addition to that there was a rise in physical performance, including improved abilities in areas such as speed, agility, endurance, abdominal strength, and leg strength of sedentary female students.
Keywords: Sport medicine, Tabata exercise, Motor fitness, Body composition, Sedentary lifestyle, Females.

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INTRODUCTION

The World Health Organisation defines inactivity as non-participation in a minimum of 150 minutes in a week of moderate-intensity aerobic activity. Füzéki & Banzer (2018) reported that a minimum of 75 minutes of high-intensity exercise in a week, or a combination of high and low intensities, Gaetano (2016), is beneficial to maintain good health. Health and lifestyle are strongly related to each other. Inactivity ranks as the fourth major cause of death worldwide, resulting in four to five million unnecessary deaths. According to the research by Dishman, Heath, Schmidt, and Lee (2021), there is a strong link between a sedentary lifestyle and specific health issues. Physical inactivity is widely seen as a potentially dangerous attribute that leads to a range of health issues (Bull & Bauman, 2011). As a result, elderly individuals who do not engage in physical activity experience reduced muscle and bone growth, which in turn raises their chances of acquiring serious health conditions.

Engaging in regular physical exercise produces advantageous results for both physical and emotional well-being. Consistent engagement in physical activity has the potential to significantly decrease the mortality rate (Taylor et al., 2004). Specifically, it helps decrease the probability of getting coronary heart disease, stroke, high blood pressure, colon cancer, and other related illnesses. Scientific studies have consistently indicated that participating in appropriate physical activity can enhance the general well-being and quality of life for individuals of all ages and health problems (Blair & Morris, 2009). Physical exercise encompasses any form of physical activity that involves the movement of skeletal muscles and necessitates the use of energy (Dasso, 2019). Physical exercise encompasses many types of movement, done for pleasure, transit, or employment, that involve both vigorous and moderately intensive activity with the goal of improving physical well-being (Jackson, 2004). Empirical data has shown that regularly participating in physical exercise helps to control and prevent non-infectious diseases, like cardiovascular disease, stroke, diabetes, and various forms of cancers. In addition, it regulates blood pressure, facilitates a healthy body weight, and enhances mental well-being, so improving the overall standard of life (Lee et al., 2012).

According to a recent study, HIIT (High-Intensity Interval Training) is the most effective training for physical exercise. This workout routine involves short bursts of intense activity, usually at 75% of the maximum heart rate, and can last for several minutes (Roxburgh, Nolan, Weatherwax, & Dalleck, 2014). Recent research has revealed that HIIT (High-Intensity Interval Training) enhances physical fitness, particularly in terms of body composition, cardiorespiratory health, and physical efficiency (Andersen et al., 2020). From a time and convenience point of view, HIIT appears to help individuals who are not engaged in regular physical activity overcome significant barriers in order to maintain a healthy lifestyle. Tabata training is a kind of HIIT (High-Intensity Interval Training), currently undergoing a substantial surge in popularity. Interval exercise stimulates a metabolic increase that leads to significant benefits in lowering the buildup of body fat. Tabata is a type of HIIT (high-intensity interval training) that was introduced by researcher Izumi Tabata in 1996 (Tabata, 2019). The objective of HIIT using the Tabata training regimen enhance aerobic and anaerobic capacity, fortify ligaments and muscles, and elevate resting metabolism, finally resulting in a gradual reduction in body fat. This interval training regimen is specifically tailored to provide a cardiovascular exercise aimed in reducing body fat (Murawska-Cialowicz et al., 2020).

The Tabata program employs the HIIT (High-Intensity Interval Training) technique, which involves 8 cycles of brief and intense exercise lasts for 20 seconds, followed by 10 seconds of rest. The curriculum incorporates high-intensity workouts that efficiently excite the cardiac muscle and enhance metabolic processes, leading to a prolonged 24-hour post-training benefit (Olson, 2014). Prior research studies investigating the impact of Tabata exercise on adipose tissues have primarily focused on adolescents (Emberts, Porcari, Dobers-Tein, Steffen, & Foster, 2013), obese men (Andersen et al., 2020), and obese women (Shah & Purohit, 2020; Zhang et al., 2015). The aforementioned studies have demonstrated notable improvements in anaerobic capacity and the physical and motor characteristics of athletes (Mulazimoglu, Boyaci, Afyon, & Çelikbilek, 2021), (Afyon, Mulazimoglu, Celikbilek, Dalbudak, & Kalafat, 2021; Munandar, Setijono, & Kusnanik, 2022). While there has been considerable study on the physiological responses to regular and consistent exercise, there is a lack of studies explicitly examining its effects on adult women. Early studies on the impact of Tabata training have shown a dearth of evidence regarding its effects, specifically in terms of reducing fat in sedentary adults with advanced physical fitness. Carrying out a study to assess the benefits of Tabata training on physically inactive women, has the potential to establish this group fitness program as a novel method for promoting healthy recreational activities. The Tabata protocol is a time-efficient training technique that allows for regular exercise without requiring a significant amount of time every session, therefore enhancing long-term sustainability. The study should be able to determine if a Tabata 12-week training program will lead to a reduction in body composition and enhancement of physical performance among sedentary women.

MATERIAL AND METHODS

Participants

The study comprised 45 participants who were in a state of good health, with an average age of 20.73 ± 1.83 years. The participants were recruited through various avenues, such as posters, emails, and social media sites. Table 1 gives a comprehensive overview of the physical attributes of the participants. Non-athletic, untrained female volunteers readily agreed to participate in the study. Physical inactivity is defined as the lack of participation in any type of physical activity for at least one hour in a week during a period of at least 12 months. The present study recruited people who satisfied the following criteria: (1) individuals who abstained from medication, and (2) those who had engaged in little physical activity, namely no exercise in the six months preceding the study. Participants granted their informed consent by affixing their signature to a written document, indicating their comprehensive understanding of the experiment's objectives and the potential adverse outcomes. We have eliminated adolescent girls from our study who have chronic illnesses, recent joint replacements, lower limb fractures within the preceding six months, or severe cognitive impairments.

Participants were randomly given either an experimental group (EXP -1) or a control group (CON-2) using a random allocation software 2.1 in a controlled trial design. During the training session, five individuals left because of health problems and personal circumstances, leaving a total of 40 active participants. Upon obtaining an elaborate account of the training conditions and comprehending the potential adverse outcomes, the participants expressed their consent by affixing their signatures. Subsequently, the 20 experimental participants were then separated in to two distinct groups, that is, experimental group and control group, with 20 persons in each group. Since only 40 participants completed the 12-week investigation successfully, only the data of those 40 participants were considered in the analysis. Four participants dropped out of the study and there was a n = 5 (Figure 1). In their study, Park et al. (2020) based the sample size on an effect size of 0.49, an alpha value of .05, and a power of 0.80. Therefore, the calculation estimated a sample size of 12 participants to achieve statistical significance. The experimental dimensions were calculated by using G*Power software, version 3.1.9.7, developed by Heinrich-Heine-UniversitätinDüsseldorf, Germany.

Procedure

The study adopted the methodology of randomized controlled experimentation. Every subject participating in the study conducted a 12-week High-Intensity Interval Training plan that consisted of 36 sessions, and all subjects completed the study. The intervention was a schedule of three sessions a week, where each session lasted for 35-45 minutes. The workout routine included 15-minute warm-up followed by 4-minute training followed by 10-minute cool-down. The sessions took place only within the confines of the indoor stadium and were conducted and observed from 7:30 to 8:30 in the morning. Data was gathered before and during the intervention at two distinct time intervals. Prior to the baseline and post-test assessments, the volunteers were given instructions to abstain from drug use, alcohol consumption, and extreme physical activities for a period of two days. The participants arrived promptly at 8:00 a.m. for the first measurement session. The subjects underwent a thorough body composition examination and their speed, agility, and sit-up performance were evaluated in a controlled setting. On the second day, at the same time, they participated in a stamina exercise called the standing long jump.

The individuals' height was measured using a stadiometer, while morphological traits like body weight, BMI, and WHR (waist-hip ratio) were determined using an Accuniq B-C 380 body composition analyser. The physical fitness exam comprises multiple components that assess various facets of fitness. The assessment battery of a 50-meter sprint to evaluate speed, a (4x10) shuttle run to examine agility, a step test to measure endurance, sit-up test to gauge muscular strength, and a broad leap to evaluate explosive power. Following the administration of the pre-test scheduled for next week, the experimental group will commence their training interventions. The identical methodologies employed for gathering initial data were also utilized for assessing post-test data subsequent to the training session.

Body composition assessments

The participants were instructed to go to the indoor stadium at 9:30 am dressed appropriately, following a briefing on the regulations. The subject complied with all instructions given by the investigator. The main purpose of using a stadiometer is to measure the height of the participants. In addition, the Standard Accuniq B-C 380 model body composition analyser calculates morphological measurements comprising body weight, WHR (waist-hip ratio), and BMI.

Physical efficiency assessments

The assessment of aerobic capacity was conducted using the Harvard Step Test. Afterwards, PEI (Physical Efficiency Index) was calculated. The test's reliability is deemed adequate, as determined by the intraclass correlation coefficient. The Harvard Step Test is advantageous due to its minimal equipment requirements, lack of calibration necessity, and suitability for indoor administration. The athlete executes a periodic motion of ascending and descending on the platform at a rate of 30 steps in a minute (equal to one step every two seconds) for a length of 5 minutes or until experiencing fatigue. Exhaustion is defined as the athlete's inability to maintain the stepping movement for a duration of 15 seconds. After finishing the test, the athlete immediately sits down and the total number of heartbeats is measured for a period of 1 to 1.5 minutes while monitoring the heart rate. The Fitness Index is calculated by dividing the product of the test duration in seconds and 100 by the product of the number of heartbeats recorded between 1 and 1.5 minutes and 5.5. The PEI (Physical Efficiency Index) is calculated using the formula by Bajaj, Appadoo, Bector, and Chandra (2008). The formula for PEI can be written as $PEI = (100 \times L)/ (5.5 \times p)$, where L represents the duration of the test in seconds ($L < 300$ seconds) and p indicates the heart rate within 1.5 minutes after the subject finished the test.

The purpose of the 50M Dash test was to assess an individual's speed. The test entails doing a solitary maximal sprint across a distance of 50 metres, while recording the elapsed time. Following the warm-up, it is advisable to incorporate workouts that specifically target initiating movement and enhancing speed. Commencing motion by placing one foot in front of the other when in a still position. Once the subject has been prepared and is completely still, the initiator provides the command to begin. Participants are permitted to conduct two trials, and the fastest time achieved is documented (Suleiman et al., 2019).

30-second sit-up test estimated the number of sit-ups performed while holding both hands at the sides of the head, knees bent at a 90-degree angle, and feet firmly held by another person. A complete sit-up is achieved when the knees make contact with the elbows and the shoulders are subsequently lowered to the floor. The precise tally of sit-ups performed with proper form within a 30-second timeframe was documented. Throughout the assessments, the evaluators intermittently notified the participants of the time left, delivering updates at intervals of 10, 20, and 30 seconds. No more verbal assistance was provided during the exam, save for audibly tallying the repetitions. All participants completed the test on a single occasion (Diener, 1992).

The shuttle run (4x10 m) was performed according to the protocol described by Ruiz et al. (2006). Two lines were laid on the ground, 10 yards apart. Subjects raced to the other line, and immediately back to the starting line, touching each line with both feet. The experimenter stood at the starting line and started stopwatch when the subjects crossed the line with one foot. The test time was measured to one decimal place. Each subject wore athletic clothing and was tested twice, with a 5-minute break between tests. The time obtained, which was the fastest, was selected.

The broad leap is a test that measures an individual's leg strength (Maulder & Cronin, 2005). The individual positions oneself behind a designated line on the ground, with their feet slightly separated. The approach employed entails a bipedal take-off and landing, whereby arm oscillation and knee flexion are utilized to provide anterior propulsion. The athlete aims to achieve maximum distance in their jump, skilfully landing on both feet without sacrificing their balance in a backward orientation. The measurement is determined by measuring the distance between the take-off line and the point of contact on the landing that is closest, and the greatest distance achieved in a jump is recorded based on three attempts.

Training Intervention

Tabata training sessions were conducted three times per week in the evening, precisely between 4:30 to 5:30 p.m. During non-business hours. There were a total of 36 training sessions. Every individual in the TPG participated in the 12-week Tabata exercise regimen, as illustrated in Table 1. The instruction was carried out by the research scholar. Each training session could not exceed 30 minutes and included warm-up, Tabata program, cool-down, and stretching. The warm-up session took 15 minutes to complete and involved performing basic exercises that increase mobility to get the body ready for the rest of the exercise program. A Tabata program consists of 8 cycles, each of which lasted for four minutes. There was a one-minute interval in between each round, thus the total exercise time amounts to 20 minutes. Each cycle completes a structured plan of exercising for 20 seconds and active recovery for 10 seconds. The concluding section of the workout entails a 10-minute time of relaxation and stretching. This entails engaging in activities such as listening to soothing music and concentrating on establishing a state of relaxation, with the objective of gradually decreasing heart rate and attaining mental and psychological tranquillity. The music's tempo is capped at a maximum of 100 beats per minute. Stretching is done to promote muscular relaxation and relieve muscle tension. During the activity, all participants utilized the palpation method to monitor their pulse rate (PR). This assessment quantifies the degree of physical exertion between the time it takes to reach maximum exercise intensity (TTP) and the maximum heart rate (HRmax) which is calculated using the formula 211 - 0.8 x age (Tanaka, Monahan, & Seals, 2001). The computed maximum heart rate was utilized to ascertain the high-intensity workout, which corresponds to a range of 75% to 80% of the maximum heart rate.

Table 1. Participants' physical characteristics, expressed as the mean value plus or minus the standard deviation (SD).

Variable	**EG(N = 20)**	**CG(N = 20)**	***p*-value**
Age (year)	20.73 ± 1.83	20.80 ± 1.69	.836
Height (cm)	158.14 ± 7.60	158.14 ± 7.60	1.230
Weight (kg)	52.44 ± 8.96	49.70 ± 7.07	.000
BMI (kg/m^2)	21.40 ± 4.20	20.37 ± 4.21	.050
WHR (cm)	75.73 ± 7.58	73.12 ± 8.42	.000

Note: SD: Standard deviation; BMI: Body mass index; WHR: waist hip ratio; EG: experimental group; CG: Control group.

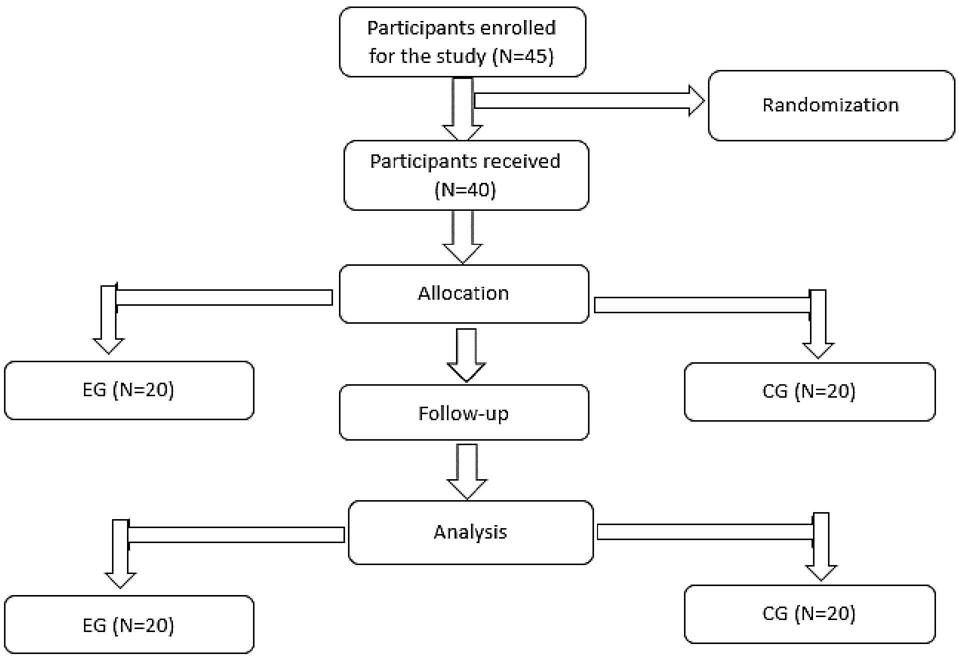

Figure 1. Participant's selection flow chart.

Table 2. Twelve week training schedule.

Week	**Strength Training Practices schedule**	**Time distribution**	**Detailed Program**
1-4 week	Warm-up & stretching	15 minutes.	Hands & Head rotation, Shoulder rotation, Chest swing, Hand stretching exercise etc.
	Tabata Training Programme	**10 minutes.** Exercise 20 Seconds. Rest between exercises 10 second. Rest between sets 1 minute. No of sets 2.	High knee, Side lunges, Back kick, squat, Jumping Jacks, Wall push ups, Mountain climbers, plank.
5-8 week	Tabata Training Programme	**15 minutes.** Exercise 20 Seconds. Rest between exercises 10 second. Rest between sets 1 minute. No of sets 3.	High knee, Side lunges, Back kick, squat, Jumping Jacks, Wall push ups, Mountain climbers, plank.
9-12 week	Tabata Training Programme	**20minutes.** Exercise 20 Seconds. Rest between exercises 10 second. Rest between sets 90 seconds No of sets 3.	High knee, Side lunges, Back kick, squat, Jumping Jacks, Wall push ups, Mountain climbers, plank.
	Cooling down	10 minutes.	Stretching, Cooling down.

Data analysis

The basic descriptive analysis, comprising the mean and standard deviation, was calculated for the initial and final measurements of body composition and physical efficiency variables in the experimental and control groups. Descriptive values were calculated for the total sample, and then separately for the experimental group and control group. The Kolmogorov-Smirnov test (K-S) was conducted for the check of normality of distribution, $p > .05$. According to the obtained result, the significance level of $p < .05$ was used for conducting an independent t-test, which was aimed at verifying possible changes in body composition and physical efficiency between the two groups of participants during the first measurement. A dependent t-test was conducted, based on the significance level of $p < .05$ for verification of statistically significant differences between the final measurements of the groups regarding the body composition parameters and physical efficiency. The effect size values were calculated and analysed using the following formula: $t^2/ t^2 +(N1+N2-2)$. According to the study by Cohen (2013), the meaning of this number was assessed; the criteria used are the following: the value of 0.01 means the impact is insignificant, 0.065 means the impact is moderate, and 0.14 means the impact is significant. The data was processed by the statistical software SPSS 20.0 (IBM, Armonk, NY).

RESULTS

Table 3 describes the body composition and physical performance characteristics of female university students in the experimental group (EG) and control group (CG) for $p < .05$. Independent T test indicated that there were no statistically significant differences in the initial measurements in between the groups. The experimental groups were equally capable at the start of the experiment since there was a significant degree of homogeneity of variance. The Levene's test indicates that there is statistically significant homogeneity of variance at the initial assessment.

Table 3. Initial measurement of pre-test and post-test of inactive female university students.

Variables	Group	Mean	SD	t-test	*p*	Mean Difference	Levene's test	
							F	*p*
Height	EG CG	158.714 157.550	7.301 8.049	0.486	.630	1.164	0.011	.917
Weight	EG CG	49.211 55.710	3.937 12.274	2.306	.027	-6.498	14.653	.006
BMI	EG CG	19.847 22.585	2.732 4.965	2.201	.034	-2.737	8.125	.007
Waist hip ratio	EG CG	73.857 77.700	4.693 9.487	1.656`	.106	-3.842	6.737	.013
Speed	EG CG	13.586 13.678	0.454 0.662	0.517	.608	0.091	7.935	.008
Agility	EG CG	14.005 13.894	1.227 0.631	0.362	.719	0.111	7.817	.008
Endurance	EG CG	49.761 44.850	6.647 2.641	3.080	.006	4.911	20.880	.016
Abdominal strength	EG CG	14.619 15.050	1.071 1.276	1.173	.248	-4.309	0.579	.451
Leg strength	EG CG	1.330 1.300	0.083 0.090	1.123	.269	0.0304	0.160	.691

Note: EG – Experimental Group; CG – Control Group; indicates p < .05; SD – Standard Deviation.

The dependent t-test showed a significant difference between the final measurements of groups, with regard to body composition attributes and physical performance (see Table 4). Levene's test showed that the variance was homogeneous at the latest measurement due to a *p*-value greater than .05. The body composition variable height did not show statistically significant differences after Tabata training. The average height of the sample was 158 ± 7.60, and that of the control group was 158.71. The statistical test T = 3.92, *p* = 1.23 found that, no significant difference in the parameters of the body composition after Tabata training.(CG Vs EG) weight: The mean weight of CG is 52.44 ± 8.96, while for EG is 49.21. The t-value is 2.01 with a *p*-value of .00. BMI: The mean BMI for CG is 21.40 ± 4.20, while for EG is 19.84. The t-value is 4.99 with *p*-value of .05. Waist-hip ratio: The mean waist-hip ratio for CG is 75.73 ± 7.58, while for EG is 73.857. The t-value is 4.638 with a *p*-value of .000. In addition, statistically significant differences were also found in the measures of physical efficiency. These included a significant difference on speed (mean CG = 13.63 ± 8.42 Vs, EG = 13.586 for T = 5.211, *p* = 5.211), agility (mean CG = 13.95 ± 2.8972 Vs, EG = 14.005 for T = 5.220, *p* =.000), endurance (mean CG = 47.36 ± 5.62 Vs, EG = 49.761 for T = 4.019, *p* =.000, and abdominal strength (mean CG = 14.82 ± 2.82 Vs, EG = 14.619 for T = 5.377, *p* =.000) and leg strength (mean CG = 1.31 ± 0.87 Vs, EG = 1.330 for T = 5.953, *p* =.000). The control group also did not show a statistically significant difference in the final measurement.

Table 4. Final measurement of pre-test and post-test of inactive female university students.

Variables	Group	Mean	SD	t-test	*p*	Mean Difference	Levene's test	
							F	*p*
Height	EG CG	158.14 158.14	7.60 7.60	3.928	1.23	0.006	0.011	.917
Weight	EG CG	52.44 49.70	8.96 7.07	2.012	.000	-2.740	0.592	.446
BMI	EG CG	21.40 20.37	4.20 4.21	4.995	.050	-1.030	0.255	.616
Waist hip ratio	EG CG	75.73 73.12	7.58 8.42	4.638	.000	-2.610	7.369	.060
Speed	EG CG	13.63 12.98	0.56 0.87	5.211	5.211	-0.650	1.452	.236
Agility	EG CG	13.95 13.43	0.972 1.18	5.220	.000	-0.520	0.269	.627
Endurance	EG CG	47.36 52.82	5.62 8.83	4.019	.000	5.460	0.338	.564
Abdominal strength	EG CG	14.82 16.92	1.18 2.82	5.377	.000	2.100	0.164	.688
Leg strength	EG CG	1.31 1.43	0.087 0.12	5.953	.000	0.120	2.331	.135

Note: EG – Experimental Group; CG – Control Group; indicates p < .05; SD – Standard Deviation.

DISCUSSION

The primary finding of this study indicates that the 12-week Tabata exercise program yielded favourable effects on the body composition and physical performance of sedentary female students. An experimental group consisting of physically fit young women was chosen, and the findings revealed a significant disparity in the final measurement values. Nevertheless, the control group did not display any measurement characteristics that were statistically significant. In addition, the Tabata training routine has shown success in reducing body composition percentage and enhancing athletic performance for experimental group. For college women, it is especially important to be aware that as they age, their body fat levels tend to gradually grow. During the perimenopausal period, there are variations in hormone levels. Consequently, this causes a decline in muscle mass and a rise in adipose tissue, namely in the abdominal region. The observed body composition metrics indicate that following the Tabata training programme led to an average reduction of 3.8

kg in weight (kg), a decrease of 1.61 in BMI (kg/m²), and a decrease of 5.45 cm in WHR for experimental group. After 12 weeks of participating in the Tabata training program, there were improvements in various physical fitness parameters. Specifically, there was an average increase in speed of 1.33 km/h, agility of 1.06 m/s, endurance of 4.05, muscular strength of 4.5, and explosive power of 0.24 for the experimental group compared to the control group.

The implementation of the Tabata training program did not have any impact on height. However, it had a favourable effect on reducing weight by an average of 3.8 kg/m2, BMI by an average of 1.61%, waist-hip ratio by an average of 5.45 kg, and speed by 1.3 m/s. The average agility declined by 1.06 m/s, the average endurance decreased by 11.5 m/s, the average abdominal strength decreased by 4.5 kg, and the average leg strength decreased by 0.24 kg. These decreases represent a 0.7% decrease in the body. In addition to changes in body composition, alterations can also be noticed in terms of body circumferences. Furthermore, there was a decrease in physical index. After examining body mass percentages of the control group (mean = 22.58 ± 4.96) and experimental group (mean = 19.84 ± 2.32) at the beginning of the program, it was concluded that the participants were classified as having a moderate to excessive level of body fat. After undergoing Tabata training, the experimental group (EG) observed a significant decline in adipose tissue percentage, with an average decrease of 4.11% (mean = 21.40 ± 4.20, $p = .05$). The reduction in body fat % resulted in the Experimental Group (EG) falling into the range of an acceptable fat percentage. This change is statistically significant when compared to the Control Group (CG), which had a mean body fat percentage of 28.55 ± 4.21 and did not see any change in body fat percentage.

A study conducted among a diverse group of women revealed that engaging in frequent Tabata workouts in a health club, with a minimum frequency of three sessions per week, can result in a reduction in body weight (Shilenko, Pyanzina, & Petrova, 2020). Moreover, studies have shown that Tabata training contributes to the process of fat oxidation, boosts physical strength, and enhances endurance.

Shah and Purohit (2020) conducted a study on body composition and found that Tabata training has a noteworthy effect on decreasing waist circumference and body mass index in a group of women between the ages of 20 and 35. Scientific research has proven that participating in 20 minutes of Tabata training leads to the stimulation of 86% of the maximum heart rate (HR_{max}) and the utilization of 74% of the maximum oxygen consumption (VO_{2max}). This finding reinforces the idea that Tabata could be a viable option for anyone looking for a short yet effective workout regimen (Emberts et al., 2013). According to Shilenko et al. (2020), engaging in Tabata courses at a health club can result in weight loss for women between the ages of 25 and 30, as long as they consistently participate in the workouts at least three times per week. Moreover, studies have shown that Tabata training has a crucial function in facilitating fat burning, boosting physical strength, and enhancing endurance.

Presently the studies evaluated the impact of HIIT-R and HIIT-F training protocols on aerobic fitness by quantifying aerobic capacity. Previous studies have demonstrated that participating in High-Intensity Interval Training (HIIT) that includes jogging can promote aerobic capacity. Several research studies have reported significant improvements in VO_{2max} after engaging in High-Intensity Interval Training (HIIT) (Pantelić & Mladenović, 2004). Furthermore, a thorough examination also shown that High-Intensity Interval Training (HIIT) has beneficial impacts on improving aerobic fitness in healthy young persons (García-Hermoso et al., 2016).

The number of sit-ups and distance achieved in the standing wide jump were significantly improved after the HIIT session. In contrast, the parameters did not change in the group that did not perform High-Intensity

Interval Training. Our findings are consistent with the conclusions of previous studies on High-Intensity Training. The study revealed a significant enhancement in muscle function following 6 weeks of HIFT (High-Intensity Functional Training), however, no improvement was observed in the HITT (High-Intensity Interval Training) group that utilized rowing as the exercise modality (Mulazimoglu et al., 2021).

CONCLUSION

The present study implies that the 12-week Tabata training intervention is favourable for reducing body weight in inactive women in a state of excellent health. The improvements mostly led to a decrease in BMI percentage and waist-hip ratio, measured in centimetres. Furthermore, there was a notable improvement in physical performance, characterized by heightened velocity, dexterity, stamina, core strength, and lower limb strength. Tabata provides a time-efficient option for improving body composition and physical efficiency, in addition to traditional weight loss methods. Moreover, this specific type of physical activity does not necessitate any apparatus, rendering it a financially efficient choice.

AUTHOR CONTRIBUTIONS

Conceptualization, SJ and MSK; methodology, SJ and JD; software, SJ and JD; investigation, JD; resource, SJ; data curation, SJ and JD; writing, SJ; writing review and editing, JD; supervision, MSK.

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REFERENCES

Afyon, Y. A., Mulazimoglu, O., Celikbilek, S., Dalbudak, I., & Kalafat, C. (2021). The effect of Tabata training program on physical and motoric characteristics of soccer players. Progress in Nutrition, 23(S2), e2021255-e2021255.

Andersen, E., Bang-Kittilsen, G., Bigseth, T. T., Egeland, J., Holmen, T. L., Martinsen, E. W., . . . Engh, J. A. (2020). Effect of high-intensity interval training on cardiorespiratory fitness, physical activity and body composition in people with schizophrenia: a randomized controlled trial. BMC psychiatry, 20, 1-12. https://doi.org/10.1186/s12888-020-02827-2

Bajaj, A., Appadoo, S., Bector, C., & Chandra, S. (2008). Measuring physical fitness and cardiovascular efficiency using harvard step test approach under fuzzy environment. Paper presented at the ASAC.

Blair, S. N., & Morris, J. N. (2009). Healthy hearts-and the universal benefits of being physically active: physical activity and health. Annals of epidemiology, 19(4), 253-256. https://doi.org/10.1016/j.annepidem.2009.01.019

Bull, F. C., & Bauman, A. E. (2011). Physical inactivity: the "Cinderella" risk factor for noncommunicable disease prevention. Journal of health communication, 16(sup2), 13-26. https://doi.org/10.1080/10810730.2011.601226

Dasso, N. A. (2019). How is exercise different from physical activity? A concept analysis. Paper presented at the Nursing forum. https://doi.org/10.1111/nuf.12296

Diener, M. H. (1992). The validity and reliability of a 1-minute half sit-ups test: University of Nevada, Las Vegas. https://doi.org/10.1249/00005768-199205001-00453

Dishman, R. K., Heath, G. W., Schmidt, M. D., & Lee, I.-M. (2021). Physical activity epidemiology: Human Kinetics.

Domaradzki, J., Cichy, I., Rokita, A., & Popowczak, M. (2020). Effects of tabata training during physical education classes on body composition, aerobic capacity, and anaerobic performance of under-, normal-and overweight adolescents. International journal of environmental research and public health, 17(3), 876. https://doi.org/10.3390/ijerph17030876

Emberts, T., Porcari, J., Dobers-Tein, S., Steffen, J., & Foster, C. (2013). Exercise intensity and energy expenditure of a tabata workout. Journal of sports science & medicine, 12(3), 612.

Füzéki, E., & Banzer, W. (2018). Physical activity recommendations for health and beyond in currently inactive populations. International journal of environmental research and public health, 15(5), 1042. https://doi.org/10.3390/ijerph15051042

Gaetano, A. (2016). Relationship between physical inactivity and effects on individual health status. Journal of Physical Education and Sport, 16(2), 1069-1074.

García-Hermoso, A., Cerrillo-Urbina, A., Herrera-Valenzuela, T., Cristi-Montero, C., Saavedra, J., & Martínez-Vizcaíno, V. (2016). Is high-intensity interval training more effective on improving cardiometabolic risk and aerobic capacity than other forms of exercise in overweight and obese youth? A meta-analysis. Obesity reviews, 17(6), 531-540. https://doi.org/10.1111/obr.12395

Jackson, A. W. (2004). Physical activity for health and fitness: Human Kinetics. https://doi.org/10.5040/9781492596905

Lee, I.-M., Shiroma, E. J., Lobelo, F., Puska, P., Blair, S. N., & Katzmarzyk, P. T. (2012). Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. The lancet, 380(9838), 219-229. https://doi.org/10.1016/S0140-6736(12)61031-9

Maulder, P., & Cronin, J. (2005). Horizontal and vertical jump assessment: reliability, symmetry, discriminative and predictive ability. Physical therapy in Sport, 6(2), 74-82. https://doi.org/10.1016/j.ptsp.2005.01.001

Mulazimoglu, O., Boyaci, A., Afyon, Y. A., & Çelikbilek, S. (2021). Acute effect of tabata workout on heart rate and blood lactate accumulation of female futsal players. Acta Medica Mediterranea, 37(5), 2457-2461.

Munandar, R. A., Setijono, H., & Kusnanik, N. W. (2022). The effect of Tabata training and High-intensity Interval Training on Agility Improvement. Internation Journal of Social Science and Human Research, 4(1), 281-283. https://doi.org/10.47191/ijsshr/v5-i1-37

Murawska-Cialowicz, E., Wolanski, P., Zuwala-Jagiello, J., Feito, Y., Petr, M., Kokstejn, J., . . . Goliński, D. (2020). Effect of HIIT with Tabata protocol on serum irisin, physical performance, and body composition in men. International journal of environmental research and public health, 17(10), 3589. https://doi.org/10.3390/ijerph17103589

Olson, M. (2014). TABATA: It'sa HIIT! ACSM'S Health & Fitness Journal, 18(5), 17-24. https://doi.org/10.1249/FIT.0000000000000065

Pantelić, S., & Mladenović, I. (2004). Changes of some anthropometrical characteristic abd body composition at women after four months of aerobics exercise. Physical Culture-Belgrade, 1, 76-78.

Roxburgh, B. H., Nolan, P. B., Weatherwax, R. M., & Dalleck, L. C. (2014). Is moderate intensity exercise training combined with high intensity interval training more effective at improving cardiorespiratory fitness than moderate intensity exercise training alone? Journal of sports science & medicine, 13(3), 702.

Ruiz, J. R., Ortega, F. B., Gutierrez, A., Meusel, D., Sjöström, M., & Castillo, M. J. (2006). Health-related fitness assessment in childhood and adolescence: a European approach based on the AVENA, EYHS and HELENA studies. Journal of Public Health, 14, 269-277. https://doi.org/10.1007/s10389-006-0059-z

Shah, N., & Purohit, A. (2020). Effect of tabata training for weight loss in overweight middle age female of Ahmedabad city: an experimental study. International Journal of Science & Healthcare Research, 5(4), 281-284.

Shilenko, O., Pyanzina, N., & Petrova, T. (2020). The Impact of Tabata Training on Body Weight Correction in Women 25-30 Years Old. Paper presented at the First International Volga Region Conference on Economics, Humanities and Sports (FICEHS 2019). https://doi.org/10.2991/aebmr.k.200114.170

Suleiman, U., Ogunleye, R., Tsauri, Y., Achikasim, N., Getso, A., Dikki, C., & Gwani, J. (2019). Assessment of 50 meters dash on physical and physiological characteristics of male Nigerian university athletes. KIU Journal of Social Sciences, 5(1), 277-282.

Tabata, I. (2019). Tabata training: one of the most energetically effective high-intensity intermittent training methods. The Journal of Physiological Sciences, 69(4), 559-572. https://doi.org/10.1007/s12576-019-00676-7

Tanaka, H., Monahan, K. D., & Seals, D. R. (2001). Age-predicted maximal heart rate revisited. Journal of the american college of cardiology, 37(1), 153-156. https://doi.org/10.1016/S0735-1097(00)01054-8

Taylor, A. H., Cable, N. T., Faulkner, G., Hillsdon, M., Narici, M., & Van Der Bij, A. K. (2004). Physical activity and older adults: a review of health benefits and the effectiveness of interventions. Journal of sports sciences, 22(8), 703-725. https://doi.org/10.1080/02640410410001712421

Zhang, H., K Tong, T., Qiu, W., Wang, J., Nie, J., & He, Y. (2015). Effect of high-intensity interval training protocol on abdominal fat reduction in overweight Chinese women: a randomized controlled trial. Kinesiology, 47(1.), 57-66.

The effects of different exercise modalities on visuospatial working memory in healthy young adults

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ABSTRACT

This study was to differentiate the acute effects of random motor skill practice and acute cardiovascular exercise on the task performance in visuospatial working memory (VSWM). 24 healthy adults with no golf experience were randomized into random motor skill practice (i.e., golf putting task) and acute cardiovascular exercise (i.e., 64% and 76 % of predicted maxi-mum heart rate) groups. Pre-test and post-test were administered for two VSWM tasks (i.e., memory matrix and rotation matrix). The performance of VSWM was improved immediately after the acute intervention. However, the improvement in retention effect was not maintained. In addition, no group differences were noted between random motor skill practice and acute cardiovascular exercise during post-test. The findings suggested the temporal effects of acute intervention. There is need to add a true control group for further research with larger sample size to examine the role of exercise modalities between acute intervention and executive function.
Keywords: Sport medicine, Sports health, Acute exercise, Executive function, Working memory, Motor learning.

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INTRODUCTION

Executive function has been considered a high-order system that controls and manages other cognitive processes to direct our behaviours to achieve a goal (Hillman et al., 2008). Inhibition, working memory, and cognitive flexibility are proposed as the primary aspects of executive function (Diamond, 2013). To date, much of the work has focused on executive function and its change in response to acute exercise. Evidence for enhanced executive function with acute exercise is rapidly growing (Chen et al., 2020; Chen and Ringenbach, 2016; Labban and Etnier, 2011; Li et al., 2014; Park and Etnier, 2019). In a meta-analytic finding of Chang et al. (2012), they observed a small yet positive effect size (overall effect size = 0.097) of acute physical activity across different aspects of executive function. Several mechanics models have been used to explain the changes in cognitive performance, including increased arousal levels (Lambourne and Thomporowski, 2010), increased neural activity (Basso et al., 2015; Li et al., 2014), and higher expressions of catecholamine (McMorris et al., 2008) or neurotrophic factors (Dinoff et al, 2017). Basso et al. (2015) noted that this increased neural effect seemed to persist for up to two hours in the prefrontal cortical region, a brain area known to be responsible for executive function. Despite this well-established relationship between acute exercise and executive function, past literature has been predominantly interested in changes in inhibition following the cessation of an acute bout of physical activity (Pontifex et al., 2019). Pontifex et al. (2019) reported that 41 percent of published studies to date focus on the effect of inhibition, but few studies focused on other components of executive function. Further, working memory is a cognitive capability to control attention to information and hold and manipulate it afterward, which plays an important role in daily tasks, such as grocery shopping and academic learning (Baddeley, 2007; Rzhanova and Alekseeva, 2020). Since Roig et al. (2012) reviewed the evidence and indicated cardiovascular exercise could improve memory with small to moderate effect sizes (effect size range from 0.12-0.32). Surprisingly, the concept of working memory has received less attention in the field of sport and exercise psychology. Therefore, the present study would extend the relevant research topic by examining the influence of an acute exercise on working memory performance.

Further, contextual interference (CI), which is experienced when practicing multiple skills, or variations of a skill, within a single practice session, has been recognized as an important variable for maximizing motor skill learning (Kaipa and Mariam Kaipa, 2018; Kim et al., 2018). Cross et al., (2007) indicated that the increasing level of CI (e.g., random sequencing practice), compared to low CI condition (e.g., blocked practice) throughout a training session could result in better motor performance on tests of retention since random practice could enhance more neural activity that was associated with motor preparation, sequencing, and response selection. Evidence to date also suggests that working memory capacity is related to motor skill learning and performance (Bo & Seidler, 2009, Unsworth & Engle, 2005). Thus, the increased involvement of cognitive processing could be expected during random practice (Li & Wright, 2000). Moreover, Motor skill learning is often implicit learning. Lee and Magill (1983) proposed the forgetting-reconstructive hypothesis to account for the CI effect on the process of working memory on every practice trial. Random motor skill practice might make the learners must continuously retrieve a motor pattern or reconstruct a new one when facing the changing visual and kinaesthetic information derived from the performance of the same action with different parameters (Rendell et al., 2009). Past literature concerning the CI effect and implicit motor learning has largely focused on gross motor skills in sports; however, few specifically investigate fine motor skills. Therefore, the golf putting task was adopted in the present study since it could be considered as it is a complex, fine motor sequence skill.

A recent study reported an association between golf putting performance and working memory capacity (Persson, 2021). Novice golfers initially need working memory for declarative knowledge and initial proceduralization. During the early stage of practice, they need to understand the rules and movement control of the degrees of freedom around the arm segment and simultaneously stabilize other body parts for putting performance. After random motor skill practice, novice golfers might create distinctive and strong memories compared to blocked practice (Fazeli et al., 2017). With the enhancement of working memory efficiency, novice golfers gradually developed procedural knowledge that led to motor improvement and skill acquisition. Therefore, it could stand to be the reason why athletes have superior working memory (Vaughan and Laborde, 2021). In other words, cognitive gains (i.e., increased working memory capacity) might be moderated by cognitive engagement during random skill practice. Therefore, in addition to the acute effect of exercise, it would be needed to investigate how cognitive abilities such as working memory could be impacted through random motor skill practice.

Taken together, the present study attempted to verify the role of random motor skill practice versus acute aerobic exercise in improving working memory. This study was restricted to novice golfers since they relied extensively on their cognitive abilities to acquire and execute skills (Baumeister et al., 2008). Given that working memory is related to long-term memory (Woltz and Was, 2006), 24-h retention test would be also conducted in the present study to observe the sustained improvements driven by acute interventions. The hypotheses of the present study were as follows: 1) working memory performance would be significantly improved immediately after acute interventions and maintained for 24 hours and, 2) group differences between random motor skill practice and acute aerobic exercise would be observed.

MATERIAL AND METHODS

Participants

Twenty-four healthy young adults participated in the present study (10 males and 14 females, 21.02 ± 0.70 years old). All participants were recruited from a southeastern university in the United States. Inclusion criteria for participants were listed as follows: (1) aged between 18-24 years old; (2) right-handed; (3) no golf experience; and (4) no physical, cognitive, emotional, and/or neurological disorder that would exacerbate physical performance or executive function. Before data collection, interested participants signed an informed consent form to be part of the study. Participants were randomized into two groups: random motor skill practice (n = 12, aged 21.08 ± 0.68 years) and acute aerobic exercise (n = 12, aged 20.97 ± 0.74 years) groups. Each group had similar age, body mass index (BMI), and numbers of females, as these variables might be associated with exercise and executive function performance (Baxi et al., 2018; Dinoff et al., 2017; Kaufman, 2007; Ludyga et al., 2016; Yang et al., 2018). The Human Subject Institutional Review Board in the university approved the study protocol.

Table1. Descriptive statistics of participants.

	Group		***p*-value**
	Random practice (n = 12)	Acute cardiovascular exercise (n = 12)	
Age (years)	21.08 ± 0.68	20.97 ± 0.74	.712
# of Females	7	7	1.00
BMI	27.20 ± 10.40	25.40 ± 2.87	.573

Note. BMI = Body Mass Index.

Procedure

Upon arrival, the demographic measures, including height, weight, age, golf experience, and handedness from the participants would be collected. Participants would visit the laboratory one at a time. Data collection for each participant was completed in two days, including pre-test, 30-min intervention, post-test, and 24-h retention test.

The pre-test consisted of two working memory tasks. Participants were asked to sit in a chair in front of a laptop to perform the working memory tasks that consisted of memory matrix and rotation matrix. The order of the two tasks was counterbalanced. A 30-min intervention was implemented after the pre-test time period. Participants were randomized into either random practice or acute aerobic exercise group. Then, there was a post-test immediately after the intervention. Lastly, participants were requested to visit the laboratory again 24 hours after interventions. The same working memory tasks were administered again to assess the intervention-induced effect.

Intervention

Acute aerobic exercise group

This group participated in a 30-min treadmill exercise, maintaining their exercise heart rates between 64% and 76 % of their predicted maximum heart rate (HR_{max}). The 64-76 % of HR_{max} could be considered as moderate intensity since it can be converted to about 40 to 60 % of VO_2max (Statton et al., 2015; Swain et al., 1994), which the American College of Sports Medicine (2018) suggested as moderate intensity. The present study employed the equation of age-predicted HR_{max} = 208 - (0.7 x age) to compute the target HR range for each participant (Tanaka et al., 2001). An HR monitor was worn (Polar H10, Finland) to monitor the intensity of exercise through a Bluetooth connection with a mobile device. The intervention session began with a warm-up phase which the treadmill speed was started at 1.0 mph and gradually increased until the participants' HR reached the target heart rate zone. The duration of the warm-up phase was up to 5 minutes. Participants started the exercise session once their exercise HRs reached the target range. The treadmill speed was manipulated as needed to maintain the participants' heart rates within the target range. The incline was set at 0% during the entire intervention period. After the 30-min exercise, participants were given another 5-min walking time at 1.0 mph for cool-down phase.

Random motor skill practice group

The random practice group practiced 3 blocks of 3 feet, 6 feet, and 9 feet golf putts. Each block had 10 trials of putting, so the total number of practice trials was 90. The distance of the putting was randomized, so the participants could not anticipate the upcoming putting distance. In addition, the attentional focus during practice was controlled and directed at an anticipated trajectory line, which was external focus of attention. An external focus of attention has been found to facilitate motor learning and outcome performance, specifically beneficial for novice golfers (Chen et al., 2021). The external proximal focus may promote cognitive engagement during practice since novice golfers were directed to compare the relationship between action planning and the surrounding environment. The total time in random motor skill practice was about 30 minutes.

Measurement

Working memory tasks

Two working memory tasks, memory matrix and rotation matrix, were administered via a web-based cognitive training program (i.e., lumosity.com). Memory matrix and rotation matrix tests have been widely used to assess VSWM function (Olfers and Band, 2018; Sternberg et al., 2103; Toril et al., 2016).

As noted in Figure 1, in the memory matrix task, the goal was to memorize a group of highlighted tiles on a grid. The highlighted tiles only revealed themselves momentarily and then flipped back over. Then, participants were requested to indicate the location of highlighted titles on a grid. Memory Matrix started with three tiles. If participants made no mistakes in one trial, then in the next trial, participants would get one more tile to remember. If participants missed one tile, then participants still got the same number of tiles in the next trial. If two or more tiles were missed, then participants would get one fewer tile in the following trial. The total of twelve trials of the memory matrix were administered. Participants could earn 250 points for every tile remembered correctly. Participants would also earn a bonus of 100 additional points per tile if they correctly selected all of the tiles on a grid.

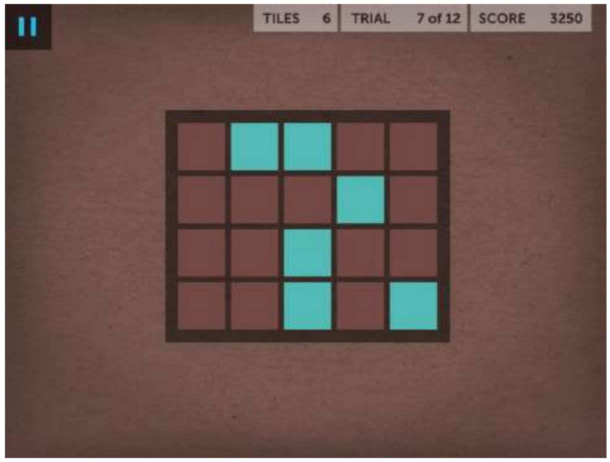


Figure 1. Example of memory matrix task.

As for the rotation matrix task, similarly, the goal was to remember the highlighted tiles. Participants needed to remember the location of the highlighted tiles before they were flipped back over after a few moments. Further, after the tiles flipped back over the entire game board would be rotated. Thus, participants had to not only remember where highlighted tiles were but also had to locate them in relation to the new board positioning. Twelve trials of the rotation matrix task were administered. The rule and scoring of the rotation matrix task were the same as the memory matrix task. The total score of both tasks was reported by the program to represent participants' VSWM performance.

Statistical analysis
Statistical analysis was carried out using the SPSS 27.0 program. First, the independent t-test and chi-square (χ^2) test were computed to confirm demographic features and pre-test performance between both groups. Data from the performance in VSWM was analysed by a 3 (time periods) x 2 (groups) ANOVA. If the main effect analysis violated the Mauchly test of sphericity, as indicated by a *p*-value of <.05, the corrected Greenhouse-Geisser F values for the main effect and the interactions between time periods and groups were reported.

The significant alpha level was set at .05 throughout the statistical analysis in the present study. Partial eta squared (η_p^2) was used in ANOVA to evaluate an effect size as follows: .01 to < .06 as small; .06 to < .14 as medium; and > .14 as a large effect size.

RESULTS

Demographic characteristics
An independent t-test was conducted to compare age and BMI factors between the groups. The Table 1 indicated Age: t (22) = -.373, p = .712, and BMI: t (22) = -.578, p = .573, were not significantly different. The

chi-squared analysis indicated sex factor (i.e., the number of females) was not significantly different across the groups: χ^2 (1, N = 24) = .000, *p* = 1.00.

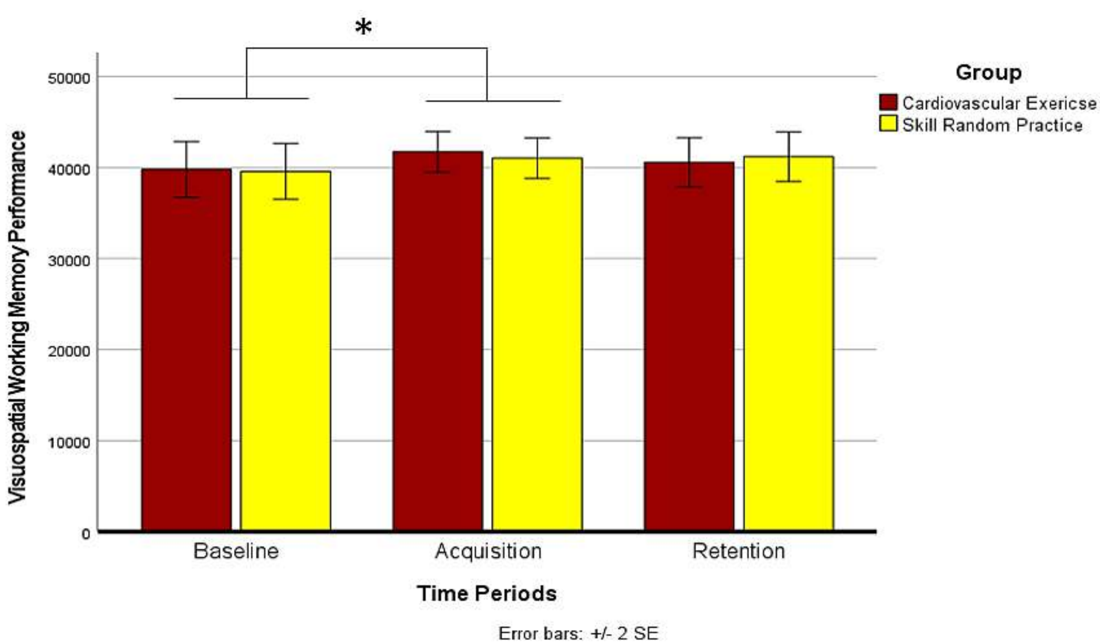
Exercise intensity

An average exercise HR in the acute cardiovascular group was 144.6 bpm, which was about 74.9 % of age predicted HR_{max}. Thus, participants performed treadmill running exercise with moderate intensity in the present study.

Visuospatial working memory performance

A two-way repeated measure ANOVA was conducted to compare the effect of skill random practice versus cardiovascular exercise training on the performance in VSWM tests. As noted in Figure 2, there was a significant effect of different time periods, *F* (2, 44) = 3.254, *p* = .048, η^2 = .129. Pairwise comparisons with an LSD correction were used to make post hoc comparisons between time periods. These indicated that there was a significant difference in acquisition period (*M* = 41393.75) and baseline period (*M* = 39687.50), *p* = .018.

Moreover, there was no interaction effect between different time periods and groups, *F* (2, 44) = .474, *p* = .626, η^2 = .021. There was also no significant main effect of groups, *F* (1, 22) = .004, *p* = .953, η^2 = .000.



*Note. * p < .5.*

Figure 2. Acute effect on visuospatial working memory performance.

DISCUSSION

The purpose of the present study was to investigate the effect of random motor skill practice versus acute aerobic exercise on VSWM. This is an important direction for future research because of our limited understanding of the time-dependent effect of random practice and acute aerobic exercise on cognitive processing. Consistent with the hypothesis and previous studies regarding acute exercise effect on working memory (Basso et al. 2015; Chang et al. 2012), the scores in VSWM tasks elicited a significant improvement after both acute interventions. Chang et al. (2012) had ever indicated the highest effect size in the executive function was within 1-15 minutes after exercise. Basso et al. (2015) suggested the exercise-induced neural activity in prefrontal cortex that was responsible for working memory performance, which could last up to 2 hours. These above-mentioned studies may explain why cognitive improvement was seen immediately after acute aerobic exercise.

However, inconsistent with our findings in a moderate-intensity exercise, the advantageous effect was not noted in some acute exercise studies (Ebisuzaki, 2020; Li et al. 2014). Li et al. (2014) found young adults did not improve behavioural performance in a working memory task, the N-back task a 20-min of moderate exercise intensity of 60% to 70% of age-predicted (220-age) HRmax, compared to control rest condition. Ebisuzaki et al. (2020) examined the effects of a bout of moderate exercise intensity of 60% to 70% of age-predicted (220-age) HRmax, versus rest condition on the performance in working memory test, List Sorting Working Memory Task, and indicated no effects of time, condition, nor an interactive effect on working memory. It was possible that the exercise intensity performed in the current study was closed to vigorous intensity. Jeon and Ha (2017) noted the change in the working memory significantly increased for the vigorous intensity exercise group compared to the low intensity aerobic group and moderate intensity exercise group.

Moreover, our findings showed that cognitive improvement was not sustained after 24 hours. The advantageous effect in 24-hour retention seemed to be noted in the high-intensity acute exercise studies (Frith et al., 2017; Winter et al. 2007). Winter et al. (2007) found that the participants could perform 20% faster in a novel vocabulary learning test after a short bout of intense exercise, compared to under moderate exercise and rest conditions. Frith et al. (2017) indicated that young adults improved their performance in memory assessment in the 24-hour retention test after a 15-min bout of progressive maximal exertion treadmill exercise. As such, future work is still needed to differentiate the mediation effect of intensity of exercise on the longevity of the memory system (working memory vs. long).

Interestingly, no interaction effect was evident in the current study. That meant there was no group differences between the effect of random motor skill practice and acute aerobic exercise on working memory. First, this type of physical practice might have increased the arousal level among participants, thereby promoting an immediate gain in working memory tests Secondly, although the intensity of exercise in golf putting practice might generated a smaller change in energy metabolism than cardiovascular exercise, participants spent much time practicing motor coordination, visual search, eye-hand coordination, balance, and spatial orientation while performing random practice in golf putting. These motor abilities demand higher level cognitive processes that were likely to be related to attention and managing visual and spatial information, thereby promoting an immediate gain in working memory tests. A review study conducted by Voelcker-Rehage and Neiman (2013) showed that exercise-metabolic exercise (i.e., cardiovascular and resistance) and coordinative (i.e., bimanual coordination) exercise affected the structural and functional brain changes differently. Random motor skill practice may affect cognitive processes differently compared to aerobic exercise. However, we did not assess other physiological data (e.g., HR, feelings) in golf putting practice that would allow investigating the underlying mechanisms in the current study. For this, the values and details of the training session should be recorded in the future.

Limitations

It is important to consider the possible limitations accompanied that need to be addressed in the future studies. To reveal significant differences in VSWM performance with Cohen's effect size f (f = .25), two groups using G*Power, were assigned. The groups underwent 2 tests, alpha of .05, and power of 80%, with the total of one hundred twenty-eight participants. Thus, our preliminary results need to be replicated with a larger sample and with randomized sampling to ensure the effectiveness of intervention. Although these results seemed to be promising, adding different duration of retention test, such as 10-min, 30-min, an hour after the intervention, would enable subsequent studies to investigate this area of interest more thoroughly. Further, the lack of a true control group. Hence, it is impossible to tell whether the performance changes following intervention was an intervention-induced effect or just a learning effect. Although an external focus instruction was provided during putting practice to promote cognitive engagement, participants' efforts was not truly verified by HR. In addition, the putting performance outcomes could be included in the future to investigate whether the improvement in golf putting may be associated with VSWM gains. Further, the age-estimated method may not be the appropriate method to determine the intensity of exercise that might moderate cognitive performance. Therefore, future work should expand these findings by utilizing maximal oxygen uptake (VO_2max) for a better understanding of the potential relationship between cognitive performance and exercise intensity in a more rigorous manner. Additionally, this study should consider other exercise modalities to comprehensively verify the association between acute intervention and executive function.

CONCLUSIONS

Taken together, the present study is one of the pioneering studies that has attempted to pair different exercise modalities and executive function. The evidence showed that the temporal effects on VSWM. Random motor skill practice and moderate exercise intensity seemed to result in an immediate increase in VSWM. There are numerous implications of these findings that could be applied to everyday settings, including the importance of daily physical activity or fine motor skill practice for facilitating better learning and memory for young students as well older adults.

AUTHOR CONTRIBUTIONS

Both Dr. Chen and Dr. Ryuh contributed to the design and implementation of the research, the analysis of the results, and the writing of the manuscript. Additionally, all authors participated in discussions about the results and contributed to the final manuscript.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

PUBLICATION ETHICS

Informed consent was obtained from all participants included in the study. All procedures in studies involving human participants were performed in accordance with the ethical standards of the institution's Human Research Ethics Committee.

REFERENCES

American College of Sports Medicine. (2018). ACSM's Guidelines for Exercise Testing and Prescription: 10th Edition. Wolters Kluwer.

Baddeley, A. (2007). Working memory, thought, and action (Vol. 45). OUP Oxford. https://doi.org/10.1093/acprof:oso/9780198528012.001.0001

Baumeister, J., Reinecke, K., Liesen, H., & Weiss, M. (2008). Cortical activity of skilled performance in a complex sports related motor task. European journal of applied physiology, 104(4), 625-631. https://doi.org/10.1007/s00421-008-0811-x

Basso, J. C., Shang, A., Elman, M., Karmouta, R., & Suzuki, W. A. (2015). Acute exercise improves prefrontal cortex but not hippocampal function in healthy adults. Journal of the International Neuropsychological Society, 21(10), 791-801. https://doi.org/10.1017/S135561771500106X

Baxi, G., Palekar, T., Nair, M., Basu, S., & Gohil, D. (2018). Effect of underwater treadmill training on cardiovascular responses in normal and overweight individuals. National Journal of Integrated Research in Medicine, 9(4), 13-19.

Bo, J. & Seidler, R. D. (2009). Visuospatial working memory capacity predicts the organization of acquired explicit motor sequences. Journal of neurophysiology, 101(6), 3116-3125. https://doi.org/10.1152/jn.00006.2009

Chang, Y.K., Labban, J.D., Gapin, J.I., & Etnier, J.L. (2012). The effects of acute exercise on cognitive performance: a meta-analysis. Brain research, 1453, 87-101. https://doi.org/10.1016/j.brainres.2012.02.068

Chen, C.-C., Ryuh, Y., Luczak, T., & Lamberth, J. (2021). The effects of attentional focus and skill level on the performance of golf putting. Journal of Motor Learning and Development, 9(3), 371-382. https://doi.org/10.1123/jmld.2020-0072

Chen, C.-C., & Ringenbach, S. D. R. (2016). Dose-response relationship between intensity of exercise and cognitive performance in individuals with Down syndrome: a preliminary study. Journal of Intellectual Disability Research, 60(6), 606-614. https://doi.org/10.1111/jir.12258

Chen, F. T., Etnier, J. L., Chan, K. H., Chiu, P. K., Hung, T. M., & Chang, Y. K. (2020). Effects of exercise training interventions on executive function in older adults: a systematic review and meta-analysis. Sports Medicine, 50, 1451-1467. https://doi.org/10.1007/s40279-020-01292-x

Cross, E. S., Schmitt, P. J., & Grafton, S. T. (2007). Neural substrates of contextual interference during motor learning support a model of active preparation. Journal of Cognitive Neuroscience, 19(11), 1854-1871. https://doi.org/10.1162/jocn.2007.19.11.1854

Diamond, A. (2013). Executive functions. Annual review of psychology, 64, 135-168. https://doi.org/10.1146/annurev-psych-113011-143750

Dinoff, A., Herrmann, N., Swardfager, W., & Lanctot, K. L. (2017). The effect of acute exercise on blood concentrations of brain-derived neurotrophic factor in healthy adults: a meta-analysis. European Journal of Neuroscience, 46(1), 1635-1646. https://doi.org/10.1111/ejn.13603

Ebisuzaki, B. T., Riemen, N. D., Bettencourt, K. M., Gonzalez, L. M., Bennion, K. A., & Greever, C. J. (2020). No change in executive function or stress hormones following a bout of moderate treadmill exercise in preadolescent children. International Journal of Exercise Science, 13(5), 1650-1666.

Fazeli, D., Taheri, H., & Saberi Kakhki, A. (2017). Random versus blocked practice to enhance mental representation in golf putting. Perceptual and Motor Skills, 124(3), 674-688. https://doi.org/10.1177/0031512517704106

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

Jeon, Y. K. & Ha, C. H. (2017). The effect of exercise intensity on brain derived neurotrophic factor and memory in adolescents. Environmental health and preventive medicine, 22, 27. https://doi.org/10.1186/s12199-017-0643-6

Kaufman, S. B. (2007). Gender differences in mental rotation and spatial visualization ability: Can they be accounted for by differences in working memory capacity? Intelligence, 35(3), 211-223. https://doi.org/10.1016/j.intell.2006.07.009

Kaipa, R. & Mariam Kaipa, R. (2018). Role of constant, random and blocked practice in an electromyography-based oral motor learning task. Journal of Motor Behavior, 50(6), 599-613. https://doi.org/10.1080/00222895.2017.1383226

Kamijo, K. & Abe, R. (2019). Aftereffects of cognitively demanding acute aerobic exercise on working memory. Medicine and Science in Sports and Exercise, 51(1), 153-159. https://doi.org/10.1249/MSS.0000000000001763

Kim, T., Chen, J., Verwey, W. B., & Wright, D. L. (2018). Improving novel motor learning through prior high contextual interference training. Acta psychologica, 182, 55-64. https://doi.org/10.1016/j.actpsy.2017.11.005

Labban, J. D., & Etnier, J. L. (2011). Effects of acute exercise on long-term memory. Research Quarterly for Exercise and Sport, 82(4), 712-721. https://doi.org/10.1080/02701367.2011.10599808

Lambourne, K. & Tomporowski, P. (2010). The effect of exercise-induced arousal on cognitive task performance: a meta-regression analysis. Brain research, 1341, 12-24. https://doi.org/10.1016/j.brainres.2010.03.091

Lee, T. D., & Magill, R. A. (1983). The locus of contextual interference in motor-skill acquisition. Journal of Experimental Psychology: Learning, Memory, and Cognition, 9(4), 730-746. https://doi.org/10.1037/0278-7393.9.4.730

Li, L., Men, W. W., Chang, Y. K., Fan, M. X., Ji, L., & Wei, G. X. (2014). Acute aerobic exercise increases cortical activity during working memory: a functional MRI study in female college students. PloS one, 9(6), e99222. https://doi.org/10.1371/journal.pone.0099222

Li, Y. & Wright, D. L. (2000). An assessment of the attention demands during random- and blocked-practice schedules. Quarterly Journal of Experimental Psychology, 53(2), 591-606. https://doi.org/10.1080/713755890

Ludyga, S., Gerber, M., Brand, S., Holsboer-Trachsler, E., & Pühse, U. (2016). Acute effects of moderate aerobic exercise on specific aspects of executive function in different age and fitness groups: A meta-analysis. Psychophysiology, 53(11), 1611-1626. https://doi.org/10.1111/psyp.12736

Olfers, K. J. & Band, G. P. (2018). Game-based training of flexibility and attention improves task-switch performance: near and far transfer of cognitive training in an EEG study. Psychological Research, 82(1), 186-202. https://doi.org/10.1007/s00426-017-0933-z

McMorris, T., Collard, K., Corbett, J., Dicks, M., & Swain, J. P. (2008). A test of the catecholamines hypothesis for an acute exercise-cognition interaction. Pharmacology Biochemistry and Behavior, 89(1), 106-115. https://doi.org/10.1016/j.pbb.2007.11.007

Park, S. & Etnier, J. L. (2019). Beneficial effects of acute exercise on executive function in adolescents. Journal of Physical Activity and Health, 16(6), 423-429. https://doi.org/10.1123/jpah.2018-0219

Persson, P. (2021). The association between working memory capacity and golf performance in a dual-task condition. Psychology - Research method and thesis, 30 ECTS. Academy of Health and Welfare: Halmstad University.

Pontifex, M. B., McGowan, A. L., Chandler, M. C., Gwizdala, K. L., Parks, A. C., Fenn, K., & Kamijo, K. (2019). A primer on investigating the after effects of acute bouts of physical activity on cognition. Psychology of Sport and Exercise, 40, 1-22. https://doi.org/10.1016/j.psychsport.2018.08.015

Rendell, M. A., Masters, R. S. W., & Farrow, D. (2009). The paradoxical role of cognitive effort in contextual interference and implicit motor learning. International Journal of Sport Psychology, 40 (4), 636-647.

Rzhanova, I. E. & Alekseeva, O. S. (2020). Successful Learning: Relationship Between Fluid Intelligence and Working Memory. Psychological Science and Education, 25(1), 63-74. https://doi.org/10.17759/pse.2020250106

Roig, M., Skriver, K., Lundbye-Jensen, J., Kiens, B., & Nielsen, J. B. (2012). A single bout of exercise improves motor memory. PloS one, 7(9), e44594. https://doi.org/10.1371/journal.pone.0044594

Statton, M. A., Encarnacion, M., Celnik, P., & Bastian, A. J. (2015). A single bout of moderate aerobic exercise improves motor skill acquisition. PloS one, 10(10), e0141393. https://doi.org/10.1371/journal.pone.0141393

Sternberg, D. A., Ballard, K., Hardy, J. L., Katz, B., Doraiswamy, P. M., & Scanlon, M. (2013). The largest human cognitive performance dataset reveals insights into the effects of lifestyle factors and aging. Frontiers in human neuroscience, 7, 292. https://doi.org/10.3389/fnhum.2013.00292

Swain, D. P., Abernathy, K. S., Smith, C. S., Lee, S. J., & Bunn, S. A. (1994). Target heart rates for the development of cardiorespiratory fitness. Medicine and science in sports and exercise, 26(1), 112-116. https://doi.org/10.1249/00005768-199401000-00019

Tanaka, H., Monahan, K. D., & Seals, D. R. (2001). Age-predicted maximal heart rate revisited. Journal of the American College of Cardiology, 37(1), 153-156. https://doi.org/10.1016/S0735-1097(00)01054-8

Toril, P., Reales, J. M., Mayas, J., & Ballesteros, S. (2016). Video game training enhances visuospatial working memory and episodic memory in older adults. Frontiers in human neuroscience, 10, 206. https://doi.org/10.3389/fnhum.2016.00206

Vaughan, R. S. & Laborde, S. (2021). Attention, working-memory control, working-memory capacity, and sport performance: The moderating role of athletic expertise. European Journal of Sport Science, 21(2), 240-249. https://doi.org/10.1080/17461391.2020.1739143

Voelcker-Rehage, C. & Niemann, C. (2013). Structural and functional brain changes related to different types of physical activity across the life span. Neuroscience & Biobehavioral Reviews, 37, 2268-2295. https://doi.org/10.1016/j.neubiorev.2013.01.028

Woltz, D. J., & Was, C. A. (2006). Availability of related long-term memory during and after attention focus in working memory. Memory & Cognition, 34, 668-684. https://doi.org/10.3758/BF03193587

Yang, Y., Shields, G. S., Guo, C., & Liu, Y. (2018). Executive function performance in obesity and overweight individuals: A meta-analysis and review. Neuroscience & Biobehavioral Reviews, 84, 225-244. https://doi.org/10.1016/j.neubiorev.2017.11.020

ORIGINAL ARTICLE

Erythrocyte, haemoglobin and haematocrit do not correlate with apnoea duration among sedentary male

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ABSTRACT

In freediving, divers rely solely on a single breath. The duration of apnoea depends on the oxygen reserves, mostly derived from the air trapped in the lungs and airways. It is necessary to investigate whether erythrocyte and haemoglobin levels correlate with the achievable apnoea duration, considering their roles as oxygen binders and carriers in the blood. This study examines the correlation between erythrocyte and haemoglobin levels and apnoea duration in 12 sedentary males. Erythrocyte and haemoglobin levels were assessed through blood sample examination in a clinical laboratory by professional personnel, while apnoea duration was measured by remaining motionless in a swimming pool at a depth of 0.5 meters, with three measurements taken. Normality test results indicated that all data were normally distributed (p > .05). Pearson correlation test results revealed no correlation between apnoea duration and erythrocyte levels, haemoglobin, or haematocrit (p > .05). From the research findings, it can be assumed that these three blood biochemical variables cannot be categorized as oxygen reserves and only function as oxygen transportation media.

Keywords: Sport medicine, Blood, Breath-hold, Diving, Sport performance.

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INTRODUCTION

Diving can be categorized into two distinct types: freediving, which does not involve the use of underwater breathing apparatus, and SCUBA diving, which relies on the utilization of a Self-Contained Underwater Breathing Apparatus (SCUBA). These two divergent types of diving are characterized by difference of techniques and procedures. In the context of SCUBA diving, divers are able to maintain continuous respiration throughout the entire dive. It is important for divers to refrain from breath-holding during the dive session in order to mitigate physiological problem. Conversely, in freediving practices, where divers initiate the dive only by relying to a single breath taken at the water's surface, followed by breath-holding throughout the dive duration. Both types of diving encounter the same environmental conditions, physical consequences at depth and causing physiological stress (Eichhorn & Leyk, 2015), where divers are confronted with significant changes of water pressure and the potential disturbances or injuries to the tympanic membrane in ear, commonly referred to as barotrauma (Jones & Wyatt, 2019; Rozycki et al., 2018).

In freediving, the diver holds their breath (apnoea) during the duration of the dive, without any exchange of ventilation between the body and the environment. The only breath-related activity that might occur is exhalation, placing the diver's body at risk of experiencing oxygen deficiency (hypoxia) leading to blackout (Lindholm & Lundgren, 2009; Pearn et al., 2015). Throughout the dive, there is no supply of oxygen from respiration, yet the body continues to consume oxygen and produce carbon dioxide incessantly. The diver relies solely on the air taken in through a single deep breath while still at the water's surface. Consequently, physiological factors within the diver's body become the primary determinants of how the body manages oxygen, directly influencing apnoea duration and, naturally, the duration of the dive.

Several studies have been conducted regarding physiological factors correlated with apnoea capability. Lung capacity has been found to be associated with an individual's ability to hold their breath. A study involving 30 male subjects indicated that There is a strong positive correlation between lung vital capacity and apnoea duration (Putra, Pratama, et al., 2020) A strong positive correlation indicates the significant role of lung vital capacity as the main provider of oxygen reserves during freediving. The body's oxygen utilization capacity (VO_{2Max}) is also recognized to be linked to breath-holding ability. A study involving 36 male subjects revealed that There is a negative correlation between VO_{2max} and apnoea duration. A higher VO_{2Max} corresponds to greater oxygen consumption by the body per minute, rendering the body more extravagant in oxygen utilization (Putra, Karwur, et al., 2020).

Oxygen is utilized to fulfil the energy metabolism requirements within cells. Oxygen is transported through blood vessels by haemoglobin of red blood cells (Guyton & Hall, 2016; Sherwood, 2015). Because of its role in oxygen binding and distribution, the levels of red blood cells and haemoglobin in the blood are also presumed to correlate with the apnoea capabilities of divers. Researchers hypothesize that higher concentrations of haemoglobin and red blood cells in the blood may signify a larger reserve capacity of oxygen flowing within the bloodstream, ready to be utilized by the tissues it passes through. The aim of this study is to explore the correlation between red blood cells and haemoglobin levels and breath-holding abilities. The findings of this research are expected to serve as a reference for freedivers in considering their red blood cell and haemoglobin levels in their training programs and dive preparations.

METHODS

Study population

This study recruited 14 male subjects using purposive sampling method. The subjects in this study were students from the physical education program selected based on inclusion criteria. The inclusion criteria applied were being male, having chest circumference between 75-85 cm, body fat percentage not exceeding 13%, no history of heart or respiratory diseases, not being in an ill or medicated condition, having no fear of swimming pool depths, and expressing willingness to participate as subjects, demonstrated by signing an informed consent form. This research was approved by the Ethics Commission of Satya Wacana Christian University with ethical clearance number 094/KOMISIETIK/EC/9/2022.

Protocol

The researchers recruited subjects who met the inclusion criteria within the Salatiga City area. Upon obtaining consent, to ascertain subject suitability, measurements of chest circumference and body fat percentage were conducted, along with interviews and medical history assessments to identify any disease history and psychological issues related to swimming pool depths.

The researchers then scheduled appointments with subjects who met the inclusion criteria to carry out apnoea duration measurements in the swimming pool and haematological examinations at the Prodia Clinical Laboratory in Salatiga City. All subjects were instructed not to consume caffeine and alcohol, avoid staying up late starting 24 hours, avoid exercise or any moderate physical activity 12 hours before the apnoea duration measurement in the swimming pool.

Body temperature, blood pressure, and capillary oxygen saturation (SpO2) examinations were conducted on the same day prior to the apnoea duration measurements and haematological examinations. The body temperature, blood pressure, and SpO2 assessments were carried out to ensure that all subjects were not in an ill condition during the apnoea duration measurements and haematological examinations. The examination of body fat levels was conducted using non-invasive Bio-Impedance Analysis method employing Omron HBF-375. Capillary oxygen saturation was measured utilizing a pulse oximeter applied to the subject's index finger, while body temperature was measured using a non-contact infrared thermometer. Blood pressure was measured using a digital sphygmomanometer. If the body temperature exceeds 37.5 degrees Celsius, systolic blood pressure is below 90 mmHg and above 125 mmHg, or the diastolic blood pressure is below 70 mmHg and above 95 mmHg, or capillary oxygen saturation below 94%, the subject is not allowed to proceed with the apnoea test and haematological examination.

The apnoea duration test in the swimming pool were conducted by the researchers. The duration of apnoea was measured by calculating the longest time a subject could hold their breath underwater while sitting still in a pool with a depth of 0.5 meters from the water surface. The apnoea duration measurement was performed through 3 trial attempts, and the longest time was recorded. Timing commenced as the head entered the water and concluded upon the head's emergence from the water. A digital stopwatch was used for timing purposes.

Haemoglobin (Hb) measurements were conducted on subjects before assessing apnoea duration. The Hb measurement was performed using the Cyanmethemoglobin method by trained professionals at the Prodia Clinical Laboratory. Blood collection was conducted once per subject, using 20 μL (microliters) of blood. Following blood collection, the blood was stored in a container placed in a cooling box along with other blood samples before being tested using the Cyanmethemoglobin method.

The Cyanmethemoglobin method involves diluting the blood with a Drabkin solution, inducing erythrocyte haemolysis, which subsequently converts haemoglobin into cyanide haemoglobin. The resulting solution is then examined using a spectrophotometer (colorimeter), where the absorbance value correlates with the haemoglobin concentration in the blood. If the obtained haemoglobin concentration result meets the criteria, the subject's ability to hold their breath (apnoea) will be assessed. Results of the haematological examinations were generated in duplicate. The original result sheets were given to the subjects, while the duplicate sheets were retained by the researchers as research data.

Statistical analysis

Data obtained were then tested for normality and correlation using SPSS version 25. To determine the normal distribution of the data, the Shapiro-Wilk test was employed since the number of subjects in this study is less than 50 individuals. The criterion used to assess normality is that if the *p*-value is greater than .05, the data can be considered normally distributed.

For correlation analysis between Hb levels and apnoea duration, the Pearson correlation coefficient was used. The criterion for determining the correlation between Hb levels and apnoea duration is that if the *p*-value is less than .05, it can be concluded that there is a correlation between haemoglobin levels and breath-holding duration (apnoea).

RESULT & DISCUSSION

From 14 subjects, it was found that one subject experienced anaemia and one subject had erythrocyte concentration above normal, consequently leading to the exclusion of two subjects from the analysis. Thus, the total number of subjects meeting the inclusion criteria amounted to 12 Subjects. Table 1 indicates that the subjects in this study are similar in age, weight, body fat percentage, and chest circumference.

Table 1. Descriptive statistic.

Variable	Mean ± SD	Min	Max
Age (yr.)	23.58 ± 1.3	21	25
Body Height (cm)	166.67 ± 5.17	157	178
Body Weight (kg)	53.18 ± 3.87	45.7	59.1
Chest Circumference (cm)	79.0 ± 2.37	76	82
Body Fat (%)	9.94 ± 1.79	7.7	12.4
SpO2 (%)	97.0 ± 1.34	95	99
Haematocrit (%)	45.03 ± 1.95	41	47
Erythrocyte (10^6/uL)	5.11 ± 0.33	4.53	5.61
Haemoglobin (g/dL)	15.35 ± 0.86	14.2	16.9
Apnoea duration (sec)	18.07 ± 6.93	9.66	31.23

Table 2. The result of normality test.

	Shapiro-Wilk		
	Statistic	df	Sig.
Apnoea duration	.917	12	.264
Erythrocyte	.933	12	.412
Haemoglobin	.956	12	.726
Haematocrit	.944	12	.548

Table 3. Result of Pearson correlation test.

		Erythrocyte	Haemoglobin	Haematocrit
Apnoea duration	Pearson Correlation	.121	.201	-.185
	Sig. (1-tailed)	.354	.266	.283
	N	12	12	12

The result of the normality test indicates that the data from all variables are normally distributed ($p > .05$). The result of the Pearson correlation test (1-tailed) indicates that there is no significant correlation ($p > .05$) between the apnoea duration and the levels of erythrocytes, haemoglobin, and haematocrit.

This study's findings surprisingly indicate the absence of correlation between apnoea duration and erythrocytes, haemoglobin, and haematocrit, thereby refuting the researcher's hypothesis. There is a possibility that erythrocytes and haemoglobin solely serve as oxygen transport media, whereas the bound oxygen within them in the blood vessels cannot be considered as oxygen reserves. This might be due to the easy binding and release of oxygen from haemoglobin anywhere in the body depending on the partial pressure of gas at that location, or the rapid distribution of oxygen from the lungs to the cells, making the oxygen in transit within the blood vessels not significant as a reserve (E. Barrett et al., 2012; Wagner, 2023).

The presence of carbon monoxide (CO) gas also needs to be considered as an interfering factor because once inhaled, it will strongly bind with haem in haemoproteins such as haemoglobin (Hb) and myoglobin (Mb), which are crucial for oxygen binding (Mao et al., 2021). Furthermore, a study (Maehira et al., 2022) suggests that haemoglobin bound to carbon monoxide (HbCO) exhibits greater physicochemical stability in aqueous conditions compared to when it is bound to oxygen (HbO_2). As a result, if CO gas is present in the blood, it can easily displace the O2 bound to haemoglobin and occupy its position in the bond with iron (Fe). Another issue is that the human body also produces CO (Nakahira & Choi, 2015). Approximately 10 mL of this gas is naturally generated throughout the human body each day during the metabolism of haem, an iron-containing molecule, by the enzyme haem oxygenase (Katsnelson, 2019).

In the context of actual sea diving, in addition to the accumulation of CO produced within the body, CO gas can also originate from surface air contaminated by the exhaust emissions of ship engines used by divers. In SCUBA diving, CO gas can come from the compressor engine used to fill the tanks; the exhaust fumes from the compressor engine are often inadvertently drawn into the tanks during filling. It is not uncommon for divers to detect the smell of diesel combustion in the air tanks they use.

As the duration of apnoea progresses, it does not allow the exchange of oxygen in the lungs with the environment outside the body, there is no new oxygen intake and there is no way for carbon dioxide and carbon monoxide to leave the body (Cheng, 2015; Wagner & Shah, 2020). As time goes on, the amount of dissolved carbon dioxide will increase, it can replace the position of oxygen in binding with haemoglobin and fill the blood vessels with carbon dioxide. If that happens, the amount of oxygen distributed by the blood will decrease because the blood is dominated by carbon dioxide. Because the exchange of oxygen and carbon dioxide in the alveoli continues to occur, over time carbon dioxide will also dominate in the lungs and airways.

The exact mechanism of the process of carbon dioxide dominance in the blood and lungs is not yet known. Does carbon dioxide dominate the lungs first and then after the partial pressure of carbon dioxide in the lungs increases the blood is also dominated, or does carbon dioxide dominate the blood first and then because of the increase in the partial pressure of carbon dioxide in the blood the lungs are also dominated? Further studies are needed to answer the exact mechanism of this process.

If apnoea activity cannot expect haemoglobin and erythrocytes to act as oxygen reserve media but only as oxygen distributors, then this means that apnoea performance is almost completely dependent on the availability of oxygen in the lung space and airways. Taking into account the results of previous studies (Putra, Pratama, et al., 2020) that lung capacity is positively correlated with the duration of apnoea, it is possible that lung capacity is the most dominant factor that determines the length of apnoea duration that can be performed. Apart from that, previous studies also found that body fat levels were negatively correlated with the duration of apnoea (Putra et al., 2022). The mechanism underlying this is not yet known for certain. Is it the presence of visceral fat that physically squeezes the lungs and occupies space that should be occupied by the lungs or is there a certain biochemical mechanism in the blood that involves blood fat, affecting erythrocytes and haemoglobin and thus affecting the distribution of oxygen in the blood.

It is also not yet known whether this only applies to sedentary individuals and whether there are differences in individuals who have routinely undergone certain types of exercise such as aerobic, anaerobic and specific exercise for apnoea. Further studies are needed studying this in trained subjects.

CONCLUSION

Haemoglobin, erythrocyte and haematocrit levels do not correlate with the duration of apnoea implying that these three blood biochemical variables cannot be expected to act as an oxygen reserve medium but actually carry out their main function as an oxygen distributor.

AUTHOR CONTRIBUTIONS

Kukuh Pambuka Putra (study design, data collection, statistical analysis, manuscript preparation). Bayu Anugroho (study design, data collection, statistical analysis). Ferry Fredy Karwur (study design, statistical analysis, manuscript preparation)

SUPPORTING AGENCIES

In this study, there is collaboration between the researchers and Prodia Clinical Laboratory, Salatiga. The researchers obtained a discount for the examination of all blood samples.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

INFORMED CONSENT STATEMENT

The researchers declare that have obtained consent from all subjects involved in this study.

DATA AVAILABILITY STATEMENT

All data supporting the findings of this study, available within the Supplementary Information.

REFERENCES

Barrett, K. E., Barman, S. M., Boitano, S., & Brooks, H. L. (2012). Ganong Buku Ajar Fisiologi Kedokteran (24th ed.). McGraw-Hill Companies.

Cheng, H. M. (2015). CO2 Respiratory Physiology. Physiology Question-Based Learning, 79-87. https://doi.org/10.1007/978-3-319-12790-3_9

Eichhorn, L., & Leyk, D. (2015). Diving medicine in clinical practice. Deutsches Arzteblatt International, 112(9), 147-158. https://doi.org/10.3238/arztebl.2015.0147

Guyton, C. A., & Hall, E. J. (2016). Textbook of medical physiology (13th ed.). Elsevier Inc.
Jones, M. W., & Wyatt, H. A. (2019). Hyperbaric, Physics. In StatPearls.
Katsnelson, A. (2019). The Good Side of Carbon Monoxide. ACS Central Science, 5(10), 1632-1635. https://doi.org/10.1021/acscentsci.9b01015
Lindholm, P., & Lundgren, C. E. G. (2009). The physiology and pathophysiology of human breath-hold diving. Journal of Applied Physiology, 106(1), 284-292. https://doi.org/10.1152/japplphysiol.90991.2008
Maehira, A., Che, D. C., & Matsumoto, T. (2022). Change in surface properties of hemoglobin induced by heme reaction with O2 and CO. Japanese Journal of Applied Physics, 61(7), 075003. https://doi.org/10.35848/1347-4065/ac77cc
Mao, Q., Kawaguchi, A. T., Mizobata, S., Motterlini, R., Foresti, R., & Kitagishi, H. (2021). Sensitive quantification of carbon monoxide in vivo reveals a protective role of circulating hemoglobin in CO intoxication. Communications Biology 2021 4:1, 4(1), 1-15. https://doi.org/10.1038/s42003-021-01880-1
Nakahira, K., & Choi, A. M. K. (2015). Carbon monoxide in the treatment of sepsis. American Journal of Physiology - Lung Cellular and Molecular Physiology, 309(12), L1387-L1393. https://doi.org/10.1152/ajplung.00311.2015
Pearn, J. H., Franklin, R. C., & Peden, A. E. (2015). Hypoxic blackout: Diagnosis, risks, and prevention. International Journal of Aquatic Research and Education, 9(3), 342-347. https://doi.org/10.1123/ijare.2015-0036
Putra, K. P., Karwur, F. F., & Hidayati, N. W. (2020). VO2max Berkorelasi Negatif dengan Kemampuan Tahan Nafas (Apnea). JOSSAE : Journal of Sport Science and Education, 5(2), 139. https://doi.org/10.26740/jossae.v5n2.p139-147
Putra, K. P., Pratama, R. P., & Nugroho, K. P. A. (2020). Kapasitas Vital Paru Berkorelasi Positif dengan Kemampuan Tahan Nafas pada Laki-Laki Usia 19-25 Tahun. JOSSAE : Journal of Sport Science and Education, 5(1), 25. https://doi.org/10.26740/jossae.v5n1.p25-32
Putra, K. P., Triandhini, R. L. N. K. R., Wicaksana, A., & Messakh, S. T. (2022). Body fat levels and its negative correlation to apnea duration. Jurnal Keolahragaan, 10(1), 110-117. https://doi.org/10.21831/jk.v10i1.48131
Rozycki, S. W., Brown, M. J., & Camacho, M. (2018). Inner ear barotrauma in divers: An evidence-based tool for evaluation and treatment. In Diving and Hyperbaric Medicine (Vol. 48, Issue 3, pp. 186-193). South Pacific Medicine Underwater Society and the European Underwater and Baromedical Society. https://doi.org/10.28920/dhm48.3.186-193
Sherwood, L. (2015). Fisiologi Manusia: Dari Sel ke Sistem (D. R. Herman Octavius Ong, Albertus Agung Mahode, Ed.; 8th ed.). EGC.
Wagner, P. D. (2023). Blood Gas Transport: Implications for O 2and CO 2Exchange in Lungs and Tissues. Seminars in Respiratory and Critical Care Medicine, 44(05), 584-593. https://doi.org/10.1055/s-0043-1771161
Wagner, P. D., & Shah, P. L. (2020). Airways and alveoli. Oxford Textbook of Medicine, C18.1.2-C18.1.2.P55. https://doi.org/10.1093/med/9780198746690.003.0397

ORIGINAL ARTICLE

Development and validation of the evaluation and selection criteria scale for coaches: Factor structure, validity and reliability

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ABSTRACT

The purpose of this study was to develop and provide initial validation of a scale designed to identify the evaluation and selection criteria of 585 coaches selected to work in 237 amateur sports clubs in Attica, Greece. The development of the scale was based on the job analysis of coaching and the review of the evaluation of coaching performance. The criterion of KMO (.934) and Bartlett's test of Sphericity test (13338.366, df 406, $p < .00001$) confirmed that the requirements for factor analysis were met. EFA revealed a scale of 29 items and identified six (6) factors interpreting the 73.396% of the overall variance: (1) results of coaching on athletes, (2) personal achievements of the coach, (3) design and implementation of coaching (4) competition management (5) psychological support of the athletes and (6) commitment to the club. CFA was used to test the accuracy of the construct revealed by EFA. The findings of this study support the factorial structure of the scale and its psychometric qualities in a Greek sample suggesting that the scale is valid for identifying the evaluation and selection criteria employed from amateur sports clubs to select their coaches.
Keywords: Sports coaching, Amateur sports clubs, Selection process.

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INTRODUCTION

Selecting a coach is an extremely important decision for a sports club; coaches contribute critically to the fulfilment of strategic organizational goals and their performance constitutes a potential source of growth as well as a significant competitive advantage (Armstrong & Taylor, 2023; Davis et al., 2022; Millar, Clutterbuck & Doherty, 2020; Taylor, Doherty & McGraw, 2015). Selection is the part of the recruitment process that refers to the decision of the applicant that will be appointed to a job position (Armstrong & Taylor, 2023). Literature suggests that effective recruitment and selection of personnel in sports organizations requires accurate analysis of the job position (Taylor, et al., 2015). Therefore, job analysis of the coaching work is a prerequisite for describing coaching tasks and specify requirements for their successful accomplishment as well as for generating selection criteria for a specific coaching position.

Coaching is recognized as a complex and behavioural dynamic work which is organized situationally in accordance to a given setting, environment or context (Cooper & Allen, 2018; Corsby, 2024; Gershkowitz et al., 2021; Lara-Bercial & Mallett, 2016; O'Boyle, 2014; Zhang et al., 2018). The coaching context represents the environment in which coaching is situated and includes in addition to the location, the nature and type of the sport, the age and competition level of the athletes, cultural and individual characteristics of those involved, the needs of the athletes (Cushion, Harvey, Muir & Nelson, 2012; Horton, 2015; Lyle, 2002; North, 2009). Therefore, coaching tasks, responsibilities, and functions vary significantly as the context in which coaching is referred (Lyle, 2002; Horton, 2015). However, regardless of the context and the coaching domain, coaches engage in functions that are common in all coaching positions and relate to strategic, instructional, organizational, and social relationship aspects of coaching. These functions refer to (1) setting the vision and strategy of the coaching process, (2) shaping the environment in which coaching occurs, (3) building relationships with athletes and others associated with coaching, (4) conducting coaching practices and preparing and managing competitions promoting learning and improvement, (5) reading and reacting to the field, observing and responding to emerging events, including field related and non-related matters (6) reflecting and learning during each practice and competition and continually seeking for improvement (Lara-Bercial, North, Hämäläinen, Oltmanns, Minkhorst, & Petrovic, 2017).

The successful accomplishment of the above-mentioned coaching functions requires a combination of general and sport-specific knowledge as well as an understanding of the coaching environment (Neelis, Faucett, & Thompson, 2020; Stodter & Cushion, 2019). Specific knowledge is referred to: (a) knowledge in the professional domain, such as knowledge in sports science, knowledge of the sport, and knowledge of pedagogy, (b) knowledge in the interpersonal domain, which concerns communication knowledge, and (c) knowledge in the intrapersonal area, such as self-awareness and reflection (Gilbert & Côté, 2013; Neelis, Faucett, & Thompson, 2020). Knowledge in these three areas is considered required for every coaching position, in a blend that differs according to the coaching domain and the level of the coaching position while the way this knowledge is used relates to success in coaching (Côté & Gilbert, 2009; Stewart et al. 2020). Effective coaching requires also qualities, skills, and characteristics of the coach that ensure the successful accomplishment of duties in every coaching domain. In this sense, coaching professional experience is considered fundamental for the development of coaching knowledge and skills to the extent that coaching expertise cannot be acquired in the absence of experience (Chan & Mallet, 2011; Kramers et al., 2020; Lyle & Cushion, 2017; Neelis, Faucett, & Thompson, 2020). Literature supports that the more experienced a coach is and the greater the diversity of their experiences, the faster the coach learns and improves coaching skills (Schempp, McCullick & Mason, 2006). In addition, skills that facilitate communication and interaction with other people are considered very important in coaching as at the centre of the coaching process is placed the coach-athlete relationship the quality of which affects coaching effectiveness and mediates leadership

(Côté & Gilbert, 2009; Horn, 2008; Jowett, 2017; Jowett & Arthur, 2019; Martens, 2012; MacLean & Chelladurai, 1995; Rhind & Jowett; 2010; Sullivan, Rhind & Jowett, 2014). Leadership, in particular, is the behaviour aimed at increasing or influencing athletes' performance and satisfaction. Pedagogical, organizational, and administrative skills are also necessary for sports coaching (Cassidy et al., 2023) as they facilitate effectiveness in shaping a welcoming, positive, inclusive, and safe training environment (Perkins & Hahn, 2019). Critical thinking, reflection, autonomy, adaptability, decision-making, and needs analysis, are some of the abilities that relate to personality and facilitate the application of theory in practice ensuring the successful fulfilment of the coaching roles (Lara-Bercial, Duffy, & Harrington, 2013). Therefore, personality which refers to a person's characteristics as well as leadership skills are considered very important in coaching as they facilitate interpersonal relationships and have a significant impact on athletes' performance (Amorose & Horn, 2001; Mageau & Vallerand, 2003; Martens, 2012; Predoiu et al., 2021; Vella, Oades, & Crowe, 2010).

Coaching performance is an extensively researched topic in sports literature. While traditional coaching performance evaluation focused on results, records, victories, and medal winnings to assess the performance of a coach research has shown that the objective measurement of coaching performance rely on criteria that are exclusively linked to the coaching work (job-specific), result from the study of the coaching behaviours required to fulfil the coaching tasks and differ depending on the coaching field or the context in which the training practice is situated and the coach-athlete relationship operates (Côté, Salmela, Trudel, Baria, & Russell, 1995; Horn, 2008; Lyle & Cushion, 2017; MacLean & Chelladurai, 1995; Behrendt, & Greif, 2022). Nevertheless, according to some authors (Côté & Gilbert, 2009) athletes' performance and achievement levels in addition to the level of their satisfaction and enjoyment are factors measuring coaching performance.

In occupations like coaching, work behaviours are considered central to job performance as they influence important aspects of athletes' development and their overall sporting experience (Thelwell et al. 2017; Smith & Smoll, 2017). As a result, an ongoing debate has been stimulated concerning the evaluation of coaching performance raising questions whether the evaluation criteria should refer to the results of the coaching intervention, the evaluation of the coaching behaviours, or both. The work of MacLean & Chelladurai (1995) supported that the evaluation criteria of coaching performance should be task-specific, measurable elements of the task and result from the study of coaching behaviours that are context specific (MacLean, 2001). Extending this work, MacLean and Zakrajsek (1996) proposed a set of job performance criteria of coaches in the context of Canadian collegiate sports that includes the coaching behaviours associated with results either for the coach or the athlete, behaviours related directly or indirectly with the coaching task and behaviours that relate to administrative tasks and public relations. Coaching behaviours were at the centre of the focus and analysis of several models developed to provide a comprehensive understanding of the coaching process and to determine the criteria appropriate to evaluate coaching performance (Lyle, 2002). From another point of view, Zhang, Hou, Wang & Xiao (2014) argued that a coach's evaluation concerns personal abilities, coaching abilities and athletes' results.

Coaching is a contextual process and therefore coaching performance should be evaluated in relation to its context (Corsby, 2024; Horton, 2015; Lyle, 2002; Lyle & Cushion, 2017). As such, coaching performance criteria should include contextual characteristics as they shape and influence constantly the roles and the responsibilities of the coach. However, successful evaluation of the performance of a coach depends on the definition of appropriate criteria (MacLean, 2017; MacLean & Chelladurai, 1995).

In the context of amateur sports, the selection decision of a coach relies on the club's executive board members who are volunteers and usually adopt less formal and less structured recruitment and selection procedures for their coaches (Papadimitriou, 2005; Taylor, et al., 2015). Given that selection of coaches refers to decisions made by club administrators which, most of the times, are based on intuition, personal rapport or experience the present study aims to develop and assess the psychometric properties of the Evaluation and Selection Criteria (ESC) scale in order to identify the evaluation and selection criteria of coaches working for amateur sports clubs. Furthermore, the study aims to validate the measurement model of the evaluation and selection criteria in the context of the Greek amateur sports clubs among the population of coaches working in the area of Attica. In a context where informal personnel selection processes are usually employed this study aims to offer a comprehensive and easy-to-use tool for the evaluation and selection of coaches and to raise attention to issues regarding recruitment and selection procedures.

MATERIAL & METHODS

Participants

The sample comprised five hundred eighty-five (N = 585) coaches selected by three hundred fifty-three (353) administrators to work in two hundred thirty-seven (237) local amateur sports clubs. Participants were selected using a simple random sampling method among the coaches working in amateur sports clubs in the Region of Attica, Greece. Demographics showed that 393 coaches were male (67,2%) while 192 were female (32.8%). The age of the coaches ranged from 18 to 69 years (M = 40.2, SD = 10.28) and their working experience ranged from 0 to 50 years (M = 14.2, SD = 8.71). Most coaches (432, 73.8%) had a university degree. 514 (87.9%) coaches had a professional license in coaching and 542 (92.6%) had a previous experience as athletes before becoming coaches. Sport coaching was the main profession of 267 (45.6%) coaches while 318 (54.4%) coaches had other than coaching as their primary occupation. The majority of the coaches in the sample (508, 86.8%) were coaches working from 1 to 35 years in the same sports club while 77 (13.2%) were new recruits. In addition, demographic data showed that 491 (83.9%) coaches were part-time employees while 94 of those were working full-time in the club. Coaches under this study covered thirty-one sports: tennis (27), weightlifting (8), gymnastics for all (9), gymnastics (17), table tennis (4), jiu jitsu (15), sailing (11), basketball (78), artistic swimming (6), aerobic gymnastics (2), canoe kayak (1), karate (13), swimming (63), rowing (2), modern pentathlon (4), muay tai (1), fencing (4), wrestling (1), volleyball (70), cycling (2), soccer (71), boxing (2), rhythmic gymnastics (25), shooting (1), athletics (82), taekwondo (21), judo (4), archery (1), trampoline (7), water polo (19), handball (14), in a total of 333 coaches (56.9%) from individual sports while 69 (20,1%) in team sports. Administrators' participation in this study was voluntary while the cover letter of the questionnaire was assuring confidentiality and anonymity of the survey.

Measures

The ESC scale for coaches is administered to measure the impact degree of each criterion on the selection decision of a specific coach. It comprises 35 items allocated in six factors representing the themes regarding the evaluation and selection of coaches in the context of amateur sports. In particular, the "*results of coaching on athletes*" factor measures the impact of coaching practice on athlete's performance as an indicator of coaching effectiveness (e.g. "*improves the performance of individual athletes or teams*", "*improves ranking positions of athletes or teams*", "*identifies talents in sport*"). Coaching in this specific context refers to participation athletes as well as to performance athletes. Coaching for participating athletes focuses on fun, learning new sports skills, development of life skills, confidence, and interaction with other people (Lyle, 2002; Nelson, 2010; Perkins, Hahn, Keegan, & Collis, 2014). Coaching for performance athletes focuses on performance and aims at developing necessary skills and techniques to ensure success in performance (Lyle, 2002; Côté & Gilbert, 2009). The second factor "*personal achievements of the coach*" represents criteria measuring coaches' performance as they relate to the acknowledgment of their coaching work from agencies and stakeholders involved in the context of amateur sports. With this construct professionalism and ongoing development of the coach can be observed through 5 items ("*publishes articles for coaching*", "*lectures in conferences or seminars for athletes/coaches*", and "*receives awards for his/her coaching work*"). The "*design and implementation of coaching*" factor represents measures of coaching knowledge and experience related to the development of the coaching process and the delivery of practices which are among the primary functions of a coach (Horton, 2015; Lyle, 2002). This factor comprises 6 items (e.g. "*teaching sports techniques effectively in training*", "*providing guidance actively and continuously to athletes and teams during training*", "*using sport equipment appropriately in training*", and "*individualized training*"). The "*competition management*" factor refers to criteria assessing coaching behaviours during competition. A coach must read and react appropriately to the field and manage emerging events during the competition (Abraham & Collins, 2011). In this respect, leadership abilities and effective decision-making are considered essential and are evaluated through the 3 criteria included in the unit (e.g., "*making appropriate decisions depending on the progress of the competition*", "*implementing tactics and strategies during competition*"). The "*psychological support of the athletes*" factor evaluates behaviours that support athletes psychologically during training or competition. Coach–athlete interactions are considered important for the outcomes of the coaching intervention as they occur constantly. In this context, coaches assume the role of supporting athletes' psychological well-being, by motivating them to improve their skills and performance. Coaches' primary functions include the responsibility to maintain positive relationships with athletes and to create a positive learning environment suitable for the implementation of the coaching program in which opportunities for life skills development are offered as well (Lyle, 2002). To that end, this specific factor through 7 items measures coaches' ability to create such a coaching environment, promote fair play, communicate effectively with athletes, motivate them, reward their efforts, prepare them appropriately for competition, and provide feedback during training or competition (e.g., "*preparing athletes or teams for competition*", "*communicating effectively with athletes or teams*", "*developing a pleasant training environment*", "*promoting fair play*"). Lastly, the "*commitment to the club*" factor deals with criteria related to the quality of relationships with club members and stakeholders as well as with the support provided for the promotion of the organization. Coaches' performance is directly related to and contributes to the welfare and the growth of a sports club. This contribution is achieved through adherence to rules, regulations, and organizational processes as well as through effective cooperation with the members of the club (McLean & Chelladurai, 1995). The last factor includes 5 items (e.g., "*cooperating effectively with club members*", "*complying with the club philosophy and operating principles*", and "*cooperating effectively with parents*").

The scale comprised 35 items to be answered on a five-point Likert-type scale (from 1 to 5: 1 = Not at all influenced, 2 = Slightly influenced, 3 = Moderately influenced, 4 = Very influenced, 5 = Extremely influenced). The instructions for completing the questionnaire were as follows: "*Indicate to what extent each of the following criteria influenced your decision to select or maintain an existing working relationship with this particular coach. There are no right or wrong answers. Please answer all questions*." The required time to complete all sections of the survey instrument was 15 minutes.

A separate section of the survey instrument was designed to collect demographic data. These data involved information related to the sports club (i.e. year of foundation, number of sports units, number of coaches), demographics of administrators responsible for selecting coaches (i.e. years of age, gender, years of experience in selecting coaches, position, years at the club) and demographic data of coaches (i.e. gender, years of age, graduation institute, level of professional license, sport, competition level of athletes, years of work experience, years of an athletic career, distinctions as an athlete, main professional occupation, working relationship with the club, type of occupation) was collected in this section.

Procedures

The development of the questionnaire followed three stages. The initial step was to conduct in person meetings with a focus group of 10 administrators of sports clubs to discuss issues regarding the selection process of their coaches. In parallel, the review of the literature relevant to employee selection, analysis of the coaching work, and performance appraisal criteria for coaches was carried out. As a result, six thematic units and a total of 35 items were generated. The assessment of content validity was the following step. Content validity of the scale was assessed by a panel of five experts. Experts were academicals holding a PhD degree in the area of sports management and sports psychology, all experienced in scientific research. The relevance of each item to the variable designated to measure was based on the Content Validity Index (CVI) with experts to indicate the relevance of each item to the field under investigation on a four-point scale (1 = not at all relevant, 2 = somewhat relevant, 3 = quite relevant and 4 = very relevant) (Davis, 1992). The CVI index (the percentage of questions rated 3 and 4 by the experts divided by the number of experts) was 0.82 with the expert-recommended value of the index at 0.80 (Davis, 1992; Polit & Beck, 2006). Experts' comments were used to modify and improve the wording of some items. Based on experts' ratings the 35 items were included in the scale. In the final step of the questionnaires' development, the instructions to be given, the demographic data section as well as the response format of the questionnaire were finalized. The questionnaire was distributed and collected over a period of eight months, during the competition season 2020-2021.

Sport club executives and administrators were contacted in person and provided with information regarding the aim of the survey. They were invited to participate and to arrange meetings with their colleagues responsible for the selection of coaches. Necessary information and clarification were provided when questionnaires were distributed to respective individuals. All participants in the survey were informed of the complete confidentiality of the data to be provided and its exclusive handling for the purposes of the study. They were asked to indicate the influence degree of each of the evaluation and selection criteria provided on their decision to select a specific coach. Distribution and collection of questionnaires conducted for eight months - October 2020 to May 2021 -during the competition season in 2020-21, a period right after the COVID-19 pandemic.

Analysis

The reliability of a questionnaire lies in its ability to provide accurate and stable measurements (i.e. consistent findings) at different times and conditions (Saunders, Lewis & Thornhill, 2012). Internal consistency is a measure of reliability and assesses whether different items measure the same concept (variable). To assess the internal consistency of each factor, the Cronbach's alpha statistic was used (Cronbach, 1951). Cronbach's α coefficient quantifies the level of agreement on a standardized 0 to 1 scale with values higher than 0.8 to indicate that the items on the scale measure the same construct and values less than 0.7 to indicate that an item on the scale may need to be deleted (Cronbach, 1951). According to researchers (Nunnally, 1978; Spector, 1992) index values greater than 0.7 are considered satisfactory. The higher the value of Cronbach's α coefficient, the higher the internal consistency reliability (Litwin, 1995).

Construct validity refers to how well a measurement tool measures the idea or the concept it claims to measure and reflects the theory it is based on. Because the validity of a conceptual construction of a tool is not directly observable, factor analysis is performed to identify the groups of items that are conceptually and statistically related to each other and to highlight the variables to be measured. To check the construct validity of the ESC scale, an Exploratory Factor Analysis was performed. For the extraction of the factors, the method of Principal Component Analysis (PCA) was applied, a method that, according to Hair, Anderson, Tatham, and Black (1995), is considered one of the most acceptable methods. The K.M.O. (Kaiser - Meyer - Olkin) measure of sampling adequacy was used to check the overall sampling suitability to factor analysis. The test measures sampling adequacy for each variable in the model and for the complete model. KMO values between 0.8 and 1 indicate the sampling is adequate. The Bartlett's Test of Sphericity was used to examine the suitability of the data for factorial analysis. The significance value of Bartlett's Test of Sphericity must be less than 0.05 for the factor analysis to be acceptable.

Exploratory Factor Analysis (EFA) techniques were used to explore if an item set is associated with a construct (or specifically designed to measure a certain psychological variable) and subsequently to refine it. Factor analysis requires to set the number of factors to be extracted. However, to determine the number of factors the criterion of the percentage of Variance (% of Variance) was used, which interprets each factor in combination with the eigenvalues. Often a solution that accounts for 60% of the total variance, and in some cases even less, is considered satisfactory (Hair, et al., 1995). Factor loadings were checked to check the percentage contribution of the variables to the formation of the factors. Factor loadings represent the correlation between the initial variables and the factor to which they belong. These values are examined in conjunction with the sample size and the significance level. Experts note that in a sample larger than 200 people, with a significance level of 5 %, loadings with an absolute value of 0.40 and above are considered significant (Hair et al., 1995). The method of Principal Component Analysis (PCA) with oblique rotation of the axes was applied as one of the most accepted methods to extract factors (Hair, et al., 1995).

Confirmatory Factor Analyses (CFA) are often used in psychological research when developing measurement models for psychological constructs. Confirmatory Factor Analysis (CFA) was used in this study to confirm the structural validity of the Evaluation and Selection Criteria scale. CFA was performed using EQS Multivariate Software Version 5.7b the results were extracted using the maximum likelihood estimation method.

However, before CFA was conducted normality of data was assessed and the distribution of variables was tested by: (a) univariate skewness, (b) univariate kurtosis, (c) Mardia univariate kurtosis (Mardia, 1970), which specifies the multivariate regularity limits. Univariate regularity was tested to check if the items should be conserved or eliminated from the factor analysis (West, Finch & Curran, 1995). Multivariate regularity was used to identify and select the appropriate factor data analysis method (Bollen, 1989; West, Finch, & Curran, 1995). According to many researchers, several goodness-of-fit indices have been developed to quantify agreement or deviation from perfect model fit and can be employed to evaluate model fit (Hu & Bentler, 1998).

Therefore, the following indexes were used to assess models' fit through the Confirmatory Factor Analysis: (1) χ^2 (chi-square), df (freedom degrees), χ^2/df ratio, Satorra – Bentler chi- square index χ^2 (2) Non- normed fit index, (3) Comparative Fit Index (CFI), (4) Robust Comparative Fit Index (RCFI), (5) Incremental Fit Index (IFI), (6) Standardized Root Mean Squared Residual (SRMR) and (7) Root Mean Squared Error of Approximation (RMSEA) and the 90% Confidence Interval of RMSEA (Bentler, 1990; Bentler & Chou, 1987; Byrne, 1994; Bollen, 1989; Hoyle & Panter, 1995; Hu & Bentler, 1999; Tabachnick & Fidell, 2006). The statistic index χ^2 is influenced by the sample size, by the freedom degrees as well as by the violation of the normality assumptions (Bentler, 1995; Hu & Bentler, 1995; Kline 1998). However, many researchers proposed that when evaluating a model, the χ^2/df ratio is considered a more reliable index compared to χ^2 (Bentler & Bonett, 1980). When χ^2/df rates are between 2 and 5, then an acceptable model structure can be supported. When χ^2/df rates are lower than 2, the model has an impressive data application (Byrne, 1989; Kelloway, 1998). NNFI, CFI, RCFI, and IFI have a range of possible values from 0 to 1; rates greater than .900 imply an acceptable factor structure of the tested model (Bentler, 1990). Hu and Bentler (1999) proposed a much stricter criterion for the acceptance of NNFI and CFI indexes, placing the acceptance limit rates to .950. On the other side, when the index rates of SRMR and RMSEA of the tested model are lower than .050, then the factor structure could be accepted (Steinger, 1990; Tabachnick & Fidell, 1996). According to Hu and Bentler (1999) the acceptance limit of SRMR index is near .080 and for the RMSEA index is .060, while other researchers identify the best fit limit at the rate of .050 (Bollen, 1989; Tabachnick & Fidell, 1996). Browne and Cudeck (1993) suggest that a 90% CI (confidence interval) of RMSEA rate between 0 and .05 indicates a close fit, less than .08 represents a reasonable fit, while greater than .08 suggests a poor fitting model. Lastly, many researchers support that a lower rate than .050, indicates the existence of a proper fit, while the rates between .050 and .100 note the existence of an acceptable factor structure of the tested model (McAuley, Duncan, & Tammen, 1989; Rupp & Segal, 1989).

According to the results of the EFA as well as the theoretical background of the current study item loadings to factors should be higher than .40 to be acceptable, which is an acceptable item loading rate for social sciences (Bentler, 1995). Furthermore, it is worth mentioning that items were «allowed» to load only from their factor. Loadings of other factors were rated at 0.00 while measurement error correlation was not permitted (Bentler, 1995).

The IBM Statistical Package for the Social Sciences (SPSS), version 22 was used for the statistical analyses of data in this study through confirmatory factor analysis (Bentler, 1995). Before factor analysis, a review of the dataset confirmed that there were no missing data in this study's dataset.

RESULTS

Bartlett's test of sphericity index (17521.324, df 595, $p < .00001$) indicated the rejection of the null hypothesis that variables are unrelated. KMO value was at an absolute satisfactory level (KMO = .946) indicating that data is suitable for factor analysis. Exploratory Factor Analysis with the Principal Component Analysis (PCA) technique was based on the above-mentioned factor selection criteria (eigenvalue plot, factor eigenvalue greater than 1, percentage of explained variance per factor, total explained variance, conceptual interpretation of factors) (Kline, 1994; Nunnally & Bernstein, 1994; Tabachnick & Fidell, 2006; Tinsley & Tinsley, 1987; Tucker, Koopman, & Linn, 1969) and supported the existence of six factors interpreting the 72.044% (% Cumulative) of total variance. Items' loadings and communalities ranged from .391 to .999 and .539 to .839 respectively. However, the results of the analysis revealed problems in some scale items. Based on statistical criteria, such as loadings, cross-loadings, communalities as well as conceptual criteria, six (6) items were excluded from further analysis in this study (items 1, 2, 5, 17, 22, 25). As a result, reliability analysis was conducted again and factor structure was retested in the 29-items scale with these variables omitted. Bartlett's test of sphericity index (13338.366, df 406, $p < .00001$) indicated the rejection of the null hypothesis that variables are unrelated while the value of KMO = .934 is at an absolutely satisfactory level. The Principal Component Analysis (PCA) technique supported six factors interpreting the 73.396% (% Cumulative) of the total variance. Items loadings and communalities ranged from .634 to .971 and .560 to .880 respectively. The results of the reliability test of the scale are presented in Table 1.

The first factor "*results of coaching on athletes*" corresponds to 3 items: "*improves the performance of individual athletes or teams*", "*improves the ranking of athletes or teams*" and "*identifies talents*". The second factor "*personal achievements of the coach*" refers to 5 items: "*receives awards for coaching by social agencies*", "*receives recognition for coaching by other coaches*", "*publishes articles for coaching*", "*gives lectures in conferences or seminars for athletes/coaches*", "*receives recognition for coaching by sports agents*". The third factor "*design and implementation of coaching*" corresponds to 6 items: "*uses sports* *equipment appropriately in training*", "*individualizes training*", "*teaches sports techniques effectively*", "*evaluates successfully athletes' potential*", "*provides guidance actively and continuously to athletes and teams during training*" and "*develops and implements the training program appropriately*". The fourth factor "*competition management*" corresponds to 3 items: "*makes appropriate decisions depending on the progress of the competition*", "*highlights and corrects mistakes during competition*" and "*implements tactics and strategies during competition*".

Table 1. Loadings and communalities of the items of the coaches' evaluation and selection criteria scale.

Item		Loadings						Communalities
		1	2	3	4	5	6	
24	Rewards psychologically athletes or teams	0.933						0.78
23	Communicates effectively with athletes or teams	0.93						0.769
20	Develops a pleasant training environment	0.828						0.683
22	Promotes fair play	0.789						0.692
18	Supports psychologically athletes or teams	0.781						0.731
21	Motivates athletes or teams to put more effort	0.764						0.713
19	Prepares athletes or teams for competition	0.635						0.738
2	Improves performance of individual athletes or teams through training		0.938					0.841
1	Improves ranking of athletes or teams		0.931			0.338		0.809
3	Identifies talents		0.867					0.726
6	Publishes articles for coaching			0.971				0.819
7	Give lectures in conferences or seminars for athletes/coaches			0.96				0.806
4	Receives awards for coaching by social agencies			0.768				0.698
5	Receives recognition for coaching by other coaches			0.673				0.693
8	Receives recognition for coaching by sport agents			0.566				0.56
29	Understands the financial potential of the club				0.827			0.699
27	Complies with the club philosophy and operating principles				0.819			0.719
28	Contributes to the promotion of the club by organizing events				0.786		0.368	0.747
26	Cooperates effectively with parents				0.76			0.695
25	Collaborates effectively with club members				0.725			0.715
16	Makes appropriate decisions depending on the progress of the competition					0.928		0.88
15	Highlights and corrects mistakes during competition					0.922		0.844
17	Implements tactics and strategies during competition					0.916		0.856
14	Uses sport equipment appropriately in training						0.634	0.607
11	Individualizes training						0.622	0.74
10	Teaches sport techniques effectively						0.601	0.728
12	Evaluates successfully athletes' potential		0.343				0.575	0.725
13	Provides guidance actively and continuously to athletes and teams during training						0.481	0.665
9	Develops and implements the training program appropriately						0.424	0.607
Eigenvalues		12.376	2.991	2.574	1.388	1.072	0.884	
% Cumulative Interpretation		42.675	10.314	8.876	4.787	3.698	3.047	

Note. Extraction Method: Principal Component Analysis. Rotation Method: Promax with Kaiser Normalization.

The fifth factor "*psychological support of the athletes*" corresponds to 7 items: "*rewards psychologically athletes or teams*", "*communicates effectively with athletes or teams*", "*develop a pleasant training environment*", "*promotes fair play*", "*supports psychologically athletes or teams*", "*motivates athletes or teams to put more effort*" and "*prepares athletes or teams for competition*". The sixth and last factor "*commitment to the club*" corresponds to 4 items: "*understands the financial potential of the club*", "*complies with club's philosophy and operating principles*", "*contributes to the club's promotion by organizing events*", "*cooperates effectively with parents*" and "*cooperates effectively with club members*".

The reliability test followed the extraction of the six factors with the 29 items in the scale using PCA technique. For that purpose, the internal consistency of the factors of the Evaluation and Selection Criteria for coaches' scale was checked. The results of the application of the scale's reliability control methods are presented in Table 2. Cronbach's α values, as a basic indicator of the internal consistency of the scale, reached a completely satisfactory level, with values higher than .70 indicating an acceptable degree of internal consistency (Hair et al., 1995; Nunnally & Bernstein, 1994). In addition, item-scale correlations as well as inter-item correlations were fully acceptable.

Table 2. Reliability indexes of the evaluation and selection criteria for coaches scale.

	Inter-item Correlations Mean (Min – Max)	**Inter-item Covariances Mean (Min – Max)**	**Item-scale Correlations Mean (Min – Max)**	**Cronbach's *α***
Results on athletes	.743 (.666 - .852)	.612 (.560 - .688)	.796 (.715 - .819)	.90
Personal achievements	.604 (.463 - .835)	.909 (.693 - 1.238)	721 (.625 - .764)	.88
Design and implementation of coaching	.602 (.451 - .717)	.390 (.313- .471)	.729 (.579 - .790)	.90
Competition management	.822 (.770 - .877)	.745 (.696 - .821)	.862 (.819 - .902)	.93
Psychological support of the athletes	.650 (.540 - .799)	.329 (.267- .460)	.773 (.736 - .806)	.93
Commitment to the club	.576 (.489 - .667)	.553 (.448 - .835)	.694 (.667 - .711)	.87

In the next step, Confirmatory Factor Analysis was carried out to specify the number of factors in the model proposed by the Exploratory Factor Analysis and confirm the measurement theory. Univariate skewness rated from -1.83 to 0.56 and univariate kurtosis rated from -0.91 to 5.64 indicating that the scale items have been normally distributed as both measures haven't exceeded the limits of 2 and 7 respectively (West Finch, & Curran, 1995). Mardia's coefficient of multivariate kurtosis supports the existence of the normalized estimate [normalized estimate = 112.0664 < 29 (29+2)]. For examining the structure of the scale, the maximum likelihood method (ML) was employed. The CFA revealed that the six-factor 29-item model fits data well. The model's goodness-of-fit indexes were as follows: χ^2 = 13582.573, $p < .001$, Satorra-Bentler χ^2 = 822.090, $p < .001$, df 359, χ^2 /df ratio = 2.290, NNFI = .926, CFI = .934, RCFI = .919, IFI = .934, SRMR = .059, RMSEA = .064 (90% CI of RMSEA = .060 - .068). In particular, the examination of the six-factor model's fit showed that χ^2 index was statistically significant, which means that there were statistically significant differences between the proposed model and the sample data, although it is appropriate to note that χ^2 index and the χ^2 /df ratio are affected by the sample size. Factor item loadings were satisfactory and ranged from .64 to .96, while the item errors received values from .30 to .77 (Figure 1).

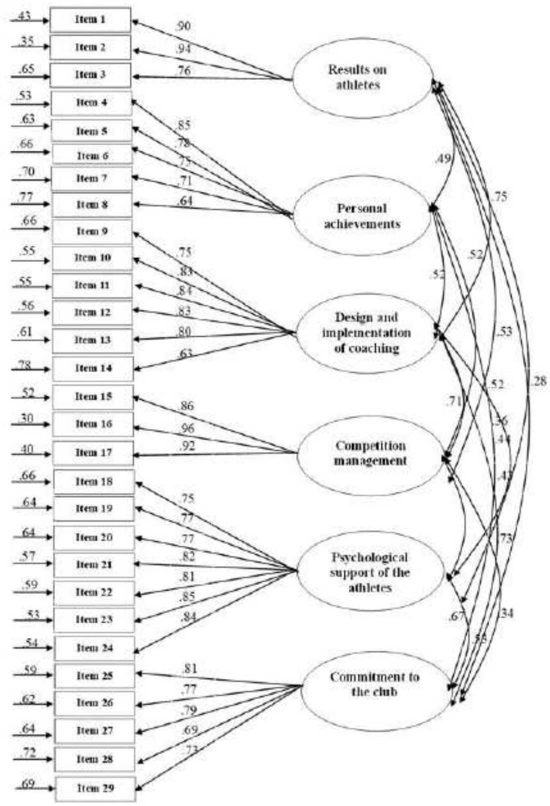

Figure 1. Item's loadings and errors of coaches' evaluation and selection criteria scale.

In order to examine the suitability of the six-factor model of the ESC scale for coaches in the confirmatory factor analysis context, two alternative models were examined. In particular, the first model included the selection of six correlated factors (FC6), while the second alternative model included the selection of one factor (OF1) to investigate whether the examined scale is a single-factor model. As a result, fit indices of the models supported that the six correlated factor solution (FC6) has the best fit while the one-factor solution (OF1) did not achieve as good indices (Table 3).

Table 3. Coaches' evaluation and selection criteria questionnaire confirmatory factor analysis: Fit indexes of two alternative factor structure models.

Fit indexes	**FC_6 Six Correlated Factors**	**OF_1 One Factor**
χ^2	1225.179	2313.45
df	359	383
p	.001	.001
NNFI	.926	.789
CFI	.934	.802
RCFI	.919	.801
IFI	.934	.787
SRMR	.059	.178
RMSEA	.064	.180
90% CI of RMSEA	.060 - .068	.135 - .230

Abbreviations: χ^2 = chi square index, df = freedom degrees, NNFI =non – normed fit index, CFI = comparative fit index, RCFI = robust comparative fit index, SRMR = standardized root mean square residual, RMSEA = root mean square error of approximation, 90% CI of RMSEA= 90% RMSA Confidence Interval.

DISCUSSION

This study attempted to develop and validate a questionnaire measure designed to assess the impact of the Evaluation and Selection Criteria in the selection decision of coaches. The validation of the scale was conducted among a sample of 585 coaches working for amateur sports clubs in the region of Attica in Greece. An initial list of 35 statements was refined while factor analyses revealed a 29-item scale. Based on the data, a six-factor structure was identified using oblique rotation. The confirmatory factor analysis performed on the 29-item scale indicated that the six-factor structure fits the data well. The first factor "*results of coaching on athletes*" assesses the results of coaching practice on athletes and focuses on the improvement of athletes' performance measuring the impact of coaching intervention. In line with the literature that supports that effective coaches are considered those who through their behaviours produce positive athlete outcomes, the items of this factor reflect the administrators' assessment of the impact of coaching practice on athletes (Boardley, Kavussanu, & Ring, 2008; Horn, 2008; Vella & Gilbert, 2014). The second factor "*personal achievements of the coach*" incorporates five items related to the recognition of the coaching work of the individual coach and his/her dedication and orientation to the development and evolution of coaching. Such accomplishments reflect the assessment of the coach's expertise and performance by sports community agents and they are taken into consideration by administrators when evaluating a coach (MacLean & Chelladurai, 1995). The "*design and implementation of coaching*" factor relates to the primary task of the coach to design, organize and deliver the practice sessions and assesses behaviours that reflect his/her expertise and effectiveness in coaching (Lara-Bercial et al., 2017). The technical skills of a coach have been found of primary importance in the selection criteria of Iranian national coaches (Hamidi & Memari, 2014). Such criteria that reflect the ability of the coach to organize and implement effectively the coaching practice are considered important in every evaluation of the coaching performance model (Antunes, Soares, Rodrigues & Velosa, 2020). In consistency with the literature that supports that a coach's main responsibility is the appropriate management of sports competition related aspects and his/her performance in this specific field is receiving attention and value, the "*competition management*" factor's items refer to the abilities of the coach to make appropriate decisions, to highlight and correct mistakes during competition, as well as to implement tactics and strategies during the competition (Lara-Bercial et al., 2017). The fifth factor "*psychological support of the athletes*" captures supportive coaching behaviours such as providing positive feedback, offering a pleasant training environment, promoting fair play, motivating, and preparing athletes or teams for competition. These behaviours relate to leadership and communication abilities which are considered required for a successful coaching performance (West, 2016). Lastly, the "*commitment to the club*" factor refers to the contribution of the coach to the viability of the organization by adhering to clubs' rules and regulations and developing and maintaining effective relations with club members and parents (MacLean & Chelladurai, 1995).

The ESC scale incorporates many key elements of the evaluation and selection of coaches from amateur sports clubs. The examination of the psychometric properties of the scale provided preliminary evidence for the validity and reliability scores of the measure. Psychometric properties supported that the overall 29-item tool had a Cronbach's alpha coefficient of .90 indicating that the measure is reliable. The six factors "*Results of coaching on athletes*", "*Personal achievements of the coach*", "*Design and implementation of coaching*", "*Competition management*", "*Psychological support of the athletes*" and "*Commitment to the club*" received Cronbach's alpha coefficients of .90, .88, .90, .93, .93 and .87 respectively indicating an acceptable degree of internal consistency.

This study highlights the importance of addressing the appropriate selection criteria for coaches to work in an amateur sports club in the domain of youth sports. However, this work serves to alert sports managers, administrators, and executives of a sports club to the need to develop a selection criteria model for every coaching position in their organization to help sports clubs set up their own systems of selecting coaches.

The present study offers a comprehensive set of evaluation and selection criteria for coaches and explains their development process. The findings of the study indicate that the 29-item scale is an adequate measure in terms of psychometric characteristics to investigate the evaluation and selection criteria of coaches in a given context. However, the participants in this study were coaches selected from amateur sports clubs in Attica, Greece. Thus, it is not known if the psychometric properties of this scale would be similar for coaches working in other regions of the country or around the world.

The primary goal of this research was to develop a reliable and valid evaluation and selection criteria scale for coaches. This new scale constitutes a measure with adequate reliability and construct validity to examine the criteria that play the most important role in the selection of a specific coach in a specific context. However, future research could possibly expand this scale by incorporating criteria that relate to another population or context.

CONCLUSIONS

The study aimed to develop and validate an instrument for measuring the impact of each selection criterion on administrators' decision to select a coach to work in a specific coaching position in order to identify the selection criteria of coaches working in amateur sports clubs. The application of factor analysis revealed a six-factor structure model for the Evaluation and Selection Criteria scale and provided evidence for the scale to be a reliable and valid tool to be used when selection criteria for coaches are investigated. Six thematic units regarding coaching competence and outcomes of coaching work were covered following the analysis of the coaching job in a specific position. This work provides literature with a comprehensive, reliable, and valid set of criteria for selection of coaches in the amateur sports context. The results of the study demonstrated strong psychometric properties of the ESC scale for coaches in terms of validity and reliability.

In addition, the results of this study can be useful for coaches as well as for the administrators of an amateur sports club providing insights on how coaching competencies and achievements are evaluated upon selection and how related criteria are developed. With appropriate modification, the ESC scale for coaches constitutes a valid, reliable, and easy-to-use tool for sports club administrators to evaluate and select their coaches.

AUTHOR CONTRIBUTIONS

This manuscript is a collaborative work of six authors who reviewed and approved its final version. The contribution of each author includes: Christina Anthi: study conception and design, review of the literature, data collection and analysis, draft manuscript. George Kipreos, study supervision and approval of final manuscript. Panagiota Antonopoulou: reviewed and approved theory and measure. Krinanthi Gdonteli: review of discussions and conclusions. Vasilios Kakkos: conceptualization and design of the study. Nektarios Stavrou: data analysis and interpretation of results.

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No potential conflict of interest was reported by the authors.

REFERENCES

Abraham, A. & Collins, D. (2011). Taking the Next Step. Ways Forward for Coaching Science. Quest, 63, 366-384. https://doi.org/10.1080/00336297.2011.10483687

Amorose, A. J., & Horn, T. S. (2001). Pre- to post-season changes in the intrinsic motivation of first year college athletes: Relationships with coaching behavior and scholarship status. J Appl Sport Psychol, 13(4), 355-373. https://doi.org/10.1080/104132001753226247

Antunes, J. Soares, J. Rodrigues, and Velosa (2020). "Performance appraisal criteria of coaches according to the age group of the athletes and the level of sports competition," Advances in Physical Education, vol. 10, no. 04, pp. 391-409. https://doi.org/10.4236/ape.2020.104032

Armstrong, M., & Taylor, S. (2023). Armstrong's handbook of human resource management practice: A guide to the theory and practice of people management. Kogan Page Publishers.

Behrendt, P., & Greif, S. (2022). Success Factors in the Coaching Process. In International Handbook of Evidence-Based Coaching: Theory, Research and Practice (pp. 877-888). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-81938-5_72

Bentler, P. M. (1990). Comparative Fit Indexes in Structural Models. Psychological Bulletin, 107, 238-246. https://doi.org/10.1037/0033-2909.107.2.238

Bentler, P. M. (1995). EQS Structural Equations Program Manual. Los Angeles, CA: BMDP Statistical Software.

Bentler, P. M., & Bonett, D. G. (1980). Significance tests and goodness of fit in the analysis of covariance structures. Psychological Bulletin, 88(3), 588-606. https://doi.org/10.1037/0033-2909.88.3.588

Bentler, P. M., & Chou, C. (1987). Practical issues in structural modeling.Sociological Methods & Research, 16(1), 78-117. https://doi.org/10.1177/0049124187016001004

Boardley, I. D., Kavussanu, M., & Ring, C. (2008). Athletes' perceptions of coaching effectiveness and athlete-related outcomes in rugby union: An investigation based on the coaching efficacy model. The Sport Psychologist, 22(3), 269-287. https://doi.org/10.1123/tsp.22.3.269

Bollen, K.A. (1989). Structural Equations with Latent Variables. John Wiley and Sons, Inc., New York. https://doi.org/10.1002/9781118619179

Browne, M.W., & Cudeck, R. (1993). Alternative ways of assessing model fit. In K.A. Bollen & J.S. Long (Eds.), Testing structural equation models (pp. 136-162). Newbury Park, CA: Sage Publications, Inc.

Byrne, B. M. (1994). Structural equation modeling with EQS and EQS/Windows: Basic concepts, applications, and programming. Thousand Oaks, CA: Sage.

Byrne, R. M. J. (1989). Suppressing valid inferences with conditionals. Cognition, 31, 61-83. https://doi.org/10.1016/0010-0277(89)90018-8

Cassidy, T., Potrac, P., & Rynne, S. (2023). Understanding sports coaching: The pedagogical, social and cultural foundations of coaching practice. Routledge. https://doi.org/10.4324/9781003184348

Chan, J. T. & Mallet, C. J. (2011). The Value of Emotional Intelligence for High Performance Coaching. International Journal of Sports Science & Coaching, 6(3), pp. 315-328. https://doi.org/10.1260/1747-9541.6.3.315

Cooper, D., & Allen, J. B. (2018). "The Coaching Process of the Expert Coach: A Coach Led Approach." Sports Coaching Review 7, no. 2: 142-70. https://doi.org/10.1080/21640629.2017.1361168

Corsby, C. L. T. (2024). Coaching practice as discovering performance: the wild contingencies of coaching. Sports Coaching Review, 13(1), 37-59. https://doi.org/10.1080/21640629.2023.2275394

Côté, J. Salmela, J., Trudel, P., Baria, A. and Russell, S., (1995). The Coaching Model: A Grounded Assessment of Expert Gymnastic Coaches Knowledge, Journal of Sport and Exercise Psychology, 17(1), 1-17. https://doi.org/10.1123/jsep.17.1.1

Côté, J., & Gilbert, W. (2009). An integrative definition of coaching effectiveness and Development and empirical tests. The Leadership Quarterly, 22(6), 1146-1164. https://doi.org/10.1260/174795409789623892

Cronbach, L. J. (1951). Coefficient alpha and the internal structure of tests. Psychometrika, 16, 297-334. https://doi.org/10.1007/BF02310555

Cushion, C. J., Armour, K. M., & Jones R. L., 2003. Coach Education and Continuing Professional Development: Experience and Learning to Coach. Quest, 55 (3): 215-30. https://doi.org/10.1080/00336297.2003.10491800

Cushion, C., & Harvey, S., & Muir, B., & Nelson, L. (2012) Developing the Coach Analysis and Intervention System (CAIS): Establishing validity and reliability of a computerised systematic observation instrument, J SPORT SCI, 30:2, 201-216. https://doi.org/10.1080/02640414.2011.635310

Davis, L. (1992). Instrument review: Getting the most from your panel of experts. Applied Nursing Research, 5, 194-197. https://doi.org/10.1016/S0897-1897(05)80008-4

Davis, L., Jowett, S., & Sörman, D. (2022). The importance of positive relationships for coaches' effectiveness and well-being. International Sport Coaching Journal, 10(2), 254-265. https://doi.org/10.1123/iscj.2021-0065

Gershkowitz, B. D., Hillert, C. J., & Crotty, B. H. (2021). Digital coaching strategies to facilitate behavioral change in type 2 diabetes: a systematic review. The Journal of Clinical Endocrinology & Metabolism, 106(4), e1513-e1520. https://doi.org/10.1210/clinem/dgaa850

Gilbert, W. & Côté, J. (2013). Defining Coaching Effectiveness: A Focus on Coaches' Knowledge. In: Potrac, P., Gilbert, W. and Denison, J., Eds., Routledge Handbook of Sports Coaching, Routledge, Abingdon, 147-159. eBook ISBN9780203132623

Hair, J. F., Anderson, R. E., Tatham, R. L., & Black, W. C. (1995). Multivariate data analysis. Englewood Cliffs, NJ: Prentice-Hall.

Hamidi, M., & Memari, Z. (2014). Determining the Explanatory Model of Iranian Elite Sport Coach Selection Criteria. Sport Management Studies, 6(24), 31-58.

Horn, T. S. (2008). Coaching effectiveness in the sport domain. In T. S. Horn (Ed.), Advances in sport psychology (3rd ed.), pp. Human Kinetics.

Horton, P. (2015). The role of the coach. In Nash, C. (Ed.) Practical Sports Coaching. Routledge: Abingdon, UK, pp. 3-15.

Hoyle, R.H., & Panter, A.T. (1995). Writing about structural equation models. In R.H. Hoyle (Eds.), Structural equation modeling: Concepts, issues and applications (pp. 158-176). Thousand Oaks, CA: Sage. https://doi.org/10.52846/jskm/37.2021.1.1

Hu, L., & Bentler, P.M. (1999). Cut off criteria for the fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. Structural Equation Modeling, 6, 1-55. https://doi.org/10.1080/10705519909540118

Jowett, S. (2017). Coaching Effectiveness: The Coach-Athlete Relationship at its Heart. Current Opinion in Psychology. 16. https://doi.org/10.1016/j.copsyc.2017.05.006

Jowett, S., & Arthur, C. (2019). Effective coaching: The links between coach leadership and coach-athlete relationship-From theory to research to practice. In M. H. Anshel, T. A. Petrie, & J. A. Steinfeldt (Eds.), APA handbook of sport and exercise psychology: Sport psychology (pp. 419-449). American Psychological Association. https://doi.org/10.1037/0000123-022

Kelloway, E. K. (1998). Using LISREL for structural equation modeling: A researcher's guide. Sage Publications, Inc.

Kline, P. (1994). An Easy Guide to Factor Analysis. Abingdon-on-Thames: Routledge.

Kline, R.B. (1998). Principles and practice of structural equation modeling. New York: Guilford Press.

Kramers, S., Turgeon, S., Bean, C., Sabourin, C., & Camiré, M. (2020). Examining the roles of coaching experience and coach training on coaches' perceived life skills teaching. International Journal of Sports Science & Coaching, 15(4), 576-583. https://doi.org/10.1177/1747954120922367

Lara-Bercial, S., & Mallett, C. (2016). The practices and developmental pathways of professional and Olympic serial winning coaches. International Sport Coaching Journal, 3(3), 221-239. https://doi.org/10.1123/iscj.2016-0083

Lara-Bercial, S., Duffy, P., and Harrington, M. (2013). International Sport Coaching Framework 1.2. Champaign, IL: Human Kinetics. ISBN: 9781450471275

Lara-Bercial, S., North, J., Hämäläinen, K., Oltmanns, K., Minkhorst, J., & Petrovic, L. (2017). The European Sport Coaching Framework. Human Kinetics: Champaign, IL.

Litwin, M.S. (1995). How to Measure Survey Reliability and Validity. Sage Publications, Inc., Thousand Oaks, CA. https://doi.org/10.4135/9781483348957

Lyle, J. W. B. (2002). Sports coaching concepts: a framework for coaches' behaviour. (London, Routledge).

Lyle, J., & Cushion, C. (2017). Sports coaching concepts: A framework for coaches' practice. London: Routledge. https://doi.org/10.4324/9780203126424

MacLean, J. (2001). Performance appraisal for sport and recreation managers. Champaign, IL: Human Kinetics.

MacLean, J. (2017). Performance management, In Hoye, R., & Parent, M. M. (Eds.), The SAGE Handbook of Sport Management (pp. 160-180), London: SAGE. https://doi.org/10.4135/9781473957961.n10

MacLean, J., & Chelladurai, P. (1995). Dimensions of coaching performance: Development of a scale. Journal of Sport Management, 9, 194-207. https://doi.org/10.1123/jsm.9.2.194

MacLean, J., & Zakrajsek, D. (1996). Factors considered important for evaluating Canadian university athletic coaches. Journal of Sport Management, 10, 446-462. https://doi.org/10.1123/jsm.10.4.446

Mageau, G.A.& Vallerand, R.J. (2003). The coach-athlete relationship: a motivational model. J. Sports Sci., 21, pp. 883-904. https://doi.org/10.1080/0264041031000140374

Mardia, K.V. (1970). Measures of multivariate skewness and kurtosis with applications. Biometrika, 57, 519-530. https://doi.org/10.1093/biomet/57.3.519

Martens, R. (2012). Successful Coaching (4th ed.). Champaign, IL. Human Kinetics.

McAuley, E, Duncan, T., & Tammen, V. V. (1989). Psychometric properties of the intrinsic motivation inventory in a competitive sport setting: A confirmatory factor analysis. Research Quarterly for Exercise and Sport, 60, 48-58. https://doi.org/10.1080/02701367.1989.10607413

Millar, P., Clutterbuck, R., & Doherty, A. (2020). Understanding the adoption of long-term athlete development in one community sport club. Managing Sport and Leisure, 25(4), 259-274. https://doi.org/10.1080/23750472.2020.1713197

Neelis, L., Faucett, A., & Thompson, M. (2020). Quality Sport Coaching: The Role of the National Standards for Sport Coaches. Strategies, 33(6), 7-13. https://doi.org/10.1080/08924562.2020.1812328

Nelson, L. J. (2010). Thesis: Understanding Coach Learning. Loughborough: Loughborough University. Retrieved from [Accessed 2024, July 12]: https://repository.lboro.ac.uk/articles/Understanding_coach_learning/9608861

North, J. (2009). The coaching workforce 2009-2016. Leeds, UK: Sports Coach.

Nunnally, J. C. (1978). Psychometric theory (2nd ed.). New York: McGraw-Hill.

Nunnally, J. C., & Bernstein, I. C. (1994). Psychometric theory (3rd ed.). New York: McGraw-Hill.

Nunnally, J.C. (1978). Psychometric theory. 2nd Edition, McGraw-Hill, New York.

O'Boyle, I. (2014). Determining Best Practice in Performance Monitoring and Evaluation of Sport Coaches: Lessons from the Traditional Business Environment. International Journal of Sports Science & Coaching, 9, 233-246. https://doi.org/10.1260/1747-9541.9.1.233

Papadimitriou, D. (2005). The Management of Sport Organizations, Athens, Kleidarithmos, pages 350.

Perkins, P., & Hahn, A. (2019). Factors Underpinning at Least Three Years of Participant Adherence to a Community-Focused Modified Boxing Program. Open Journal of Social Sciences, 7, 298-331. https://doi.org/10.4236/jss.2019.72023

Perkins, P., Hahn, A., Keegan, R., & Collis, I. (2014). Why Do Community-Based Athletes Choose to Participate in a Modified, Low-Risk form of Boxing? An Interpretative Phenomenological Analysis. Quest Journals of Research in Humanities and Social Science, 2, 60-69. https://doi.org/10.9790/9467-2116069

Polit, D. F., & Beck, C. T. (2006). The content validity index: are you sure you know what's being reported? Critique and recommendations. Research in nursing & health, 29(5), 489-497. https://doi.org/10.1002/nur.20147

Predoiu, R., Predoiu, A., Cosma, G., Bota, A., & Mitrache, G. (2021). Contributions to the shaping of the successful coach personality profile. Journal of Sport & Kinetic Movement, 1(37), 3-13.

Rhind, D. J. A., & Jowett, S. (2010). Relationship maintenance strategies in the coach-athlete relationship: The development of the COMPASS model. J Appl Sport Psychol, 22(1), 106-121. https://doi.org/10.1080/10413200903474472

Rupp, M. T., & Segal, R. (1989). Confirmatory factor analysis of a professionalism scale in pharmacy. Journal of Social and Administrative Pharmacy, 6, 31-38.

Saunders M., Lewis P., Thornhill A. (2012). Research Methods for Business Students (6th edition), Pearson Education Limited.

Schempp, P., McCullick, B., & Mason, I. (2006). The Development of Expert Coaching. In R. L. Jones (Ed.), The Sports Coach as Educator: Reconceptualising Sports Coaching (pp. 145-161). London: Routledge.

Smith, R.E., & Smoll, F.L. (2017). Coaching Behavior and Effectiveness in Sport and Exercise Psychology. https://doi.org/10.1093/acrefore/9780190236557.013.188

Spector, P. E. (1992). Summated Rating Scale Construction: An Introduction. Newbury Park, CA: Sage. https://doi.org/10.4135/9781412986038

Stewart, L. J., Palmer, S., Wilkin, H., & Kerrin, M. (2020). Toward a model of coaching transfer: Operationalizing coaching success and the facilitators and barriers to transfer. Coaching Researched: A Coaching Psychology Reader, 379-407. https://doi.org/10.1002/9781119656913.ch20

Stodter, A., & Cushion, C. J. (2019). Evidencing the impact of coaches' learning: Changes in coaching knowledge and practice over time. J Sport Sci, 37(18), 2086-2093. https://doi.org/10.1080/02640414.2019.1621045

Sullivan, P., Rhind, D., & Jowett, S. (2014). Communication. In A. Papaioannou & D. Hackfort (Eds.), Routledge Companion to Sport and Exercise Psychology: Global Perspectives and Fundamental Concepts (pp. 559-570). Routledge.

Tabachnick, B.G. and Fidell, L.S. (2006). Using multivariate statistics. (5th ed.) Boston: Allyn and Bacon.

Taylor, T., & Doherty, A., & McGraw, P. (2015). Managing people in sport organizations: A strategic human resource management perspective. Second edition. Routledge. https://doi.org/10.4324/9781315881881

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. J Sport Sci, 35(19), 1928-1939. https://doi.org/10.1080/02640414.2016.1241422

Tinsley, H. E. A., & Tinsley, D. J. (1987). Uses of factor analysis in counseling psychology research. Journal of Counseling Psychology, 34(4), 414-424. https://doi.org/10.1037/0022-0167.34.4.414

Tucker, L. R., Koopman, R. F., & Linn, R. L. (1969). Evaluation of factor analytic research procedures by means of simulated correlation matrices. Psychometrika, 34(4, Pt. 1), 421-459. https://doi.org/10.1007/BF02290601

Vella, S., & Gilbert, W. (2014). Coaching young athletes to positive development: Implications for coach training. In A. R. Gomes, R. Resende & A. Albuquerque (Eds.), Positive Human Functioning From a Multidimensional Perspective: Promoting High Performance (Vol. 3, pp. 83-105). New York: Nova Science.

Vella, S., Oades. L. G., & Crowe, T. P. (2010). The application of coach leadership models to coaching practice: Current state and future directions. International Journal of Sports Science and Coaching, 5, 425-434. https://doi.org/10.1260/1747-9541.5.3.425

West, L. (2016). Coach-athlete communication: Coaching style, leadership characteristics, and psychological outcomes. Master of Education in Human Movement, Sport, and Leisure Studies Graduate Projects. 16. Retrieved from [Accessed 2024, July 12]: https://scholarworks.bgsu.edu/hmsls_mastersprojects/16

West, S.G., Finch, J.F., & Curran, P.J. (1995). Structural equation models with nonnormal variables: Problems and remedies. In R.H. Hoyle (Ed.), Structural equation modeling: Concepts, issues, and applications (pp.56-75). Thousand Oaks, CA: Sage.

Zhang, C., Starczewski, A. P., Lakens, D., & IJsselsteijn, W. A. (2018). A decision-making perspective on coaching behavior change: a field experiment on promoting exercise at work. In Persuasive Technology: 13th International Conference, PERSUASIVE 2018, Waterloo, ON, Canada, April 18-19, 2018, Proceedings 13 (pp. 87-98). Springer International Publishing. https://doi.org/10.1007/978-3-319-78978-1_7

Zhang, Q., Hou, B., Wang Y., & Xiao, Y. (2014). A comprehensive model for evaluation of sport coaches' performance. International Journal of Engineering and Innovative Technology, 3(9), 265-271. Retrieved from [Accessed 2024, July 12]: https://www.ijeit.com/Vol%203/Issue%209/IJEIT1412201403_43.pdf

ORIGINAL ARTICLE

Effect of implicit and explicit learning on the dart throwing task in the morningness-eveningness people

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ABSTRACT

The interaction of constraints causes learning. It was examined how explicit and implicit learning affected the dart-throwing task in morningness-eveningness people to test this claim. 120 morning-type individuals (AgeM ± SD = 23.38 ± 2.58) were chosen using the MESSi questionnaire. Then, randomly divided into four 30-person groups: explicit morning practice, implicit morning practice, explicit evening practice, and implicit evening practice. Each group received 10 training sessions (3 sets of 10 attempts). Mixed ANOVA (4x4) demonstrated significant main effects of different tests, group, and group test interaction. Additionally, Tukey's test demonstrated that explicit training groups outperformed implicit training groups in both immediate and delayed retention tests. The retention test with a two-week delay and transfer test outperformed explicit training groups. So, it can be said to some extent that implicit practice outperforms explicit. Learning will last longer if this practice is based on individual characteristics like circadian rhythm.

Keywords: Learning, Circadian rhythm, Implicit practice, Explicit practice, Dart throwing.

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INTRODUCTION

Education is critical in all aspects of development, growth, learning, and psychological, cognitive, and physical factors. Training in physical education is done with movement interventions; different training methods are introduced and used in this direction. Among the many types of interventions in motor learning, one of the most widely used ones that has attracted the attention of researchers in recent years is implicit and explicit (traditional) learning (Ellis, 2009). In traditional methods, it is assumed that learning progress occurs due to a verbal-cognitive stage (Kleynen et al., 2014). It is thought that in this comprehensive stage, he/she acquires his/her expressive knowledge about points such as the rules or facts of skill implementation, ultimately leading to mastery of the skill (Ellis, 2009). However, to achieve automaticity, the learner needs an active working memory or is involved in executing the skill because verbal knowledge is related to working memory (Kleynen et al., 2014).

Compared to the traditional teaching method, implicit learning has been proposed as an alternative or effective method in coaching and sports psychology books (Gulbin et al., 2013; Raab et al., 2016). In implicit learning methods, motor skill acquisition is thought to occur as a result of procedural knowledge (not verbal knowledge) (Maxwell et al., 2000). This knowledge is inaccessible to consciousness and does not depend on working memory processing (Savani et al., 2022). In other words, learners in this method cannot verbally describe the technical points of the skill (Leh et al., 2022).

Therefore, implicit learning focuses on the automaticity of the skill or the execution of the skill with little awareness (Maxwell et al., 2000). Although in traditional learning, the attempt is to perform the skill automatically, it is thought that procedural knowledge is more effective in achieving automaticity and probably requires less time (Modchalingam et al., 2023). This issue has also been confirmed in experimental studies. In this regard, Kal, Prosée, Winters, & Van Der Kamp, (2018) by reviewing 39 studies in this field showed that implicit learning is more effective than explicit learning(Kal et al., 2018).

Based on the perspective of ecological dynamics (Davids et al., 2012), working memory, expressive knowledge, procedural knowledge, and even education are not the only factors that determine learning. Instead, learning, acquiring, and performing skills as a result of the interaction between organismic constraints (such as working memory, procedural knowledge, verbal knowledge, physical strength, psychological factors, etc.), environment (such as light, night, or day, morning or afternoon, presence or absence of spectators, environmental changes of specific sports, and the task (such as the rules of any sport or exercise manipulation) occurs (Newell, 1986). This shows that working memory (procedural and verbal knowledge) in explicit and implicit learning is only one constraint of organismic constraints that can affect learning, and this effect is related to other limitations, such as environmental and task constraints. One of the environmental constraints that can affect a person's learning is the changes in the circadian rhythm, which also affects the active memory (procedural or expressive knowledge) and the cognitive factors of people (organismic constraint) (Garren et al., 2013). In this regard, some people are morning- types (their memory is more active in the morning), and others are evening types (Garren et al., 2013).

Circadian rhythm is introduced and recognized as an effective factor in alertness and memory retention (Souza et al., 2022). In this regard, Natale & Cicogna, (2002) have shown in their study that the circadian rhythm affects working memory performance(Natale & Cicogna, 2002). In another study, Lyons & and Roman (2009) investigated the effect of circadian rhythm on the structure of working memory in 15 male participants and found that the structure of memory is set based on a circadian pattern(Lyons & Roman, 2009). In this study, it was shown that the peak performance in working memory occurs in morning- types people in the early hours of the morning and evening-types people in the early hours of the night, more recent research (Curran et al., 2019; Fernandez et al., 2020; Price & Obrietan, 2018) also confirmed this issue. It seems that the environmental constraint (circadian rhythm) affects the organismic constraints of people (working memory) in the decision-making factor. Leone, Slezak, Golombek, & Sigman, (2017) in their study in this field asked morning- types participants to make about 40 decisions in a computer game that was tested in two sessions, morning and afternoon, and as a result, stated that the people who took the test in the morning worked slower but made more correct decisions(Leone et al., 2017). The people who took the test in the evening acted faster but made fewer correct decisions. However, the study in motor learning is limited in this direction, and by conducting a study in this field, it is possible to improve the performance and learning of sports skills in athletes/non-athletes and help them learn faster and better.

Reviewing the above contents shows three important issues:

1. Training methods by affect working memory (procedural or verbal knowledge) affect the learning and performing of motor skills.
2. Training is not the only factor affecting working memory, and working memory is only one of the constraints affecting motor learning.
3. Learning is the result of the interaction of environmental constraints, tasks, and individuals.

Although these issues are accepted from the perspective of ecological dynamics, their empirical investigation based on the authors' information in the background review is limited. Therefore, to reach a specific result and to confirm the point of view of ecological dynamics, we investigated the effect of the environmental condition (circadian rhythm) on the organismic constraints (morning- types and evening types) through the amount of learning to throw darts in implicit and explicit practices. Therefore, the aim of this study was to the effect of implicit and explicit learning on learning to throw darts, considering the circadian rhythm of morning-types and evening types.

MATERIALS AND METHODS

This was a semi-experimental study with a control group. At first, for the test MANCOVA: Repeated measure within interaction; f = 0.25, a = 0.05, and 1-B = 0.80 (Brocken, van der Kamp, Lenoir, & Savelsbergh, n.d.; Motoki, Saito, Nouchi, Kawashima, & Sugiura, 2019) G*Power software showed that at least 87 subjects are needed. Therefore, in this study, 120 men over the age of 18 were purposefully selected based on the MESSI (active morning) questionnaire from (Blinded for Reviewer). The demographic information of the subjects is shown in Table 1. There was no significant difference between the groups. Inclusion criteria included: 1) being over 18 years old, 2) all participants being morning-types according to the MESSI questionnaire, and 3) commitment to cooperation throughout the test. This study was approved and conducted in 2021 by the Ethics Committee of the Movement Behaviour Department, Faculty of Physical Education, (Blinded for Reviewer), and all participants signed a written consent form before entering the study.

Table 1 Demographic characteristics (Mean ± SD).

Variable	All N = 120	G1* N = 30	G2* N = 30	G3* N = 30	G4 N = 30	F	*p*
Age (years)	23.38 ± 2.58	23.07 ± 1.99	23.12 ± 2.54	25.16 ± 2.82	22.19 ± 2.99	2.11	.21
Weight (kg)	80.04 ± 5.73	78.44 ± 7.3	80.01 ± 6.4	81.11 ± 4.1	80.6 ± 5.14	1.88	.33
Height (cm)	178.99 ± 5.9	177.57 ± 5.4	179.46 ± 7.83	180.33 ± 6.69	178.33 ± 3.69	2.52	.12

Measuring instruments

MESSI questionnaire

MESSi is a self-report instrument consisting of 15 items. The total items are divided into three subscales, each consisting of five items: morning affect, evening affect, and distinctiveness. The items on the morning affect subscale measure morning preferences (early schedules). while the eveningness subscale items assess evening preferences (late schedules). The remaining five items form the differentiation subscale, i.e. the domain dimension of this instrument. Each item is answered using a 5-point Likert scale and scored from 1 to 5. The validity and questionnaire of this questionnaire have been reported by Morales et al. (2017) for the age group of 18-30 years old (Díaz-Morales et al., 2017). This has been confirmed in other studies (Rahafar et al., 2017).

Procedure

To conduct this study, a MESSI questionnaire was distributed among students (masked for reviewer). Then, according to the purpose of the study, 120 morning-type people were selected. In the next step, these people were randomly divided into four groups of 30 people. The classifications were done by someone who did not know the participants. Group One at 9-11 on Mondays and explicitly, Group Two practiced darts at 9-11 on Tuesdays implicitly, Group Three explicitly practiced darts at 17-19 on Mondays, and Group 4 implicitly practiced darts on Tuesdays at 17-19. At the beginning of each session, the subjects of two groups were given three types of training for correct throwing and how to perform dart throwing. This training was conducted by an expert trainer with 10 years of experience in dart training (37 years). The coach had no information about the division of groups. In the first training, the proper way of taking was presented. The subject was told to use his thumb to find the centre of gravity of the dart. Then, keep the dart in the width of the finger, turn its tip out, keep your wrist up, and note that the dart is in line with the target. In the second training, the subjects were told how to stand, and they were reminded that their weight should be more on the front leg and the distance between the legs should be shoulder-width apart. In the third type of throwing feedback, the subject was told to have a soft, coordinated throw and continue the movement. In this step, the trainer showed the movement pattern in each step (Cline et al., 2009; Schmidt et al., 2018). In addition to receiving no instructional instructions, the implicit groups were also engaged in a secondary task of counting down numbers (Masters, 1992). This test is a useful tool for presenting a dual task that has been used many times in previous studies (Geroin et al., 2018). In this task, the subjects had to say numbers from 3726 to zero with the condition that they had to subtract four digits from the numbers each time, and the second number was the first number minus 4 (Geroin et al., 2018).

Ten training sessions were provided for each group. In each session, each person did three sets of 10 attempts. For throws, at the beginning, it was reminded to throw with the handedness hand. The way of scoring and the distances (173cm distance between the board and the ground, 293cm distance between the player and the board) were by the scoring of international darts competitions, which is shown in Figure one. In this section, the outer thin lines were awarded twice each grade. If the dart hits the wide parts, it gets its score; the inner thin line gets three times the score; if the dart hits the middle (inner bull), it gets 50 points; and if it hits the (outer bull), it gets 25 points. All training and testing stages were done in the gymnasium of (masked for reviewer).

After the practice sessions, four types of tests were taken from the subjects. The tests were performed by a third person who did not know about the initial classification and practice. 1- Instant retention test immediately after finishing the last training attempt. 2- A delayed retention test was one day after the last training session. 3- a delayed retention test two weeks after the last training session. 4-Transfer test two weeks after the last training session in such a way that we increased the throwing distance by half a meter (Simpson et al., 2022).

The number of test attempts was 10 attempts and the time of all tests was around 2 pm. Before the test, a warm-up was done, which included slow running, muscle stretching, and relaxation.

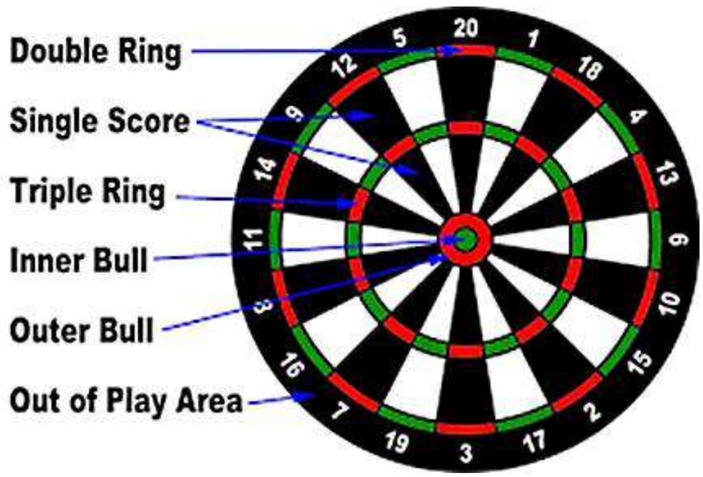

Figure 1. How to score darts.

To make sure that the implicit training was done correctly, we asked the subjects to participate in an oral declarative knowledge test after the transfer test, and everyone was asked if they could describe the correct throwing method in full detail. (Masters, 1992). The results showed that the explicit training groups mentioned more details about how to execute the dart-throwing skill. The one-way analysis of variance statistical test showed a significant difference between the groups ($p < .001$).

Statistical analysis

The normality of data distribution was checked using the Shapiro-Wilk test, and the homogeneity of variances was also confirmed with the Levene test ($p > .05$). Differences between groups and measurements were analysed using the composite analysis of variance test (4x4). ANOVA's Post Hoc test with Tukey's correction was used to examine differences between groups and measurements.

RESULTS

The results of the composite ANOVA test about groups and measurements showed that the main effect of different tests is significant ($f(3,348) = 9.362$, $p < .001$, $\eta^2p = 0.075$). Also, the main effect of the group was statistically significant ($f(3,116) = 15.577$, $p < .001$, $\eta^2p = 0.287$). A significant statistical interaction was also observed between the test and the group ($f(9,348) = 32.004$, $p < .001$, $\eta^2p = 0.453$) (Table 2).

As can be seen in the graph (Figure 2), both explicit training groups performed better than the implicit training groups in the instant retention test and the one-day delayed retention test. But with time, their performance decreased so that in the retention test with a delay of two weeks and the transfer test, both of them were ranked lower than the implicit learning groups.

Table 2. Intra-group and inter-group comparisons.

	Explicit exercise in the morning (1)		**Implicit exercise in the morning (2)**		**Afternoon explicit practice (3)**		**Afternoon implicit practice (4)**		**Intergroup Post-hoc test**
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Instant retention (a)	16.97	6.27	10.67	1.99	16.40	3.22	8.01	2.21	F(3,116)=39.25 *p*<.001,η²p=0.504 1>2 & 1>4 & 1=3 3>2 & 3>4 & 2>4
Retention one day later (b)	13.72	3.66	11.36	3.08	13.12	2.77	8.96	1.45	F(3,116)=16.68 *p*<.001,η²p=0.301 1>4 & 1>2 & 1=3 2=3 & 3>4 & 2>4
Retention after two weeks (c)	11.96	3.93	15.37	4.64	48199.64	2.23	12.91	2.13	F(3,116)=14.49 *p*<.001,η²p=0.273 2>1 & 1=3 & 1=4 2>3 & 2>4 & 4>3
Transfer (d)	9.56	2.73	14.75	2.78	7.24	2.45	12.10	3.78	F(3,116)=35.30 *p*<.001,η²p=0.477 2>1 & 1>3 & 4>1 2>3 & 2>4 & 4>3
Intragroup Post-hoc test	F(3,87)=15.80 *p* < .001 η²p=0.353 a>b – a>c a>d – b=c b>d – c>d		F(3,87)=16.06 *p* < .001 η²p=0.356 a=b – c>a d>a – c>b d>b – c=d		F(3,87)=72.21 *p* < .001 η²p=0.713 a>b – a>c a>d – b>c b>d – c>d		F(3,87)=25.71 *p* < .001 η²p=0.470 a=b – c>a d>a – c>b d>b – c=d		

Note. Sign (=) means no significant difference and sign (<) means a significant difference.

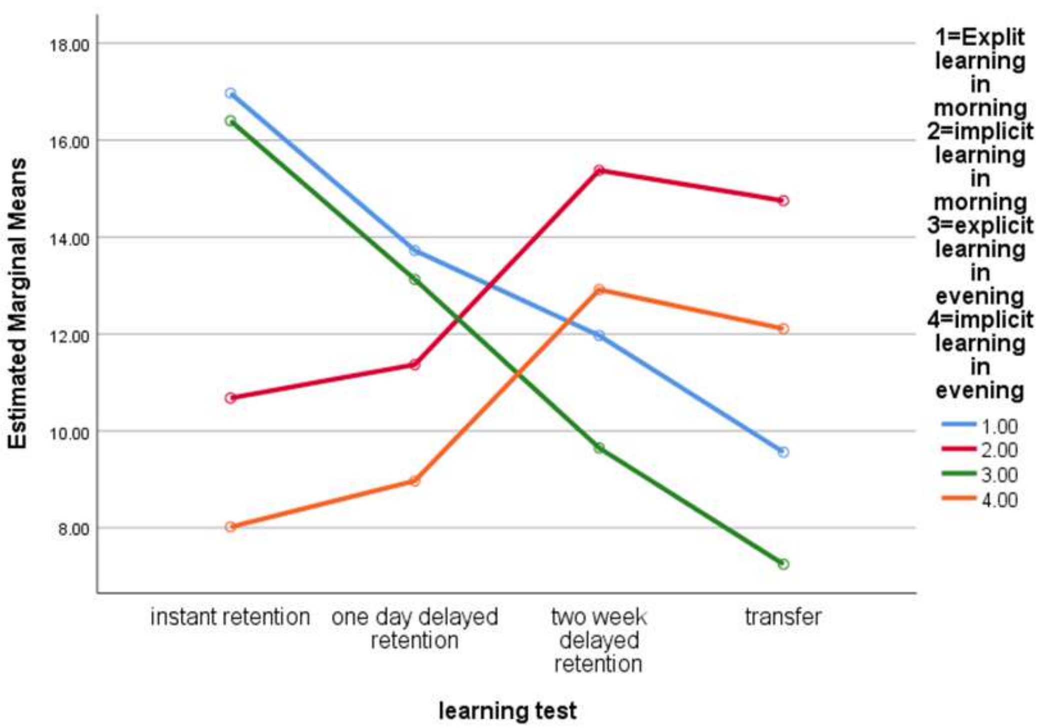

Figure 2. The process of changes in scores of groups during different stages of measurement.

DISCUSSION

This study investigated the effect of implicit and explicit learning on the dart-throwing task, taking into account the circadian rhythm in morning- types and evening types. The results showed that explicit training in the phase of instant retention and one-day delayed retention compared to implicit training helps to perform dart throwing more. However, in the two-week delayed retention and the transfer test, the group that was trained implicitly performed better. In this regard, the interesting results are that the evening-types group with implicit training performed better than the morning-types group with explicit training. These results emphasize the importance of the type of training in the first place; however, aligning the type of training with individual and environmental constraints can help in movement performance. Although no study has been done in sports science in line with the present study, our results agree with the results of Leone et al., (2017) in that They also emphasized that the circadian rhythm (being evening-types / morning- types is aligned with decision accuracy) can be effective in making the right decisions, and people who are morning- types make more accurate decisions in playing computer games in the morning(Leone et al., 2017).

In explaining the results of this study, the role of implicit practice compared to explicit practice in learning and performance should be highlighted. According to the results of this study and previous studies (Kal et al., 2018), the intervention with the implicit training method has a greater effect on learning and sports performance. In this regard, it can be said that those who practice in an obvious way do not need to think about the execution of skills at every stage of performance, and this issue is more important in single skills such as throwing darts. In other words, by performing the first throw or the first few throws, he reaches relative automaticity, and his mind is almost not involved in performing the skill (Kal et al., 2021; Schmidt et al., 2018). But in implicit practice, given that the learner is engaged in another activity, they need to recover their mind in each performance to perform the skill correctly. This issue may hinder one's performance in the early stages of learning, but in the long term, it helps in one's learning (Kal et al., 2021; Leh et al., 2022). This was confirmed in our results. It can also be said that in implicit practice, one's procedural knowledge is considered, which is more effective for learning than expressive knowledge (Leh et al., 2022). This is important because in general, expressive knowledge requires knowledge of verbal cues about the skill, and since in the implicit practice in each step, the learner must restore the performance of the skill, therefore, the implicit practice has an effect on the procedural knowledge (effective in learning) (Ellis, 2009). The interesting discussion in the context of the results of this study is that individual characteristics such as evening types and morning- types affect people's learning and performance. Although this topic has been discussed in the literature related to ecological dynamics (Wood et al., 2023) and the Newell & Simon model (1972) for decades(Newell & Simon, 1972), in this study, this issue has been confirmed experimentally. In this regard, our results show that people who are morning- types when they practice in the morning are better at learning than people who are evening types. This issue shows the interaction between the environment and the person, which is in the model of Newell & Simon, (1972) (Newell & Simon, 1972).

The model of Newell & Simon, (1972) (Newell & Simon, 1972) specifically states that a person's performance is the result of the interaction between individual characteristics such as psychological factors, environmental factors such as whether it is night or day, and tasks such as the rules of any sport. Undoubtedly, being day or night affects humans and based on light changes and even climate changes, humans are different from each other (Curran et al., 2019; Fernandez et al., 2020; Price & Obrietan, 2018). In this regard, it can be said that one of the reasons for individual differences or individual characteristics is the impact of the environment on humans (Price & Obrietan, 2018). Therefore, the alignment of training to learn more with changes in the circadian rhythm makes each person learn according to their characteristics, which this issue showed in our study leads to learning and performing more sports performance. However, this discussion is not limited here;

our results show that practice can even overcome personal preferences. Because evening-types people who trained implicitly performed better than morning-types people who trained explicitly. This topic again points to the complexity of the sciences related to learning and sports training and emphasizes that learning results from complex interactions of many factors.

The strength of this study is that, for the first time in motor learning, we tried to put environmental factors alongside individual factors and emphasized the effectiveness of the type of exercise, taking into account the individual's and the environment's limitations. However, one of the limitations of this study was that we only selected morning- types, and we do not know what the results would be for evening types. Because people of the evening types may have different training abilities, the research results can be expanded in future studies considering this issue. Finally, it is better to consider other characteristics, such as gender, in future research because research has shown that women and men have different training abilities.

In general, the results of the present study showed that implicit training is better than explicit training. Nevertheless, if this exercise is based on individual characteristics such as circadian rhythm, it will have a more lasting and better effect on performance and learning. In this regard, to learn to throw darts, choosing the proper training method is very helpful and is, first and foremost, important. However, learning sports skills is very complex and results from the interaction of many factors. Therefore, training should be designed based on environmental and individual characteristics.

AUTHOR CONTRIBUTIONS

Behrouz Ghorbanzadeh: review and editing, formal analysis and funding. Rasoul Yaali: writing – review and editing, supervision, project administration, investigation, conceptualization. Behzad Mohammadi Orangi: writing original draft, investigation, data curation. Zahra Miri: writing original draft, methodology, investigation.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

DATA AVAILABILITY STATEMENT

The data of this research is available based on request from corresponding author.

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REFERENCES

Cline, D., Jeschke, S., White, K., Razdan, A., & Wonka, P. (2009). Dart throwing on surfaces. Computer Graphics Forum. https://doi.org/10.1111/j.1467-8659.2009.01499.x

Curran, J. A., Buhl, E., Tsaneva-Atanasova, K., & Hodge, J. J. (2019). Age-dependent changes in clock neuron structural plasticity and excitability are associated with a decrease in circadian output behavior and sleep. Neurobiology of aging, 77, 158-168. https://doi.org/10.1016/j.neurobiolaging.2019.01.025

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, 2, 112-130.

Díaz-Morales, J. F., Randler, C., Arrona-Palacios, A., & Adan, A. (2017). Validation of the MESSi among adult workers and young students: General health and personality correlates. Chronobiology international, 34(9), 1288-1299. https://doi.org/10.1080/07420528.2017.1361437

Ellis, R. (2009). Implicit and explicit learning, knowledge and instruction. Implicit and explicit knowledge in second language learning, testing and teaching, 42, 3-25. https://doi.org/10.21832/9781847691767-003

Fernandez, M. P., Pettibone, H. L., Bogart, J. T., Roell, C. J., Davey, C. E., Pranevicius, A., Huynh, K. V., Lennox, S. M., Kostadinov, B. S., & Shafer, O. T. (2020). Sites of circadian clock neuron plasticity mediate sensory integration and entrainment. Current Biology, 30(12), 2225-2237. e2225. https://doi.org/10.1016/j.cub.2020.04.025

Garren, M. V., Sexauer, S. B., & Page, T. L. (2013). Effect of circadian phase on memory acquisition and recall: operant conditioning vs. classical conditioning. PloS one, 8(3), e58693. https://doi.org/10.1371/journal.pone.0058693

Geroin, C., Nonnekes, J., de Vries, N. M., Strouwen, C., Smania, N., Tinazzi, M., Nieuwboer, A., & Bloem, B. R. (2018). Does dual-task training improve spatiotemporal gait parameters in Parkinson's disease? Parkinsonism & Related Disorders, 55, 86-91. https://doi.org/10.1016/j.parkreldis.2018.05.018

Gulbin, J., Weissensteiner, J., Oldenziel, K., & Gagné, F. (2013). Patterns of performance development in elite athletes. European journal of sport science, 13(6), 605-614. https://doi.org/10.1080/17461391.2012.756542

Kal, E., Prosée, R., Winters, M., & Van Der Kamp, J. (2018). Does implicit motor learning lead to greater automatization of motor skills compared to explicit motor learning? A systematic review. PloS one, 13(9), e0203591. https://doi.org/10.1371/journal.pone.0203591

Kleynen, M., Braun, S. M., Bleijlevens, M. H., Lexis, M. A., Rasquin, S. M., Halfens, J., Wilson, M. R., Beurskens, A. J., & Masters, R. S. (2014). Using a Delphi technique to seek consensus regarding definitions, descriptions and classification of terms related to implicit and explicit forms of motor learning. PloS one, 9(6), e100227. https://doi.org/10.1371/journal.pone.0100227

Leh, A., Langhanns, C., Zhao, F., Gaschler, R., & Müller, H. (2022). Muscle activity in explicit and implicit sequence learning: Exploring additional measures of learning and certainty via tensor decomposition. Acta Psychologica, 226, 103587. https://doi.org/10.1016/j.actpsy.2022.103587

Leone, M. J., Slezak, D. F., Golombek, D., & Sigman, M. (2017). Time to decide: Diurnal variations on the speed and quality of human decisions. Cognition, 158, 44-55. https://doi.org/10.1016/j.cognition.2016.10.007

Lyons, L. C., & Roman, G. (2009). Circadian modulation of short-term memory in Drosophila. Learning & memory, 16(1), 19-27. https://doi.org/10.1101/lm.1146009

Masters, R. S. (1992). Knowledge, knerves and know-how: The role of explicit versus implicit knowledge in the breakdown of a complex motor skill under pressure. British journal of psychology, 83(3), 343-358. https://doi.org/10.1111/j.2044-8295.1992.tb02446.x

Maxwell, J. P., Masters, R. S., & Eves, F. F. (2000). From novice to no know-how: A longitudinal study of implicit motor learning. Journal of sports sciences, 18(2), 111-120. https://doi.org/10.1080/026404100365180

Modchalingam, S., Ciccone, M., D'Amario, S., 't Hart, B. M., & Henriques, D. Y. (2023). Adapting to visuomotor rotations in stepped increments increases implicit motor learning. Scientific Reports, 13(1), 5022. https://doi.org/10.1038/s41598-023-32068-8

Natale, V., & Cicogna, P. (2002). Morningness-eveningness dimension: is it really a continuum? Personality and individual differences, 32(5), 809-816. https://doi.org/10.1016/S0191-8869(01)00085-X

Newell, A., & Simon, H. A. (1972). Human problem solving (Vol. 104). Prentice-hall Englewood Cliffs, NJ.

Newell, K. M. (1986). Constraints on the development of coordination. Motor development on children: Aspects of coordination and control. https://doi.org/10.1007/978-94-009-4460-2_19

Price, K. H., & Obrietan, K. (2018). Modulation of learning and memory by the genetic disruption of circadian oscillator populations. Physiology & behavior, 194, 387-393. https://doi.org/10.1016/j.physbeh.2018.06.035

Raab, M., Wylleman, P., Seiler, R., Elbe, A.-M., & Hatzigeorgiadis, A. (2016). Sport and exercise psychology research: from theory to practice. Academic Press.

Rahafar, A., Randler, C., Díaz-Morales, J. F., Kasaeian, A., & Heidari, Z. (2017). Cross-cultural validity of morningness-eveningness stability scale improved (MESSi) in Iran, Spain and Germany. Chronobiology international, 34(2), 273-279. https://doi.org/10.1080/07420528.2016.1267187

Savani, K., Morris, M. W., Fincher, K., Lu, J. G., & Kaufman, S. B. (2022). Experiential learning of cultural norms: The role of implicit and explicit aptitudes. Journal of Personality and Social Psychology, 123(2), 272. https://doi.org/10.1037/pspa0000290

Schmidt, R. A., Lee, T. D., Winstein, C., Wulf, G., & Zelaznik, H. N. (2018). Motor control and learning: A behavioral emphasis. Human kinetics.

Simpson, T., Ellison, P., Marchant, D., & Carnegie, E. (2022). Effects of attentional strategies on novice dart throwing, quiet eye duration and pupillary responses. Journal of Motor Behavior, 54(1), 1-13. https://doi.org/10.1080/00222895.2020.1869681

Souza, K. A., Powell, A., Allen, G. C., & Earnest, D. J. (2022). Development of an age-dependent cognitive index: relationship between impaired learning and disturbances in circadian timekeeping. Frontiers in Aging Neuroscience, 14, 991833. https://doi.org/10.3389/fnagi.2022.991833

Wood, M. A., Mellalieu, S. D., Araújo, D., Woods, C. T., & Davids, K. (2023). Learning to coach: An ecological dynamics perspective. International Journal of Sports Science & Coaching, 18(2), 609-620. https://doi.org/10.1177/17479541221138680

ORIGINAL ARTICLE

Effects of plyometric warm-up performed with different resistances on jumping performance as post-activation potentiation

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ABSTRACT

The purpose of this study was to investigate the effect of plyometric warm-up with different resistances as post activation potentiation stimulus on vertical jump performance. Fifteen athletes from short and middle distance branches of athletics who have been training regularly for at least 5 years and at least 5 days a week attended the study voluntarily. The athletes in this study were warmed up for 5 minutes at a speed of 8 km/h on a treadmill, followed by 5 minutes of passive rest. Completing 5 minutes of passive rest, the athletes were randomly sampled and any of the 50 lb, 60 lb, 70 lb, 80 lb resistance or non-resistance warm-up protocols consisting of 3 sets on the vertimax device were carried out. After warming up, 5 minutes of passive rest was given and then squat jump (SJ) and countermovement jump tests were performed. Repeated measures ANOVA test was conducted in the analyses of the measurements of jump distance and power of the athletes participating in this study both without resistance and after the applied resistances. As a result of the analysis, significant differences were observed in SJ and CMJ values after PAP warm-up without and with resistance ($p < .05$). The height and power values of SJ after PAP warm-up with 70 lb and 80 lb resistance bands were found significantly higher than those without resistance ($p < .05$). Furthermore, the height and power values of CMJ after PAP warm-up with 80 lb resistance bands were found significantly higher than the values of warm-up without resistance ($p < .05$). In conclusion, even though an increase in jump height and power values was observed with each resistance increment, significant increases in power and height values as a PAP response were achieved at 70 and 80 lb resistance for SJ and 80 lb resistance for CMJ.
Keywords: Performance analysis, Post activation potentiation, Jump, Resistance.

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INTRODUCTION

Warm-up is a widely used exercise before nearly all athletic activities (Bishop, 2003). In this regard, warm-up practices, which are deemed as a critical factor, are routinely utilised by athletes to prevent injuries and reach high performance in training and competition (Sotiropoulos, 2014). Additionally, multiple physiological and neural mechanisms have been assessed to determine the contribution of warm-up to performance and responses to different warm-up strategies, which have been reported to include augmented muscle metabolism, high oxygen uptake (VO_2) kinetics and post activation potentiation (PAP) (Mcgowan et al., 2015).

Post activation potentiation is the transient increment in the contractile performance of the muscle following a prior contractile activity (Sale, 2002). PAP, typically resulting from a voluntary contraction performed at or very close to maximal intensity (Tillin and Bishop, 2009), signifies the phenomenon of an acute gain in muscle strength as a result of a history of contraction (Robbins, 2005). It has been claimed that two basic mechanisms are responsible for PAP. One of these is the phosphorylation of myosin regulatory light chains and the second is the increased activation of motor units at a higher rate. Nevertheless, it has been stated that changes in the penetration angle may also contribute to the PAP response (Tillin and Bishop, 2009).

In the literature, resistance training (Chatzopoulos et al., 2007; Chıu et al., 2003; Villalon-Gasch et al, 2020; Mitchell and Sale, 2011; Seitz et al., 2014) and plyometric activities (Ciocca et al., 2021; Turner et al., 2015; Tobin and Delahunt, 2014; Johnson et al., 2019) are frequently chosen as preconditioning stimulus in studies that aim to boost performance with PAP. Despite the fact that intensities of 60% 1 RM and above are sufficiently high for the PAP effect to occur in resistance applications (Kobal et al., 2019; Smilios et al., 2005), it has been indicated that higher effects can be seen at intensities of 85-90% 1 RM (Garbisu-Hualde and Santos-Concejero, 2021). Besides, plyometric activities are a variation of dynamic movements that are integrated into warm-up routines to generate a PAP stimulus and hence strengthen the force building capacity of the muscle (Johnson, 2019). It has been pointed out that a plyometric activity stimulus might have the potentiation to induce a PAP response similar to a weighted resistance stimulus (Tobin and Delahunt, 2014). Thus, plyometric protocols may be preferred as an ideal PAP stimulus since they efficiently strengthen the muscle with less fatigue than traditional weight-based protocols (Johnson et al., 2019).

Furthermore, plyometric activities have been seen to enhance physical performance more than weighted resistance training in terms of PAP response (Sharma et al., 2018). Nonetheless, further studies are needed to support this finding. Although PAP responses following weighted resistance protocols have been broadly studied (Chatzopoulos et al., 2007; Chıu et al., 2003; Villalon-Gasch et al., 2020; Mitchell and Sale, 2011; Seitz et al., 2014; Kobal et al., 2019; Smilios et al, 2005), there are limited number of studies examining the PAP effect following a plyometric stimulus (Ciocca et al., 2021; Turner et al., 2015; Tobin and Delahunt, 2014; Johnson et al., 2019; McBride et al., 2005; Till and Cooke, 2009). Even though there are studies showing an impact on performance during the process using plyometric activities as PAP stimuli (Turner et al., 2015; Tobin and Delahunt, 2014; Ciocca et al., 2021), there are also studies showing no effect (Till and Cooke, 2009; McBride et al., 2005). This inconsistency among studies might be attributed to methodological differences and variability in individual characteristics (training history, gender, muscle fibre type, recovery time after PAP stimulus, etc.). One of the methodological approaches using plyometric activities as PAP stimuli is plyometric activity include resistance. Though the contribution of plyometric activities to performance in terms of PAP response has been noted in some studies (Tobin and Delahunt, 2014; Ciocca et al., 2021), it has been obtained that plyometrics performed with resistance have an extra contribution to athletic performance (Turner, 2015). However, to the best of our knowledge, there is not any study in the literature that examines the effect of PAP stimulus on athletic performance in plyometric activities performed with resistance in terms of the amount of load used. Thus, the purpose of this study was to investigate the effects of plyometric warm-up with different resistances as PAP stimulus on vertical jump performance.

METHODS

Participants

Fifteen athletes (age: 20.13 ± 3.20 years; height: 175.60 ± 8.75 cm; body weight: 70.69 ± 15.94 kg) from the short and middle distances of athletics, who have been training regularly for at least 5 years and at least 5 days per week, voluntarily participated in this study. Prior to the start of the study, the athletes were instructed about both the study and progress and signed an informed consent form. Participants were asked to refrain from intense physical activity, to adjust their sleep patterns, and to refrain from using stimulants or alcohol for 24 hours prior to the start of the tests. Previously, before the beginning of the tests, the height and body weight of the athletes were measured. Measurements were carried out between 15:00 and 18:00. The study was approved by the Social and Human Sciences Ethics Committee of Kütahya Dumlupınar University (dated 04.09.2023 and number 334).

Body weight and height measurements

Body weights of the athletes were measured at least 2 hours after the meal in shorts, T-shirt and bare feet using a scale (Tanita HD 358, Tokyo, Japan) with a sensitivity of 0.1 kg. Height was determined with a wall mounted stadiometer (Holtain Ltd. U.K.) with an accuracy of 1 mm in the anatomical posture and with the head in the Frankfort plane, barefoot.

Jump measurements

The measurements of SJ and CMJ of the athletes in the study were detected with a device (FitJump, Türkiye) that monitors the jump height depending on the duration of stay in the air (with a sampling frequency of 1000 Hz) through a photoelectric sensor located on the ground. The data which were obtained from the device were transferred to the computer software programme (fitjump-v1.0) via Bluetooth.

Test procedure

Within the content of the study, body weight and height measurements were performed before PAP warm-up protocols and test administrations at the first arrival of the athletes to the laboratories. Additionally, they were briefed about the study and allowed to make a trial to get used to the warm-up protocols. The following day after the trial phase, all athletes were invited to the laboratory again. Prior to each PAP warm-up protocol, the athletes performed a 5-min warm-up on a treadmill (Proforce Q3, China) at a speed of 8 km/h, immediately preceded by a 5-min passive rest. Subsequently, a warm-up protocol consisting of 3x10 repetitions (1 min rest between sets) with 4 different resistance loads (50 lb, 60 lb, 70 lb and 80 lb) was performed to create a PAP stimulus. The athletes completed the resistive PAP warm-up protocols involving vertical jumping on the vertimax device in a randomised manner and at 48 hours intervals. After the PAP warm-up protocols with different resistances, athletes were provided with a passive rest for 5 min and SJ and CMJ tests were performed immediately later. During the vertical jump tests, the midpoint of the athletes' feet was centred in front of the photoelectric sensor in the sagittal plane. SJ tests were carried out with maximal force after waiting 3-5 s with hands on waist, trunk in upright position and knees in ~ 90^{o} flexion. CMJ tests were done with maximal power without a pause after hands on waist, trunk in upright position and knees in ~ 90^{o} flexion. Each vertical jump test (SJ and CMJ) was repeated twice with 30 s passive rest breaks and the best score was assessed as the measurement outcome. On the other hand, in the non-resistance warm-up protocol, the athletes performed a 5-min warm-up on the treadmill at a speed of 8 km/h and immediately afterwards they performed a passive rest for 5 min. Following the rest, they were subjected to SJ and CMJ tests. The workflow diagram of the study is visualised in Figure 1.

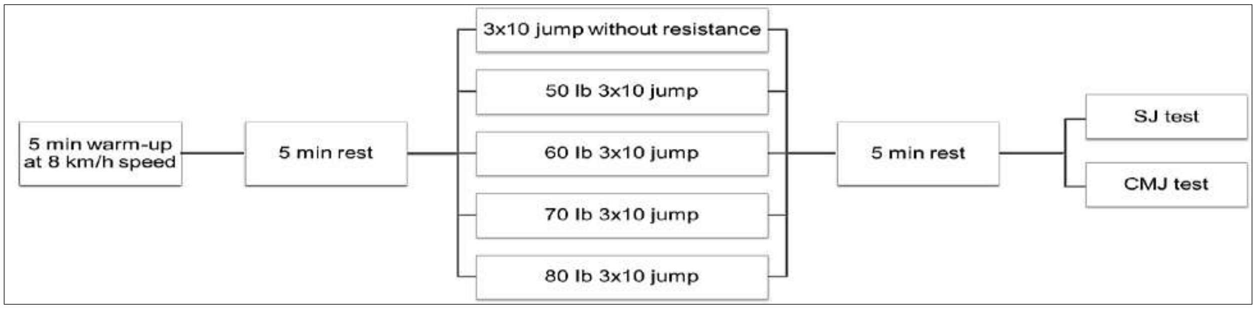

Figure 1. Workflow diagram for non-resistive and resistive PAP warm-up.

Statistical analysis
Kolmogorov-Smirnov (KS) test was utilised to determine if all variables of the athletes who participated in the study had a normal distribution. Results of the analysis showed that all of the variables had normal distribution ($p > .05$). Repeated Measures of ANOVA (Repeated Measures of ANOVA) test was used for the analysis of the measurements of jump height and power of the athletes (SJ and CMJ) participating in the study after non-resistance and resistance PAP warm-up protocols. Bonferroni correction was applied for multiple comparisons among different resistances. Significance level was acceptable as $p < .05$.

RESULTS

The findings of SJ height and power values of the athletes participating in this study after warm-up without resistance and PAP warm-up with 50 lb, 60 lb, 70 lb, 80 lb resistance consisting of 3x10 repetitions are listed in Table 1.

Table 1. SJ values of athletes for non-resistance warm-up and PAP warm-up protocols with resistance.

Variables	**n**	**Non-resistive warm-up**	**Resistances PAP warm-up**				**F**
			50 lb	60 lb	70 lb	80 lb	
		Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	
SJ height (cm)	15	35.14±7.18[a,b]	36.44±7.48	37.82±6.03	37.98±6.87[a]	38.59±6.24[b]	4.708*
SJ power (watt)	15	914.11±264.25[c,d]	932.16±276.24	949.63±261.24	951.10±265.58[c]	956.71±255.23[d]	7.774*

*Note. * a,b,c.d = p < .05 statistical differences at significance level.*

Based on the statistical analysis, it was observed that there were significant differences in SJ height and power values after PAP warm-up without resistance and PAP warm-up with resistance ($p < .05$). After PAP warm-up which were performed with 70 lb and 80 lb resistance bands, SJ height and power values were found to be significantly higher than the non-resistance warm-up values ($p < .05$).

The results of CMJ height and power values of the athletes participating in this study after warm-up without resistance and PAP warm-up with 50 lb, 60 lb, 70 lb, 80 lb resistance made up of 3x10 repetitions are presented in Table 2.

Table 2. CMJ values of athletes for non-resistance warm-up and PAP warm-up protocols with resistance.

Variables	n	Non-resistive warm-up	Resistances PAP warm-up				F
			50 lb	60 lb	70 lb	80 lb	
		Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	
CMJ height (cm)	15	37.42±6.49[a]	38.72±6.15	38.73±7.03	39.54±5.94	40.95±6.32[a]	3.615*
CMJ power (watt)	15	944.42±270.11[b]	960.85±269.03	961.19±275.44	969.69±261.98	985.43±261.16[b]	2.968*

*Note. * a,b = p < .05 statistical differences at significance level.*

The results of the statistical analysis determined that there were significant differences in CMJ height and power values after PAP warm-up without resistance and PAP warm-up with resistance ($p < .05$). CMJ height and power values after PAP warm-up with 80 lb resistance bands were notably higher than those after warm-up without resistance ($p < .05$).

DISCUSSION

In this research, it was attempted to investigate the effect of plyometric warm-up performed with different resistances as PAP stimulus on vertical jump performance scores. The major finding of this study was that plyometric warm-up performed with higher resistances caused a significant rise in SJ and CMJ height and power values. According to this study, after plyometric warm-up protocols performed with different resistances (50 lb, 60 lb, 70 lb, 80 lb) as PAP stimulus, linear increase in SJ and CMJ values with loading increase [(50lb = 3% for SJ height. 7%, 60lb = 7.6%, 70lb = 8.1% and 80lb = 9.8% for SJ height) (50lb = 3.5%, 60lb = 3.5%, 70lb = 5.7% and 80lb = 9.4% for CMJ height)], yet this increase was significant at higher resistances (70 and 80 lb for SJ, 80 lb for CMJ; $p < .05$).

The intensity of resistance is one of the critical factors affecting PAP responses. In this regard, high loads (1 RM > 85%) have been prioritised (Bevan et al, 2010; Boullosa et al, 2013; de Villarreal et al, 2007) in studies conducted to evaluate the intensity of resistance used as a PAP stimulus (generally in weight training). In a systematic review, it was mentioned that high volume and moderate intensity (65% 1RM) PAP warm-up protocols performed with weights can also improve performance, but warm-up performed at high loads (85-90% 1RM) could be more beneficial if longer rest intervals are given (Garbisu-Hualde and Santos-Concejero, 2021). In addition, it has been reported that the similarity of the movements applied in PAP warm-up with the movements to be practised after warm-up may favourably affect performance (Suchomel et al., 2016). In this respect, plyometric activities were analysed as PAP stimuli in order to improve power activities by taking into cognisance their kinematic similarity to the subsequent performance (Ciocca et al., 2021; Turner et al., 2015; Maloney et al., 2014; Till and Cooke, 2009; Kilduff et al., 2007).

In several studies that have used plyometric activities as PAP stimuli, jumps consisting of different sets, repetitions and methods have been employed (Ciocca et al., 2021; Turner et al., 2015; Maloney et al., 2014; Till and Cooke, 2009; Kilduff et al., 2007; McBride et al., 2005). In some of the conclusions obtained from these studies, it was noted that plyometric warm-up as a PAP stimulus increased subsequent performance (Ciocca et al., 2021; Turner et al., 2015; Tobin and Delahunt, 2014), while in others it was reported that there was no significant effect (Till and Cooke, 2009; McBride et al., 2005). Nonetheless, it is useful to keep in mind some variables in order to achieve improvement in performance after PAP stimulus. It has been specified that the type of exercise, recovery time between PAP stimulus and performance, muscle fibre type, gender, fitness level, the structure of the applied test protocol (Chatzopoulos et al., 2007), warm-up intensity, volume, etc. can be effective on performance enhancement after PAP warm-up (Suchomel et al., 2016; Chatzopoulos et al., 2007).

Looking at the studies using plyometric activities as PAP stimuli, it is clear that different protocols are applied, including resistant (Turner et al., 2015; McBride et al., 2005) and non-resistant (Ciocca et al., 2021; Sharma et al., 2018; Turner et al., 2015; Tobin and Delahunt, 2014; Till and Cooke, 2009) plyometrics. In cases where non-resistance plyometric activities are preferred as PAP stimulation, there are studies reporting that they have an effect on performance (Ciocca et al., 2021; Sharma et al., 2018; Turner et al., 2015; Tobin and Delahunt, 2014) as well as studies reporting that they do not (Till and Cooke, 2009). In a study conducted with rugby players, Tobin and Delahunt (2014) examined that a total of 40 jumping exercises including a series of different plyometric activities (ankle/hurdle hops and drop jumps) increased CMJ height and power. Till and Cooke (2009) examined the effects of PAP warm-up consisting of dynamic (plyometric and weight) and maximal isometric contraction (MVC) protocols on sprint and vertical jump performance and found that plyometric warm-up (1x5 repetition tuck jump) did not have a meaningful influence on sprint and vertical jump performances. Nevertheless, the researchers have emphasised that PAP is to be evaluated individually owing to the wide differences in individual responses in this study (Till and Cooke, 2009).

Besides, it has been reported that performance outcomes may vary according to whether or not additional load is used in plyometric exercises in terms of PAP response (Turner et al., 2015). Turner et al. (2015) examined the effects of warm-up protocols including unloaded and loaded plyometric activities as PAP stimuli on sprint performance in their studies. They found that alternate-leg bounding conducted with body and additional weight of 10% of body weight markedly improved 10 m and 20 m sprint performance. Moreover, they have shown that the loaded (10% body weight) plyometric warm-up protocol had a superior effect on sprint performance in terms of PAP response in comparison to the unloaded protocol. Similarly, McBride et al. (2005) reported that a loaded (30% of 1 RM) multiple jump stimulus consisting of 1x3 repetitions had no efficacy on sprint performance. At this point, it is worth considering whether the amount of workload used during plyometric warm-up has an adverse effect on subsequent performance. This suggests that the amount of load used during plyometric warm-up, as in weighted warm-ups, might also have an effect on subsequent performance. During our study, despite the increase in vertical jump height and power values with the increase in the amount of resistance used during plyometric warm-ups, this increase was meaningful at relatively high resistances. Regarding the joint effect of volume and intensity, it is stated that the activation of type II muscle fibres is essential to elicit a PAP response in sportive performance (Sirieiro et al., 2021, Maloney et al., 2014). Therefore, it has been found that the neural stimulation obtained after heavy loads is higher in type II muscle fibres (Sirieiro et al., 2021; Hamada et al., 2000; Parry et al., 2008), and it has also been noted that low loads cannot be nearly as effective as high loads for more motor units to be activated (Schoenfeld et al., 2010). Hence, the use of high loads is generally prescribed to obtain a greater PAP response due to the increased engagement of higher threshold motor units stimulating type II muscle fibres (Sirieiro et al., 2021; Seitz et al., 2014). The results of the current study also confirmed that warm-up protocols using higher resistances were more successful in terms of promoting PAP stimulus.

This study was conducted on male athletes and no comparison was made in terms of gender. It is reported that one of the factors that the effect of PAP warm-up on subsequent performance is gender (Tsolakis et al., 2011; Terzis et al., 2009). In this respect, one of the limitations of this study is that the participant group consists of only male athletes. In addition, the structure of muscle fibres is reported as another factor affecting the PAP response. It is stated that type II muscle fibres increase performance outputs in terms of PAP response more than type I muscle fibres (Hamada et al., 2000). Another limitation of our research is that the effects of muscle fibre type on power parameters in terms of obtaining PAP response are not taken into account. It can be evaluated in further studies in terms of the effects of gender and muscle type distribution on performance outcomes in plyometric warm-up with different resistances as PAP stimulus.

CONCLUSION

In conclusion, whereas each resistance level used in this study (50 lb, 60 lb, 70 lb and 80 lb) caused a linear increase in vertical jump height and power values, this increment was significant at higher resistance levels (70 and 80 lb for SJ and 80 lb for CMJ). Consequently, the evidence from this study demonstrated that the amount of load used in resistance plyometric warm-up is influential in terms of producing a PAP effect on subsequent performance. Considering the amount of load used in resistance plyometric warm-up would be more appropriate in terms of PAP effect.

AUTHOR CONTRIBUTIONS

Halit Harmancı: collection of data, taking measurements, carrying out statistical analysis and writing the article. Pınar Demirel: collection of data, taking measurements, writing the article. Harun Koç: Collection of data, taking measurements, writing the article. Recep Tekin: Collection of data, taking measurements, writing the article. All authors read and approved the final version of the manuscript.

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No potential conflict of interest was reported by the authors.

REFERENCES

Bevan, H.R., Cunningham, D.J., Tooley, E.P., Owen, N.J., Cook, C.J., & Kilduff LP. (2010). Influence of Postactivation Potentiation on Sprinting Performance in Professional Rugby Players. Journal of Strength & Conditioning Research, 24(3), 701-705. https://doi.org/10.1519/JSC.0b013e3181c7b68a

Bishop, D. (2003). Warm Up II: Performance Changes Following Active Warm Up and How to Structure The Warm Up. Sports Medicine, 33, 483-498. https://doi.org/10.2165/00007256-200333070-00002

Boullosa, D.A., Abreu, L., Beltrame, L.G., & Behm, D.G. (2013). The Acute Effect of Different Half Squat Set Configurations on Jump Potentiation. The Journal of Strength & Conditioning Research, 27 (8), 2059-2066. https://doi.org/10.1519/JSC.0b013e31827ddf15

Chatzopoulos, D.E., Michailidis, C.J., Giannakos, A.K., Alexiou, K.C., Patikas, D.A., Antonopoulos, C.B., & Kotzamanidis, C.M. (2007). Postactivation Potentiation Effects after Heavy Resistance Exercise on Running Speed. The Journal of Strength & Conditioning Research, 21(4), 1278-1281. https://doi.org/10.1519/R-21276.1

Chiu, LZ., Fry, A.C., Weiss, L.W., Schilling, B.K., Brown, L.E., & Smith, S.L. (2003). Postactivation Potentiation Response in Athletic and Recreationally Trained Individuals. The Journal of Strength & Conditioning Research, 17(4), 671-677. https://doi.org/10.1519/00124278-200311000-00008

Ciocca, G., Tschan, H., & Tessitore, A. (2021). Effects of Post-Activation Performance Enhancement (PAPE) Induced by a Plyometric Protocol on Deceleration Performance. Journal Of Human Kinetics, 80(1), 5-16. https://doi.org/10.2478/hukin-2021-0085

Garbisu-Hualde, A., & Santos-Concejero, J. (2021). Post-Activation Potentiation in Strength Training: A Systematic Review of the Scientific Literature. Journal of Human Kinetics, 78(1), 141-150. https://doi.org/10.2478/hukin-2021-0034

Hamada, T., Sale, D.G., MacDougall, J.D., & Tarnopolsky, M.A. (2000). Postactivation Potentiation, Fiber Type, and Twitch Contraction Time in Human Knee Extensor Muscles. Journal of Applied Physiology, 88(6), 2131-2137. https://doi.org/10.1152/jappl.2000.88.6.2131

Johnson, M., Baudin, P., Ley, A.L., & Collins, D.F. (2019). A Warm-Up Routine that Incorporates a Plyometric Protocol Potentiates the Force-Generating Capacity of the Quadriceps Muscles. The Journal of Strength & Conditioning Research, 33(2), 380-389. https://doi.org/10.1519/JSC.0000000000002054

Kilduff, L.P., Bevan, H.R., Kingsley, M.I.C., Owen, N.J., Bennett, M.A., Bunce, P.J., Hore, A.M., Maw, J.R., Cunningham, D.J. (2007). Postactivation Potentiation in Professional Rugby Players: Optimal Recovery, The Journal of Strength & Conditioning Research, 21(4), 1134-1138. https://doi.org/10.1519/R-20996.1

Kobal, R., Pereira, L.A., Kitamura, K., Paulo, A.C., Ramos, H.A., Carmo, E.C., Roschel, H., Tricoli, V., Bishop, C., Loturco, I. (2019). Post-Activation Potentiation: Is There an Optimal Training Volume and Intensity to Induce Improvements in Vertical Jump Ability in Highly-Trained Subjects?. Journal of Human Kinetics, 66(1), 195-203. https://doi.org/10.2478/hukin-2018-0071

Maloney, S. J., Turner, A.N., & Fletcher, I.M. (2014). Ballistic Exercise as a Pre-Activation Stimulus: A Review of The Literature and Practical Applications. Sports Medicine, 44 (10), 1347-1359. https://doi.org/10.1007/s40279-014-0214-6

McBride, J.M., Nimphius, S., & Erickson, T.M. (2005). The Acute Effects of Heavy-Load Squats and Loaded Countermovement Jumps on Sprint Performance. The Journal of Strength & Conditioning Research, 19(4), 893-897. https://doi.org/10.1519/R-16304.1

McGowan, C.J., Pyne, D.B., Thompson, K.G., & Rattray, B. (2015). Warm-Up Strategies for Sport and Exercise: Mechanisms and Applications. Sports Medicine, 45(11), 1523-1546. https://doi.org/10.1007/s40279-015-0376-x

Mitchell, C.J., & Sale, D.G. (2011). Enhancement of Jump Performance After A 5-RM Squat is Associated with Postactivation Potentiation. European Journal Of Applied Physiology, 111(8), 1957-1963. . https://doi.org/10.1007/s00421-010-1823-x

Parry, S., Hancock, S., Shiells, M., Passfield, L., Davies, B., & Baker, J.S. (2008). Physiological Effects of Two Different Postactivation Potentiation Training Loads on Power Profiles Generated during High Intensity Cycle Ergometer Exercise. Research in Sports Medicine, 16(1), 56-67. https://doi.org/10.1080/15438620701878998

Robbins, D.W. (2005). Postactivation Potentiation and Its Practical Applicability. The Journal of Strength & Conditioning Research, 19(2), 453-458. https://doi.org/10.1519/00124278-200505000-00035

de Villarreal, E.S., González-Badillo, J.J., & Izquierdo, M. (2007). Optimal Warm-Up Stimuli of Muscle Activation to Enhance Short and Long-Term Acute Jumping Performance. European Journal of Applied Physiology, 100(4), 393-401. https://doi.org/10.1007/s00421-007-0440-9

Sale, D.G. (2002). Postactivation Potentiation: Role in Human Performance. Exercise and Sport Sciences Reviews, 30(3), 138-143. https://doi.org/10.1097/00003677-200207000-00008

Schoenfeld, B.J., Contreras, B., Willardson, J.M., Fontana, F., & Tiryaki-Sonmez, G. (2014). Muscle Activation during Low-Versus High-Load Resistance Training in Well-Trained Men. European Journal of Applied Physiology, 114(12), 2491-2497. https://doi.org/10.1007/s00421-014-2976-9

Seitz, L.B., de Villarreal, E.S., & Haff, G.G. (2014). The Temporal Profile of Postactivation Potentiation is Related to Strength Level. The Journal of Strength & Conditioning Research, 28(3), 706-715. https://doi.org/10.1519/JSC.0b013e3182a73ea3

Sharma, S.K., Raza, S., Moiz, J.A., Verma, S., Naqvi, I.H., Anwer, S., & Alghadir, A.H. (2018). Postactivation potentiation following acute bouts of plyometric versus heavy-resistance exercise in collegiate soccer players. Biomed Research International, 1-8. https://doi.org/10.1155/2018/3719039

Sirieiro, P., Nasser, I., Dobbs, W. C., Willardson, J. M., & Miranda, H. (2021). The Effect of Set Configuration and Load on Post-Activation Potentiation on Vertical Jump in Athletes. International Journal of Exercise Science, 14(4), 902-911.

Smilios, I., Pilianidis, T., Sotiropoulos, K., Antonakis, M., & Tokmakidis, S. P. (2005). Short-Term Effects of Selected Exercise and Load In Contrast Training on vertical Jump Performance. The Journal of Strength & Conditioning Research, 19(1), 135-139. https://doi.org/10.1519/14463.1

Sotiropoulos, K., Smilios, I., Douda, H., Christou, M., & Tokmakidis, S. P. (2014). Contrast loading: power output and rest interval effects on neuromuscular performance. International Journal of Sports Physiology and Performance, 9(3), 567-574. https://doi.org/10.1123/ijspp.2013-0181

Suchomel, T.J., Lamont, H.S., & Moir, G.L. (2016). Understanding Vertical Jump Potentiation: A Deterministic Model. Sports Medicine, 46, 809-828. https://doi.org/10.1007/s40279-015-0466-9

Terzis, G., Spengos, K., Karampatsos, G., Manta, P., & Georgiadis, G. (2009). Acute Effect of Drop Jumping on Throwing Performance. The Journal of Strength & Conditioning Research, 23(9), 2592-2597. https://doi.org/10.1519/JSC.0b013e3181b1b1a3

Till, K.A., & Cooke, C. (2009). The Effects of Post Activation Potentiation on Sprint and Jump Performance of Male Academy Soccer Players. The Journal of Strength & Conditioning Research, 23(7), 1960-1967. https://doi.org/10.1519/JSC.0b013e3181b8666e

Tillin, N.A., & Bishop, D. (2009). Factors Modulating Post-Activation Potentiation and Its Effect on Performance of Subsequent Explosive Activities. Sports Medicine, 39(2), 147-166. https://doi.org/10.2165/00007256-200939020-00004

Tobin, D.P., & Delahunt, E. (2014). The Acute Effect of A Plyometric Stimulus on Jump Performance in Professional Rugby Players. The Journal of Strength & Conditioning Research, 28(2), 367-372. https://doi.org/10.1519/JSC.0b013e318299a214

Tsolakis, C., Bogdanis, G.C., Nikolaou, A., & Zacharogiannis, E. (2011). Influence of type of muscle contraction and gender on post activation potentiation of upper and lower limb explosive performance in elite fencers. Journal of Sports Science & Medicine, 10(3), 577-583.

Turner, A.P., Bellhouse, S., Kilduff, L.P., & Russell, M. (2015). Post Activation Potentiation of Sprint Acceleration Performance Using Plyometric Exercise. The Journal of Strength & Conditioning Research, 29(2), 343-350. https://doi.org/10.1519/JSC.0000000000000647

Villalon-Gasch, L., Jimenez-Olmedo, J.M., Sebastia-Amat, S., & Pueo, B. (2020). Squat-Based Post-Activation Potentiation Improves The Vertical Jump of Elite Female Volleyball Players. International Journal of Environmental Research and Public Health, 19(1): 462. https://doi.org/10.3390/ijerph19010462

REVIEW ARTICLE

Effect of aerobic training volume on VO_{2max} and time trial of runners: A systematic review

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ABSTRACT

Several conditioning indicators are necessary when performing running events, such as: the ability to sustain speed during a test and obtain good competitive rates in medium and long distance events. Purpose: This systematic review was to verify the distribution of weekly training volume during the preparatory phase of recreational runners and analyse the effect of this volume on maximum oxygen consumption and time-trial running. Results: The seven studies included analysed the training volume effect. A total of 120 adult participants were included with age of 27.80 ± 5.52 years, VO_2 of 47.45 ± 7.82 ml/kg/min^{-1}. All presented different aerobic training methods: HIIT, undulatory training, Linear, Reverse and Sprints. The interventions had an average duration of 10.00 ± 3.57 weeks. Training volume at the beginning of the interventions of 30 ± 7.21 km/week. A total of 59 adult participants with experience in road running and with performance in the 10 km and 1 km distances of 44.22 ± 8.43 min and 5.17 ± 0.24 min. Conclusion: The present review indicates that adjustments in training volume, specifically increments of up to 42% during the preparatory phase, can produce significant improvements in VO_{2max} and time trial performance.

Keywords: Endurance, Peak oxygen uptake, Sports performance, Physical exercises, Running.

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INTRODUCTION

Road races are among the sports with the greatest mass participation. Their popularity is attributed to the variety of environments, terrains, climates, and the diversity of age groups involved (Cuk et al., 2019), with participation rates ranging between 12.5% and 25% of the population (Tejero-González, 2015; Videbæk et al., 2015). It also offers opportunities for races of various distances, catering to runners of different competitive levels, from recreational to elite. Recreational athletes (Damsted et al., 2017) typically have between two to ten years of experience in the sport, train two to six times per week, run at an intensity of 4 to 7 minutes per kilometre, and/or cover a weekly distance of 10 to 65 kilometres (Kozlovskaia et al., 2019).

Several conditioning indicators are necessary for performing well in races. These include the ability to sustain speed during a race and achieve competitive times in medium and long-distance events. These abilities are influenced by physiological, anthropometric, neuromuscular, and psychological factors (Olaya-Cuartero et al., 2023). The best predictors of good performance in races, regardless of the athlete's competitive level, traditionally include maximum oxygen consumption (VO_{2max}), anaerobic threshold, and running economy (Bernans et al., 2023). Additionally, variables related to training strategies, such as volume, intensity, frequency, and rest, play a significant role (Fredette et al., 2022).

Therefore, it is known that variables such as intensity and weekly training volume, which are related to training planning and periodization, are essential for coaches and running athletes to monitor (Casado et al., 2022), as they are associated with performance development, particularly in terms of maximum oxygen consumption and time trial performance (Midgley et al., 2007). Thuany et al. (2020) found that, in a study with Brazilian recreational runners, greater volume and frequency of weekly aerobic training were four times more likely to produce superior performance compared to runners with lower training volumes (Thuany et al., 2020).

However, in practice, it appears that there is a certain negligence in controlling and adjusting these variables based on the objective and phase of the runner's periodization, which can increase non-functional overload (fatigue associated with a drop in performance or injury). A lack of proper adjustment can also harm the performance of recreational runners (Ramskov et al., 2018). Moreover, training volume is an excellent predictor of endurance performance (Suwankan et al., 2024). There is little experimental evidence demonstrating whether there is a minimum aerobic training volume capable of generating positive adaptations in terms of maximum oxygen consumption and improving runners' times (García-Pinillos et al., 2017). Through a systematic review of randomized studies, Campos et al. (2021) demonstrated that recreational runners cover an average of 30 to 120 km per week. However, there is no control over the runners' profiles or preparation phases (Campos et al., 2021).

Thus, there is no consensus on the ideal training volume to start a running program, much less on the necessary increments throughout an aerobic training program to optimize maximum oxygen consumption and improve race performance. Therefore, the aim of this systematic review was to examine the distribution of weekly training volume during the preparatory phase of recreational runners and analyse the effect of this volume on maximum oxygen consumption and time-trial performance.

METHODS

Study design

This systematic review followed the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Liberati et al., 2009). The study protocol was registered in the International Prospective Register of Systematic Reviews (PROSPERO) under the protocol CRD42023453769.

Search strategy

Original articles published in journals indexed in electronic databases including PubMed, Web of Science, EMBASE, Scopus, and Cochrane CENTRAL were searched up to May 2023 (Figure 1), without language restrictions. Advanced search tools were utilized to combine descriptors and terms.

The search strategy involved two blocks: one for training strategies and another for outcomes. The training strategy block included terms such as "*long distance runners*," "*endurance runners*," "*middle distance runners*," "*half marathon runners*," "*endurance running*," "*distance runners*," "*recreational runners*," and "*marathoners*." The outcome block included terms like "*training volume*," "*load*," "*volume*," "*training load*," "*training volumes*," and "*distance running*." These blocks were combined using the Boolean operator "*AND*" during the search process.

Inclusion and exclusion criteria

Study Design

The search process included chronic, randomized comparative studies with pre/post evaluative monitoring, and progressive sequential detailing of the modulation of changes in the intervention concerning outcome variables. Acute studies and intervention studies involving animals were excluded.

Characterization of participants

The review included studies involving recreational runners with an average of 2.8 ± 1.82 years of racing experience. The participants were adults aged 26.73 ± 9.13 years, engaging in an average of 3.39 ± 1.43 training sessions per week. They had a body mass index (BMI) of 24.5 ± 2.45 kg/m² and a VO_{2max} of 49.46 ± 9.0 ml/kg/min. Participants of both genders were included in the preparatory and/or conditioning phases of testing.

Intervention type

Participants were categorized based on their running profile as average or long distance (Midgley et al., 2007), ensuring homogeneity in the analysis of intervention protocols for recreational athletes. Volumes within the preparation phases were classified according to different Training Intensity Distributions (TID) for comparison (Bellinger et al., 2020), aiming to enhance VO_{2max} conditioning and time trials for runners. The three-phase model served as a framework for prescribing and monitoring runners using cardiorespiratory and conditioning indicators, quantified through training zones (Festa et al., 2020).

Zone 1 is defined as a light domain (<2 nmol.L^{-1}; <First Lactate Threshold – LT1; <Ventilatory Threshold 1 – VT1), corresponding to a subjective Rating of Perceived Exertion (RPE) of 1 to 4, indicating low intensity. Zone 2 is moderate and continuous (>2 nmol.L^{-1} and <4 nmol.L^{-1}; > LT1 and < LT2; > VT1 and < VT2 or Respiratory Compensation Point - RCP), with an RPE between 5 and 6. Zone 3 is characterized by high intensity (>4 nmol.L^{-1}; > LT2; > VT2 or RCP), with an RPE > 7 (Clemente-Suarez et al., 2018).

This intensity model quantifies distribution using the following strategies: 1. **Polarized:** Applies 80% of the training volume in Zone 1, with most of the remaining 20% in Zone 3, and minimal training in Zone 2 (80% Zone 1 + 0–5% Zone 2 + 20% Zone 3) (Muñoz et al., 2014). 2. **Undulatory:** Alternates volumes with moderate fluctuations, incorporating 10% to 30% increments of external training load (Casado et al., 2022). 3. **Linear:** Stabilizes volume and intensity throughout the training (Seiler, 2010). 4. **Sprint/High Intensity Interval Training (HIIT):** Involves multiple series of short (6–30s) or long (30–240s) stimuli at vigorous intensity (>80% - 100% of maximum heart rate [HR], heart rate reserve [HRR], maximum oxygen consumption [VO_{2max}], peak oxygen consumption [VO_{2peak}], and peak power [Ppeak]), followed by brief or extended periods of recovery (passive and/or active) (Buchheit & Laursen, 2013). Sprints are typically very short (<20s) and involve maximal effort, emphasizing high-intensity applications.

Analysis of outcome

The primary outcome assessed was VO_{2max} in the specific preparation of recreational runners, including average values and their variation amplitudes (Δ) from the initial phase to the end of preparation. Secondarily, time trial performance variables were analysed across several distances (1 to 10 km) against the clock, with mean values and standard deviations reported for each training strategy (interval and/or continuous).

Risk of bias evaluation

The methodological quality of the studies was assessed and classified using a quality scale (Van Velzen et al., 2006). This scale evaluates internal and external study validity across 15 criteria, which are detailed in Table 1. Each criterion was scored as YES (1.0), NOT CLEAR (0.5), or NO (0), contributing to a maximum score of 15 points based on the total number of indicators (Marocolo et al., 2019).

Table 1. Quality criteria and score assigned to studies.

Studies	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	*Score*	%
Esfarjani et al., 2007	1	1	1	1	1	1	1	1	0.5	1	1	1	1	0	1	13.5	90.00
Munoz et al., 2014	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15	100.00
Vesterinen et al. 2015	1	1	0.5	1	1	1	1	1	1	1	1	1	1	1	1	14.5	96.67
Lum et al., 2016	1	1	1	0.5	1	1	1	1	0.5	1	1	1	1	1	1	14	93.33
Bradbury et al., 2018	1	1	0	0.5	1	1	1	1	1	1	1	1	1	0	1	12.5	83.33
Costa et al., 2019	1	1	1	0.5	1	1	1	1	1	1	1	1	1	1	1	14.5	96.67
Faelli et al., 2019	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	14	93.33

Legend: Q1: Is the hypothesis/objective of the study clearly described? Q2: Are the key results to be measured clearly described in the introduction? Q3: Are the characteristics of the subjects included in the study clearly described? Q4: Are the interventions of interest clearly described? Q5: Are the main findings of the study clearly described? Q6: Does the study provide estimates of the random variability of the data for the main results? Q7: Were the testing instruments reliable? Q8: Was the duration of follow-up sufficiently described and consistent in the study? Q9: Was the number of participants included in the study findings? Q10: Have actual probability values been reported (e.g. .035 rather than <.05) for the main outcomes, except where the probability value is less than .001? Q11: Was there a statement adequately describing or referencing all statistical procedures used? Q12: Were the statistical analyses used adequate? Q13: 13. Was the presentation of results satisfactory? Q14: Were confidence intervals given for the main results? Q15: Is the conclusion drawn from the statistical analysis justified?

RESULTS

Included studies

As shown in Figure 1, a total of seven potential articles were identified through the search process and eligibility criteria application. These studies analysed the effect of training volume on maximum oxygen consumption and/or time trial performance during the specific preparation period for recreational runners.

Effect of training volume on maximum oxygen consumption

Six studies investigated the effect of training volume on maximum oxygen consumption as the primary outcome, with no reported adverse effects. The studies collectively included 120 adult participants (110 men and 22 women) with a mean age of 27.80 ± 5.52 years, mean BMI of 24.77 ± 2.48 kg/m², pre-intervention

VO2max of 47.45 ± 7.82 ml/kg/min, and average running experience of 2.59 ± 2.12 years. VO_{2max} was evaluated using ergospirometry in all studies conducted in a controlled laboratory environment.

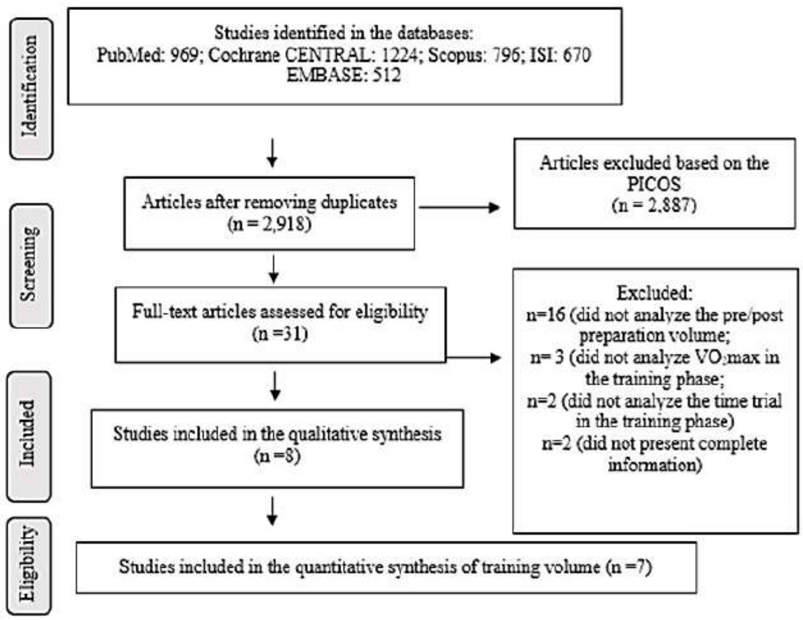

Figure 1. Flowchart of the stage for included articles.

Among the six studies included in this review, each utilized distinct aerobic training methodologies, resulting in a total of six interventions: high-intensity interval training (Faelli et al., 2019; Vesterinen et al., 2016), undulatory training (Costa et al., 2019), Linear training (Bradbury et al., 2018), Reverse training (Bradbury et al., 2018), and Sprint training (Lum et al., 2016). These interventions spanned an average duration of 10.00 ± 3.57 weeks, ranging from six to 16 weeks. Initial training volumes at the onset of interventions averaged 30 ± 7.21 km/week, with a range of 15 to 38 km/week, conducted at a frequency of 3.74 ± 1.40 days per week on average.

Changes in training volume, calculated as post-intervention minus pre-intervention values, are presented as mean ± standard deviation. Results indicated that an average 32.11% increase in training volume over approximately 10 weeks led to a notable improvement in maximum oxygen consumption by 10.44%.

Effect of training volume on time trial

Three studies (Faelli et al., 2019; Lum et al., 2016; Muñoz et al., 2014) investigated the impact of training volume on time trial performance as a secondary outcome, with no reported adverse effects. A total of 59 adult participants (mean age 33.52 ± 3.33 years, average BMI 22.88 ± 0.62 kg/m²) with experience in races (5.12 ± 2.02 years) and performance times of 44.22 ± 8.43 minutes for 10 km and 5.17 ± 0.24 minutes for 1 km distances were included. All studies evaluated time trials conducted on asphalt (track or test).

Each of the three studies employed different aerobic training methods, totalling four interventions: high-intensity interval training (Faelli et al., 2019), sprints (Lum et al., 2016), polarized training (Muñoz et al., 2014), and cross-threshold training (Muñoz et al., 2014). The interventions averaged 8 weeks in duration (ranging from 6 to 10 weeks). Initial training volumes averaged 32.54 ± 17.50 km/week (ranging from 15 to 50 km/week), conducted at a frequency of 2.8 ± 0.5 days per week on average.

Regarding periodization models and manipulation of intensity and volume variables, two studies increased training volume (Faelli et al., 2019; Muñoz et al., 2014), while two others focused on increasing training intensity and reducing volume (Faelli et al., 2019; Lum et al., 2016).

Table 2. Characterization of runners and training protocols.

Intervention	Author	Participants	Program
Interval Training	Esfarjani et al., 2007 (a)	G1 – n = 6; HIIT	HIIT G1 - completed five to eight intervals at VO_{2max} for a duration equal to 60% Tmax, with a 1:1 work: recovery ratio. The HIT sessions for G1 included high-intensity running bouts at 15,7 ± 0.7 kmh^{-1} for 3.5 ± 0.7 min followed by low-intensity recovery runs at 7.8 ± 0.3 km/h^{-1} for 3.5 ± 0.7 min.
	Esfarjani et al., 2007 (b)	G2 – n = 6 (19 ± 2 years, 73 ± 3 kg, 1.72 ± 0.04 m);	HIIT G2 - seven to twelve 30 s bouts at 130% VVO_{2max} separated by 4,5 min of recovery. This equated to a supramaximal run at 19,9 ± 0,6 km/h^{-1} for 30 s followed by a recovery run at 7.8 ± 0.3 km/h^{-1} for 4,5 min
	Vesterinen et al., 2015	HIIT – n = (35 years) (M =7, F =7)	HIT replaced three low-intensity training sessions during each intense training week with three moderate- or high-intensity (HR above lactate threshold 2, LT2) training sessions: (a) constant speed run 20–40 min at 80–90% HRmax; (b) 4 × 4 min at 90–95% HRmax, with 3 min of recovery at intensity below LT1; and (c) 6 × 2 min at 100% RSpeak, with 2 min of recovery at intensity below LT1, whereas training volume was maintained the same.
	Lum et al., 2016	Sprint – n = 7 (28.9 ± 3.4 years; 66.3 ± 6.8 kg; 1.71 ± 0.06 m)	Sprint = training plan of ∆ 3x 3x 10-m sprint / ∆ 4x 3x 50-m sprint
	Faelli et al., 2019 (a)	HIIT 10/20/30 – n = 11 (32.54 ± 3.05 years; 69.83 ± 2.76 kg; 1.74 ± 0.01 m)	HIIT 10/20/30 - 10 min warm-up at a low intensity, followed by 5 min running period, interspersed by 2 min of rest. Each 5 min running period consisted of five consecutive 1 min intervals, divided into 30, 20, and 10 s, at an intensity corresponding to 30, 60, and 90–100% of MAS, respectively.
	Faelli et al., 2019 (b)	HIIT 30/30 – n = 11 (38.18 ± 3.57 years; 68.11 ± 2.68 kg; 1.69 ± 0.02 m)	HIIT 30/30 - consisted of a standardized 10 min warm-up at a low intensity, followed by the 30–30 interval training, that consisted of 30 s at 90–100 % MAS interspersed with 30 s of active recovery (50% MAS)
High volume training	Vesterinen et al., 2015	HVT – n = 14 (35 years) (M =7, F =7);	HVT were instructed to increase their training volume by 30–50% whereas training intensity remained same as during PREP.
Undulatory	Costa et al., 2013	Undulatory-Undulatory – n = 18 (27 ± 9.3 years, 25.8 ± 4.6 kg/m^2);	Undulatory (training plan of ∆ 70% - 90% loads volume + ∆ 70% - 100% loads volume + 70% loads intensity)
		Undulatory-Linear – n =19 (26.3 ± 6.5 years, 25.8 ± 5.2 kg/m^2);	Staggered (training plan of ∆ 70% - 100% loads volume + 70% loads intensity)
		Staggered-Linear – n = 18 (24.3 ± 4 years, 25.9 ± 4.6 kg/m^2);	Linear (∆ 20% - 0% loads volume).
Linear	Bradbury et al., 2018	LP – n = 11	LP = training plan of ∆ 31.7 ± 3.86 km / 19.5 ± 2.51 km + ∆ 1075 ± 188 min*RPE / 548 ± 68 min*RPE
		RPG – n = 11	RPG = training plan of ∆ 31.8 ± 3.97 km / 19.1 ± 2.42 km + ∆ 739 ± 93 min*RPE / 556 ± 78 min*RPE
Polarized	Muñoz et al., 2014	BThET – n = 15 (34 ± 7 years, 67 ± 10.4 kg, 1.73 ± 0.07 m);	BThET = training plan of 1: followed a training plan designed to achieve a total percentage distribution in zones 1, 2, and 3 of ~45/35/20 (mean of ~350 TRIMPs/wk.)
		PET – n = 15 (34 ± 9 years, 71.4 ± 8.9 kg, 1.77 ± 0.05 m)	PET = training plan of 1: was designed to achieve a total percentage distribution in zones 1, 2, and 3 of ~75/5/20 based on HR distribution (mean of ~350 TRIMPs/wk.).

*Legend. *HVT: High Volume Training; HIIT: High Intensity Interval Training; BThET: Between-thresholds endurance training program; PET: Polarized endurance-training; LP: Linear periodization; RLP: Reverse Linear periodization.*

Munoz et al. (2014) and Faelli et al. (2019) demonstrated that a 26.97% increase in training volume over a nine-week period resulted in a 7.3% improvement in time trial performance. Conversely, Lum et al. (2016) and Faelli et al. (2019) reported that reducing training volume by 17.19% initially, followed by a progressive increase up to the final week, with intensity ranging from 33% to 112%, led to a 28.51% improvement in time trial performance compared to other training strategies. Changes in training volume [post-intervention minus pre-intervention] were calculated for each study and expressed as mean ± standard deviation (Faelli et al., 2019; Lum et al., 2016).

Table 3. Table of internal and external performance load indexes for recreational street runners.

Authors	Pre-volume (km)	Post-volume (km)	△ Volume variation in km (%)	p-value	Pre-VO_{2max} (ml/kg/min)	Post-VO_{2max} (ml/kg/min)	△ VO_{2max} variation ml.kg.min^{-1} (%)	p-value
The VO_2 response to training volume								
Esfarjani et al., 2007_HIIT_G1	38	43.6	↑ Δ = 5.6 (↑ 14.73 %)	<.05	51.3	56	↑ Δ = 4.7 (↑9.16%)	<.05
Esfarjani et al., 2007_HIIT_G2	38	36.6	↓Δ = -1.4 (↓ - 3.68 %)	>.05	51.7	54.9	↑ Δ = 3.2 (↑6.18%)	<.05
Vesterinen et al. 2015_HVT	35	47	↑ Δ = 12 (↑ 34.28 %)	<.001	49.3	50.5	↑ Δ = 1.2 (↑ 2.43 %)	>.05
Vesterinen et al. 2015_HIIT	33	39	↑ Δ = 6 (↑ 18.18 %)	>.05	50.7	52.8	↑ Δ = 2.1 (↑ 4.14 %)	<.01
Lum et al., 2016_Sprint	32.7	28.8	↓Δ = -3.9 (↓ - 11.92 %)	=.03	53.9	54.6	↑ Δ = 0.7 (↑ 1.29%)	=.47
Bradbury et al., 2018_LP	31.7	19.5	↓Δ = -12.2 (↓ -38.48 %)	<.05	59.46	62.09	↑ Δ = 2.63 (↑ 4.42 %)	>.05
Bradbury et al., 2018_RLP	31.8	19.1	↓Δ = -12.7 (↓ -39.93 %)	<.05	59.95	62.52	↑ Δ = 2.57 (↑ 4.28%)	>.05
Costa et al., 2019_UND	30.1	43	↑ Δ = 12.9 (↑ 42.85 %)	<.05	37.9	46.3	↑ Δ = 8.4 (↑ 22.1 %)	=.01
Costa et al., 2019_LINEAR	30.1	43	↑ Δ = 12.9 9↑ 42.85 %)	<.05	38.9	45.2	↑ Δ = 6.3 (↑ 16.19 %)	=.02
Costa et al., 2019_ Staggered-undulatory	30.1	43	↑ Δ = 12.9 (↑ 42.85 %)	<.05	41.3	46.1	↑ Δ = 4.8 (↑ 11.62 %)	=.02
Costa et al., 2019_ Staggered-linear	30.1	43	↑ Δ = 12.9 (↑ 42.85 %)	<.05	38.6	42.9	↑ Δ = 4.3 (↑ 11.13 %)	=.04
Faelli et al., 2019_HIIT 10/20/30	15	11.63	↓Δ = -3.37 (↓ -22.46 %)	=.002	43.01	46	↑ Δ = 2.99 (↑6.95%)	<.001
Faelli et al., 2019_HIIT 30/30	15	15.14	↑ Δ = 0.14 (↑ 0.93 %)	>.05	40.77	43	↑ Δ = 2.23 (↑5.46%)	<.001
The time trial response to volume of training								
Time trial 10,000 meters								
Muñoz et al., 2014_BthET	50	70	↑ Δ = 20 (↑ 40 %)	<.05	2364	2280	↓Δ = -84 (↓- 3.55 %)	<.001
Muñoz et al., 2014_PET	50	70	↑ Δ = 20 (↑ 40 %)	<.05	2358	2220	↓Δ = -138 (↓- 5.85 %)	<.0001
Lum et al., 2016_Sprint	32,7	28.8	↓Δ = -3.9 (↓ - 11.92 %)	=.03	3237	3117	↓Δ = -120 (↓- 3.7 %)	=.03
Time trial 1,000 meters								
Faelli et al., 2019_HIIT 10/20/30	15	11.63	↓Δ = -3.37 (↓ -22.46 %)	=.002	300	460	↑ Δ = 160 (↑53.33 %)	<.05
Faelli et al., 2019_HIIT 30/30	15	15.14	↑ Δ = 0.14 (↑ 0.93 %)	>.05	320	280	↓Δ = -40 (↓- 12.5 %)	<.05

Legend: ↑ = Increased running volume; ↓ = Decrease in running volume; Δ = Variation pre (Baseline) / post (Training). *HVT: High Volume Training; HIIT: High Intensity Interval Training; BThET: Between-thresholds endurance training program; PET: Polarized endurance-training; LP: Linear periodization; RLP: Reverse Linear periodization.

DISCUSSION

To our knowledge, this is the first systematic review to analyse the impact of training volume distribution on maximum oxygen consumption (VO_{2max}) and time trial performance in recreational runners. Key findings from this study include: i) Aerobic training programs with an initial volume ranging from 15 to 50 km/week, conducted at a frequency of 3.7 ± 1.4 days/week over intervention periods lasting 6 to 16 weeks, were sufficient to elicit positive adaptations in maximum oxygen consumption (ml/kg/min-1); and; ii) Aerobic training programs with an initial volume of 15 to 50 km/week, conducted at a frequency of 2.8 ± 0.5 days/week and lasting between 6 and 10 weeks, were effective in improving time trial performance (seconds).

Effect of training volume on VO_{2max}

VO_{2max} stands as a pivotal measure in assessing the competitive proficiency of runners and evaluating post-training athletic performance. Training volume is widely recognized as a critical variable in aerobic training protocols that can significantly influence VO_{2max}, thereby enhancing overall runner performance. However, there remains a paucity of studies that rigorously control this variable throughout the entirety of a training cycle.

The findings of this review revealed considerable variability regarding the optimal volume adjustments across training programs, lacking standardization. Nonetheless, it was observed that moderate increments of approximately 10% in training volume were sufficient to yield significant improvements in VO_{2max} among recreational runners. Conversely, interventions prescribing larger increases in volume demonstrated more pronounced improvements.

Our findings align with prior research (Billat et al., 2003), which investigated the impact of high-intensity aerobic interval training programs featuring incremental weekly volume adjustments in professional Kenyan runners, resulting in notable increases in VO_{2max}%. Similar outcomes were reported in a systematic review conducted by Campos et al. (2021), underscoring that aerobic training programs incorporating higher weekly volumes elicited greater enhancements in VO_{2max} among recreational runners across various competitive levels.

It is crucial to prioritize higher weekly training volumes during the preparatory phase, emphasizing moderate to vigorous intensities and preferably incorporating interval stimuli. This approach aims to foster both central and peripheral adaptations associated with endurance capacity. Although none of the included studies specifically analysed the mechanisms through which high-volume aerobic training enhances VO_{2max}, these mechanisms are well-documented in the literature. They include increased capillarization of muscle fibres and mitochondrial density, as well as enhancements in systolic volume and circulating haemoglobin concentration (Thompson, 2017). These adaptive changes contribute to an improved tolerance to [H+] accumulation during intense sections of races, whether influenced by elevation, temperature, or competitive conditions (Casado et al., 2023).

Effect of training volume on time trial

Time-trial running serves as a crucial measure for assessing physical conditioning progress and simulating physiological demands akin to competitive races. Additionally, it correlates significantly with endurance performance (Russell et al., 2004). Recent systematic reviews have explored the impact of different aerobic training intensity distributions on time trials among recreational runners (Campos et al., 2021; Rosenblat et al., 2019). These reviews suggest that pyramidal and polarized training models are particularly effective in enhancing time-trial performance.

Despite extensive research on training intensity, there remains no consensus regarding the effect of training volume on time trials. Some studies indicate that higher volumes correlate with improved running speed (Rust et al., 2011). However, systematic reviews have highlighted that weekly volume increases exceeding 65 km for men and 48 to 63 km for women are associated with higher injury rates (Fokkema et al., 2020), underscoring a direct relationship between training volume and injury risk. In our study, aerobic training programs ranging from 15 to 70 km per week were found to produce a significant 12.5% improvement in time-trial performance. These findings suggest that reducing training volume by more than 22.4% may not yield substantial improvements in time-trial running.

We encountered challenges in determining optimal training volumes for recreational runners due to the intricate interplay of associative factors. Variables such as experience, age, and gender (Knechtle et al., 2011) serve as foundational elements in training regimen customization. However, our review highlighted a scarcity of literature addressing the specific needs of recreational runners, with existing recommendations predominantly derived from professional or elite athletes, often misaligned with the practical realities and aspirations of these participants (Kozlovskaia et al., 2019).

The transformation of these findings into actionable insights is pivotal for runners aiming to optimize performance efficiency. This involves leveraging predictive biomechanical metrics to identify and rectify energy expenditure inefficiencies on the track, thereby mitigating injury risks.

Practical applications

This systematic review offers practical insights to guide training strategies for recreational runners. It emphasizes the importance of mapping out preparation strategies that optimize performance indices while mitigating the risks of excessive training loads, thereby promoting longevity in sport and preserving structural integrity. Specifically, starting with a weekly training volume ranging from 15 to 50 km over approximately 8 weeks has been found effective in significantly improving maximum oxygen uptake (VO_{2max}) and time trial performance. Moreover, a moderate increase of about 10% in training volume has shown to enhance VO_{2max} levels. To minimize injury risks, it is essential to maintain a balanced approach between training volume and intensity, especially when weekly volumes exceed 65 km for men and 48 km for women. Coaches are advised to consider individual factors such as experience, age, and gender when adapting these recommendations, ensuring personalized training adjustments that optimize outcomes.

CONCLUSION

We conclude that improving the preparation of recreational runners hinges on understanding training volume distribution. This review demonstrates that adjusting training volume, with increases of up to 42% during the preparatory phase, significantly enhances VO_{2max} and time trial performance. The identified average of 32.7 km/week establishes a starting point for medium-distance runners, potentially increasing to 38.15 km/week. Coaches must consider these findings, adapting them to each runner's needs and characteristics, prioritizing health, injury prevention, and continual performance improvement.

These insights aim to enhance the effectiveness and safety of training programs tailored for recreational runners, facilitating sustainable improvements in performance metrics and overall athletic development.

AUTHOR CONTRIBUTIONS

Rhennan Rodrigues Barbosa: Scientific methods, scientific writing and data collection. Raphael José Perrier Melo: Scientific methods, scientific writing and data collection. Jorge Luiz de Brito Gomes: Scientific writing and statistical data analysis. Fernando José de Sá Pereira Guimarães: Scientific writing and statistical data analysis. Manoel da Cunha Costa: Scientific writing and general review.

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No potential conflict of interest was reported by the authors.

REFERENCES

Bellinger, P., Arnold, B., & Minahan, C. (2020). Quantifying the training-intensity distribution in middle-distance runners: The influence of different methods of training-intensity quantification. International Journal of Sports Physiology and Performance, 15(3), 319-323. https://doi.org/10.1123/ijspp.2019-0298

Bernans, E., Abolins, V., & Lanka, J. (2023). Does step frequency as a single factor affect running economy? A systematic review. Journal of Human Sport and Exercise, 18(3), 743-754. https://doi.org/10.14198/jhse.2023.183.20

Billat, V., Lepretre, P. M., Heugas, A. M., Laurence, M. H., Salim, D., & Koralsztein, J. P. (2003). Training and bioenergetic characteristics in elite male and female Kenyan runners. Medicine and Science in Sports and Exercise, 35(2), 297-304. https://doi.org/10.1249/01.MSS.0000053556.59992.A9

Bradbury, D. G., Landers, G. J., Benjanuvatra, N., & Goods, P. S. R. (2018). Comparison of linear and reverse linear periodized programs with equated volume and intensity for endurance running performance. Journal of Strength and Conditioning Research, 34(5), 1345-1353. https://doi.org/10.1519/JSC.0000000000002805

Buchheit, M., & Laursen, P. B. (2013). High-intensity interval training, solutions to the programming puzzle: Part II: Anaerobic energy, neuromuscular load and practical applications. Sports Medicine, 43(10), 927-954. https://doi.org/10.1007/s40279-013-0066-5

Campos, Y., Casado, A., Vieira, J. G., Guimarães, M., Sant'Ana, L., Leitão, L., Silva, S. F. da, Azevedo, P. H. S. M. de, Vianna, J., & Domínguez, R. (2021). Training-intensity Distribution on Middle- and Long-distance Runners: A Systematic Review. Int J Sports Med, 43(04), 305-316. https://doi.org/10.1055/a-1559-3623

Casado, A., Foster, C., Bakken, M., & Tjelta, L. I. (2023). Does Lactate-Guided Threshold Interval Training within a High-Volume Low-Intensity Approach Represent the "Next Step" in the Evolution of Distance Running Training? International Journal of Environmental Research and Public Health, 20(5). https://doi.org/10.3390/ijerph20053782

Casado, A., González-Mohíno, F., González-Ravé, J. M., & Foster, C. (2022). Training Periodization, Methods, Intensity Distribution, and Volume in Highly Trained and Elite Distance Runners: A Systematic Review. International Journal of Sports Physiology and Performance, 17(6), 820-833. https://doi.org/10.1123/ijspp.2021-0435

Clemente-Suarez, V. J., Dalamitros, A., & Nikolaidis, P. T. (2018). The effect of a short-term training period on physiological parameters and running performance: intensity distribution versus constant-intensity exercise. The Journal of Sports Medicine and Physical Fitness, 58(1), 1-7. https://doi.org/10.23736/S0022-4707.16.06756-6

Costa, P., Simão, R., Perez, A., Gama, M., Lanchtermacher, R., Musialowski, R., Braga, F., de Mello Coelho, V., & Palma, A. (2019). A Randomized Controlled Trial Investigating the Effects of Undulatory, Staggered, and Linear Load Manipulations in Aerobic Training on Oxygen Supply, Muscle Injury, and Metabolism in Male Recreational Runners. Sports Medicine - Open, 5(1). https://doi.org/10.1186/s40798-019-0200-5

Cuk, I., Nikolaidis, P. T., Markovic, S., & Knechtle, B. (2019). Age differences in pacing in endurance running: Comparison between marathon and half-marathonMen and Women. Medicina (Lithuania), 55(8). https://doi.org/10.3390/medicina55080479

Damsted, C., Parner, E. T., Sørensen, H., Malisoux, L., & Nielsen, R. O. (2017). Design of ProjectRun21: a 14-week prospective cohort study of the influence of running experience and running pace on running-related injury in half-marathoners. Injury Epidemiology, 4(1). https://doi.org/10.1186/s40621-017-0124-9

Faelli, E., Ferrando, V., Bisio, A., Ferrando, M., Torre, A. La, Panasci, M., & Ruggeri, P. (2019). Effects of Two High-intensity Interval Training Concepts in Recreational Runners. International Journal of Sports Medicine, 40(10), 639-644. https://doi.org/10.1055/a-0964-0155

Festa, L., Tarperi, C., Skroce, K., La Torre, A., & Schena, F. (2020). Effects of Different Training Intensity Distribution in Recreational Runners. Frontiers in Sports and Active Living, 1, 70. https://doi.org/10.3389/fspor.2019.00070

Fokkema, T., van Damme, A. A. D. N., Fornerod, M. W. J., de Vos, R. J., Bierma-Zeinstra, S. M. A., & van Middelkoop, M. (2020). Training for a (half-)marathon: Training volume and longest endurance run related to . In PLoS Medicine performance and running injuries. Scandinavian Journal of Medicine and Science in Sports, 30(9), 1692-1704. https://doi.org/10.1111/sms.13725

Fredette, A., Roy, J. S., Perreault, K., Dupuis, F., Napier, C., & Esculier, J. F. (2022). The Association between Running Injuries and Training Parameters: A Systematic Review. Journal of Athletic Training, 57(7), 650-671. https://doi.org/10.4085/1062-6050-0195.21

García-Pinillos, F., Soto-Hermoso, V. M., & Latorre-Román, P. A. (2017). How does high-intensity intermittent training affect recreational endurance runners? Acute and chronic adaptations: A systematic review. Journal of Sport and Health Science, 6(1), 54-67. https://doi.org/10.1016/j.jshs.2016.08.010

Knechtle, B., Knechtle, P., Barandun, U., Rosemann, T., & Lepers, R. (2011). Predictor variables for half marathon race time in recreational female runners. Clinics, 66(2), 287-291. https://doi.org/10.1590/S1807-59322011000200018

Kozlovskaia, M., Vlahovich, N., Rathbone, E., Manzanero, S., Keogh, J., & Hughes, D. C. (2019). A profile of health, lifestyle and training habits of 4720 Australian recreational runners-The case for promoting running for health benefits. Health Promotion Journal of Australia, 30(2), 172-179. https://doi.org/10.1002/hpja.30

Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gøtzsche, P. C., Ioannidis, J. P. A., Clarke, M., Devereaux, P. J., Kleijnen, J., & Moher, D. (2009). The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: Explanation and elaboration (Vol. 6, Issue 7). https://doi.org/10.1371/journal.pmed.1000100

Lum, D., Tan, F., Pang, J., & Barbosa, T. M. (2016). Effects of intermittent sprint and plyometric training on endurance running performance. Journal of Sport and Health Science, 8(5), 471-477. https://doi.org/10.1016/j.jshs.2016.08.005

Marocolo, M., Simim, M. A. M., Bernardino, A., Monteiro, I. R., Patterson, S. D., & da Mota, G. R. (2019). Ischemic preconditioning and exercise performance: shedding light through smallest worthwhile change. European Journal of Applied Physiology, 119(10), 2123-2149. https://doi.org/10.1007/s00421-019-04214-6

Midgley, A. W., Mcnaughton, L. R., & Jones, A. M. (2007). Training to Enhance the Physiological Determinants of Long-Distance Running Performance Can Valid Recommendations be Given to Runners and Coaches Based on Current Scientific Knowledge? Sports Med, 37(10), 857-880. https://doi.org/10.2165/00007256-200737100-00003

Muñoz, I., Seiler, S., Bautista, J., España, J., Larumbe, E., & Esteve-Lanao, J. (2014). Does polarized training improve performance in recreational runners? International Journal of Sports Physiology and Performance, 9(2), 265-272. https://doi.org/10.1123/ijspp.2012-0350

Olaya-Cuartero, J., Plaza-Morales, D., Jimenez-Olmedo, J. M., & Lipinska, P. (2023). Sensor analysis for the assessment of biomechanical parameters in endurance runners: a systematic review. Journal of Physical Education and Sport, 23 (9), 2385-2393.

Ramskov, D., Rasmussen, S., Sørensen, H., Thorlund, E., Lind, M., Nielsen, R., & Lagerloefsvej, S. (2018). Progression in running intensity or running volume and the development of specific injuries in recreational

runners. Run Clever a randomized trial using competing risks. Journal of Orthopaedic & Sports Physical Therapy, 48(10), 740-748. https://doi.org/10.2519/jospt.2018.8062
Rosenblat, M. A., Perrotta, A. S., & Vicenzino, B. (2019). Polarized vs. Threshold Training Intensity Distribution on Endurance Sport Performance: A Systematic Review and Meta-Analysis of Randomized Controlled Trials. Journal of Strength and Conditioning Research, 33(12), 3491-3500. https://doi.org/10.1519/JSC.0000000000002618
Russell, R. D., Redmann, S. M., Ravussin, E., Hunter, G. R., & Larson-Meyer, D. E. (2004). Reproducibility of Endurance Performance on a Treadmill Using a Preloaded Time Trial. Medicine and Science in Sports and Exercise, 36(4), 717-724. https://doi.org/10.1249/01.MSS.0000121954.95892.C8
Rust, C. A., Knechtle, B., Knechtle, P., Barandun, U., Lepers, R., & Rosemann, T. (2011). Predictor variables for a half marathon race time in recreational male runners. Open Access Journal of Sports Medicine, 113. https://doi.org/10.2147/OAJSM.S23027
Seiler, S. (2010). What is Best Practice for Training Intensity and Duration Distribution in Endurance Athletes? BRIEF REVIEW. International Journal of Sports Physiology and Performance, 5, 276-291. https://doi.org/10.1123/ijspp.5.3.276
Suwankan, S., Suwankan, S., Theanthong, A., & Kemarat, S. (2024). Prediction of 10 km running time by physical and training characteristics in recreational runners. Journal of Human Sport and Exercise, 19(1), 193-201. https://doi.org/10.14198/jhse.2024.191.17
Tejero-González, C. M. (2015). The number of runners in Spain increased during the first decade of the 21st century. Apunts. Educacion Fisica y Deportes, 120, 73-75. https://doi.org/10.5672/apunts.2014-0983.es.(2015/2).120.10
Thompson, M. A. (2017). Physiological and biomechanical mechanisms of distance specific human running performance. Integrative and Comparative Biology, 57(2), 293-300. https://doi.org/10.1093/icb/icx069
Thuany, M., Gomes, T. N., & Almeida, M. B. (2020). Validação de um instrumento para caracterização e verificação de fatores associados ao desempenho de corredores de rua. Scientia Plena, 16(3). https://doi.org/10.14808/sci.plena.2020.032801
Van Velzen, J. M., Van Bennekom, C. A. M., Polomski, W., Slootman, J. R., Van Der Woude, L. H. V., & Houdijk, H. (2006). Physical capacity and walking ability after lower limb amputation: A systematic review. Clinical Rehabilitation, 20(11), 999-1016. https://doi.org/10.1177/0269215506070700
Vesterinen, V., Häkkinen, K., Laine, T., Hynynen, E., Mikkola, J., & Nummela, A. (2016). Predictors of individual adaptation to high-volume or high-intensity endurance training in recreational endurance runners. Scandinavian Journal of Medicine & Science in Sports, 26(8), 885-893. https://doi.org/10.1111/sms.12530
Videbæk, S., Bueno, A. M., Nielsen, R. O., & Rasmussen, S. (2015). Incidence of Running-Related Injuries Per 1000 h of running in Different Types of Runners: A Systematic Review and Meta-Analysis. Sports Medicine, 45(7), 1017-1026. https://doi.org/10.1007/s40279-015-0333-8

Comparison of four methods in recovery delayed onset muscle soreness

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ABSTRACT

The aim of the study was to investigate four treatments for the recovery of delayed onset muscle soreness (DOMS). DOMS was induced in 56 women forced by the "*Drop Set*" system and they were divided into four treatment groups: home, massage, proprioceptive neuromuscular facilitation (PNF) and passive stretching. The volunteers answered two pain scales: a numerical scale and a visual analogue scale (VAS) in five stages: 0 h, 24 h, 48 h, 72 h, 96 h and 120 h, before each treatment session. The statistical analysis between the scales and at the different times was carried out using one-way analysis of variance; and the comparison between the groups at the same time was carried out using repeated measures analysis of variance, followed by the Tukey-Kramer post-test. There was no significant difference between the pain measures of the scales. Massage had the lowest pain intensity at 24 and 48 hours compared to the other treatments. Massage is the best method for treating DOMS and passive stretching is the worst. The pain scales are equivalent to each other and could be relevant tools for monitoring recovery from intense physical training.

Keywords: Sport medicine, Massage, Pain measurement, Stretching.

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INTRODUCTION

The delayed onset muscle soreness (DOMS) is a discomfort feeling, which occurs due to some changes in athletes' training or in any non-usual activity that request strength and/or endurance (Thilo Hotfiel et al., 2018). This condition is frequently experienced by all regular physical exercise practitioners, or even by daily life activities. However, sedentary individuals are more likely to feel it more intensely and with longer time, mainly after the practice of movements or intensity they are not accustomed perform (Sadacharan & Seo, 2021).

The DOMS is caused by a muscle structural injury, harm caused in the Z band of sarcomere of muscle myofibrils, increase of sensibility due to oedema and allogenic substances, released post-injury in the muscle fibre and causing inflammatory reaction, local swelling, elevation in white globules count, monocytes' and lymphocytes' buildup and muscle spasms (Douglas et al., 2017). Therefore, present features related to DOMS are: discomfort and skeletal musculature pain a few hours after intense or uncommon physical activity practice, muscle sensibility, severe pain and weakness, loss of strength and movement amplitude, swelling on exercised muscles. These symptoms may reduce athletes' performance and the adhesion of people to strength trainings (Thilo Hotfiel et al., 2018; Sadacharan & Seo, 2021). The eccentric phase of resisted exercise may be the major responsible for the rising of DOMS, due to the muscle is stretched at the same time that should be maintained the cross-bridge cycle intensely, to control the weight loaded, distinct from other muscle actions (Douglas et al., 2017).

It was shown that women are more sensitive and less tolerant than men to the DOMS sensations. However, authors propose that, due to a bigger concentration of oestrogen on women, it acts as a protective effect by its augmented capacity in skeletal muscle receptor de estrogenic-α activation in response to eccentric exercise. It is regulating myogenic-related gene expression, regulating plasticity and muscle mass, this increasing the regeneration process and diminishing the inflammatory response after muscle damage (Haines et al., 2018; McKinley-Barnard et al., 2018). Age is also an important variable, because as years go by, intolerance to pain increases (McKinley-Barnard et al., 2018).

To examine the damages caused to the muscle deriving from strength training, direct methods are used, muscle samples' analysis or exams such as Magnetic Resonance Image; and indirect ones, scales and questionnaires, being these the most used due to its low cost and easiness in execution, especially the pain subjective perception scales (Afridi et al., 2021; Thilo Hotfiel et al., 2018). Regarding a way of training to prevent the DOMS, it hasn't a unique way to prevent this, but the gradual increase in the charge of training is important to reduce this situation.

Several interventions are inquired in order to diminish or DOMS after eccentric physical exercise, including by means of medication, which in high dosages might cause addiction (Gergin et al., 2019; Hotfiel et al., 2018). Primary treatment has been widely advocated to include the Protection, Rest, Ice (Cold), Compression and Elevation (the acronym "*PRICE*"), despite the lack of any high-quality studies to support its evidence (Heiss et al., 2019; Hotfiel et al., 2018).

However, strategies such as regular practice of physical exercises and stretching, from which the passive method, stretching by proprioceptive neuromuscular facilitation (PNF) and massage are highlighted, as resources that may alleviate the DOMS symptoms without harming the organism. Therefore, in this study we compared the response in DOMS recovery in four ways: the massage, proprioceptive neuromuscular facilitation (PNF), passive stretching and resting as a control in sedentary women submitted to arm flexion.

MATERIALS AND METHODS

Subjects

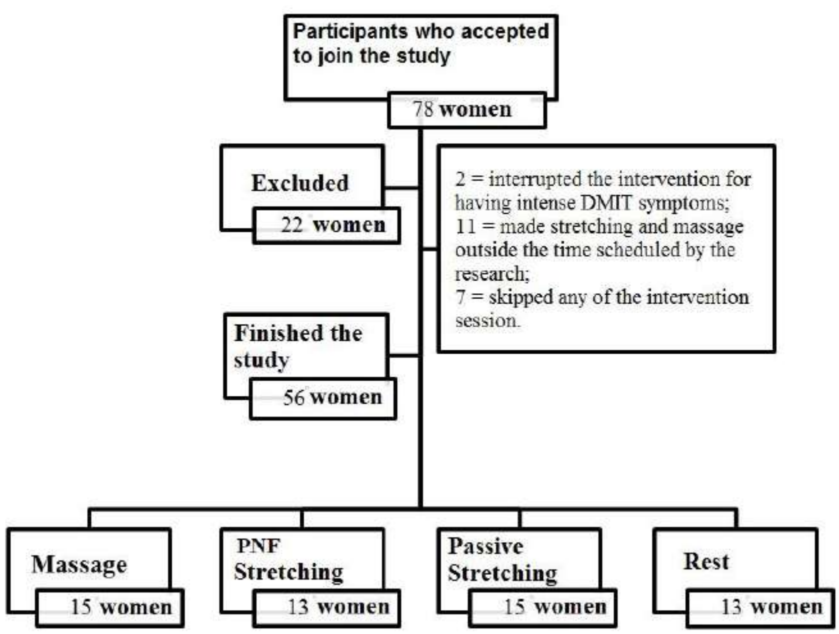
We selected young women, sedentary for at least six months, aged 18–26-year-old with body mass index (BMI) between 18,5 and 30 kg/m² to participate the present study. The voluntaries were not supposed to present any kind of joint injury, acute or chronic inflammatory processes (arthritis, arthrosis, muscle-joint injuries) or any kind of injury that might hinder the execution of free, complete movements. They were not supposed to use any anti-inflammatory drug or muscle relaxant or being pregnant either. All of them signed the consent form to participate the study, approved by the Research ethics committee from "*Cep-Saúde*" (Process n. 5.709.528/CEP-SAÚDE-UFMT/2022).

An exclusion criterion was the use of any intervention besides the ones scheduled in the study, including the usage of any kind of anti-inflammatory such as drugs, gels, ointments, adhesives, massage treatment or stretching in times other than the intervention or the used of hot-water bottle, ice and those who did not attend to the intervention.

Before beginning the intervention, the load of the eccentric test was established by the maximum repetition test (1RM) in the biceps curl exercise to each one volunteer. Weight progression varied from ½ to 1 kg per trial, until it reaches the maximum load possible to be lifted with the maximum of five trials, and the interval of rest from one trial to the other was of three minutes (Lau, Blazevich, Newton, Wu, 2015).

Study design

Seventy-eight women participated the study; however, 22 voluntaries were excluded due to the following reasons: two interrupted the intervention by experiencing heavy symptoms of DOMS, eleven made stretching's and massage outside the time established by the research protocol and seven skipped to any session of intervention. Thus, 56 women finished the study: massage group (n = 15), PNF stretching group (n = 13), passive stretching group (n = 15) and rest group (n = 13) (Figure 1).



Note. Interventions and evaluations lasted for 5 days; PNF = Proprioceptive neuromuscular facilitation.

Figure 1. Experimental design.

Interventions

The voluntaries were divided into four groups according to protocols, being: massage; PNF stretching, passive stretching; and rest group being the control one, as described below:

Massage protocol

Manoeuvres were made in the front part of the forearm, on the biceps muscle and spreading to the front deltoid, being made three kinds of manoeuvres: superficial sliding with fingers, deep sliding with fingers and the digital kneading by using the thumbs. Manoeuvres in each muscle was made in two minutes for superficial sliding, three minutes for deep sliding and three minutes for digital kneading.

PNF stretching protocol

Stretching were made in a way to prioritize the musculature of the elbows' flexors, especially biceps and brachial. It was made with 10 seconds for the passive stretching phase, 10 seconds of isometric contraction at the stretched position and more 10 seconds of passive stretching, totalizing 30 seconds repeated in 02 series.

Passive stretching protocol

It was made by leading the voluntary to the final position of her movement amplitude (ADM in Portuguese) (light pain), and keeping this position for 30 seconds, being that the stretching were made in two series of 30 seconds. The intensity of isometric contraction was approximately 60% of the maximum.

Rest protocol

They only responded to the questionnaires, with no other kind of intervention. At the first day of intervention (0 h) all voluntaries underwent the biceps curl exercise to cause DOMS using an 8 kg bar and ½ kg and 1 kg rings. This exercise was made using the adjusted/helped Drop-Set system, with emphasis on the eccentric phase on biceps muscle beginning at 80% of 1-RM, being decreased the weight in 20% at each muscle failure, until it remains only 20% of 1-RM until total muscle failure, which consisted of no longer controlling the eccentrical phase of muscular contraction. After the 1-RM, the voluntaries were split by simple random raffle, composing the groups with the respective protocols, massage, PNF stretching, passive stretching and rest. After exercise (0 h) the voluntaries waited five minutes to receive the first training session according to the group they belonged to. This treatment was repeated in 24h, 48h, 72h and 96h. On the sixth day (120 h), the voluntaries only responded the questionnaires, without intervention.

DOMS evaluation

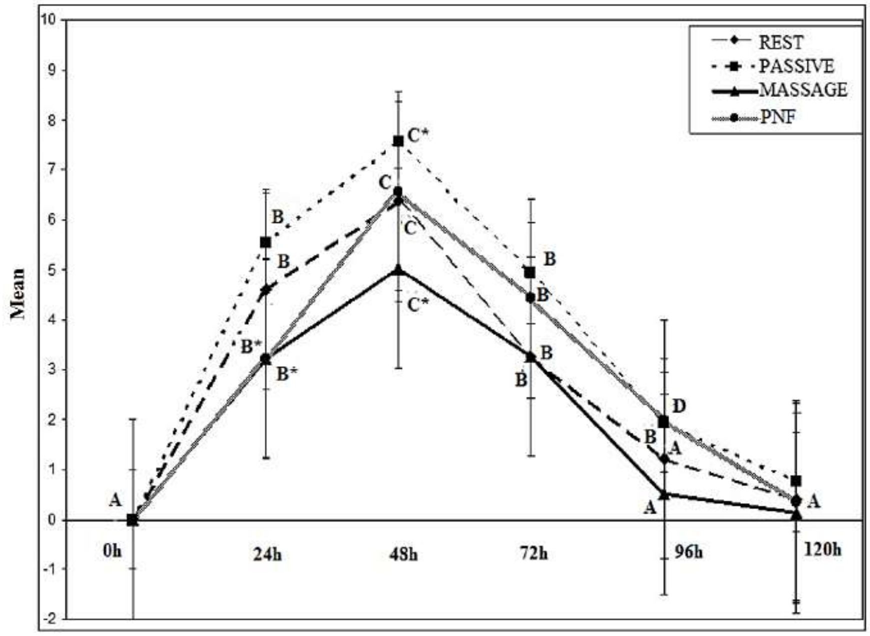
The questionnaires of pain used were the Analogical Visual Scale (AVS) and the Numeric Scale (NS), in the following moments: before interventions (0, 24, 48, 72 and 96 hours) and on the sixth day, post-intervention (120 hours) (Afridi et al., 2021).

Statistical analysis

Results are presented as average and standard deviation. For comparison of the different moments inside the same group was method of Variance Analysis for Repeated Measures, non-paired. The statistical significance was considered with $p < .05$ and confidence interval of 95%.

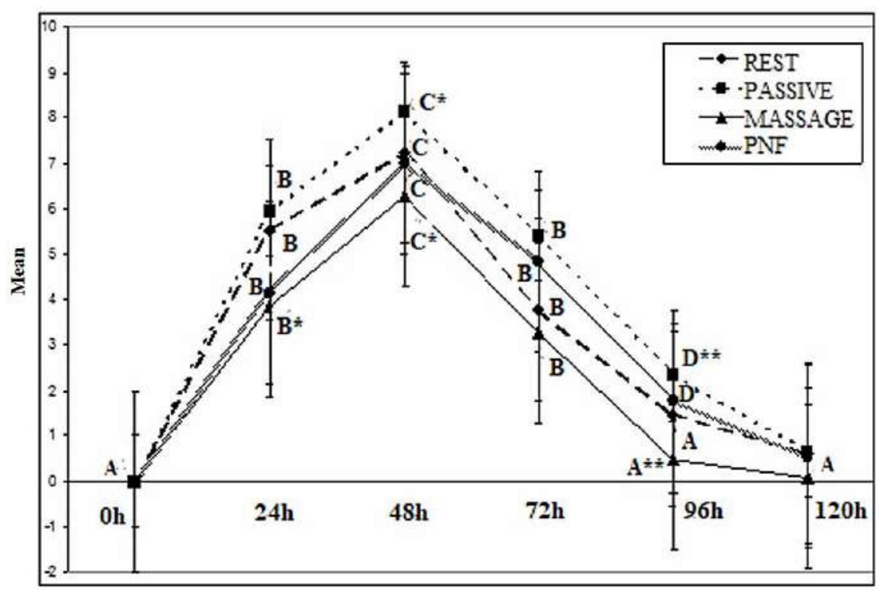
RESULTS

In comparison to the same moment between the two pain scales, VAS and NS, not significantly differences among them was found. Comparing the groups on the same moments, we found significant difference between massage and passive stretching and between passive stretching and rest in 24h and 48h on EVA, and between passive stretching and the massage in 24h, 48h and 96h on NS (Figures 2 and 3).



*Note. Passive = passive stretching. PNF = proprioceptive neuromuscular facilitation. Letters (A, B, C and D) compare moments at each training and equal letters show that there is not significantly difference (p > .05). * indicate statistical difference between variables at the same moments (p < .05).*

Figure 2. Average and standard deviation of Visual Analogue Scale (VAS) of the volunteers after muscular exhaustion training in different moments.



*Note. Passive = passive stretching. PNF = proprioceptive neuromuscular facilitation. Letters (A, B, C and D) compare moments at each treatment and same letters indicate that there is no meaningful difference. * and ** indicate statistical difference between variables at the same moments (p < .05) and (p < .01), respectively.*

Figure 3. Average and standard deviation of Pain Numeric Scale (NS) of the volunteers after muscular exhaustion training in different moments.

DISCUSSION

When compared at the same moments between groups and for the same group in different moments, results obtained between the scales, NS and VAS, were equivalent for DOMS evaluation which analyse only the pain intensity variation (Afridi et al., 2021). The only differences observed were that NS, in 24h, 48h and 96h moments, presented smaller significantly values for massage, compared to passive stretching; VAS, by its turn, presented differences between 24 and 48h for massage compared to passive stretching and for PNF and compared to the passive stretching at the 24h moment.

The exercise protocol probably caused injuries in the musculature, because symptoms were observed, such as pain, swelling, rigidity, loss of strength, difficulties in performance in daily living activities such as brushing hair and carrying objects. However, there were no major risks or immediate damages and in long term, and after some days, they came back to basal values. The local of major intensity of pain was next to the insertion of biceps muscle, extending also to the forearm, as already seem in another study (Lau, Blazevich, Newton, Wu, 2015).

Two cases of more severity of DOMS were verified among voluntaries who did not finish the intervention period, undergoing some treatment to minimize the symptoms such as usage of anti-inflammatory and massage. To this observed fact, one must take into account the individuality once all volunteers were undergone to the same procedures of maximum protocol, in order to assure all of them would respond to the rising of DOMS (Nahon, Silva Lopes, 2021).

In other studies, the DOMS peak was 48 hours after exercise (Hedderson et al., 2020; Lee et al., 2015), similar to our results. However, Fleckenstein et al (2017) observed that there was no significant difference in DOMS between 24 to 48 hours. In another study, the decrease in DOMS occurred 72 hours after exercise (Lee et al., 2015), corroborating our findings.

From a physiological point of view, the micro-injuries in the Z band induced by resistance training occur in the first week of training, and protein synthesis initially serves to repair these damages. However, from the third week of training, the microlesions are attenuated, however, with protein synthesis causing an increase in sarcomeres in series (muscle hypertrophy) (Damas et al., 2016). Perhaps, this adaptation explains why DOMS is usually caused in the first few sessions. Another possible physiological explanation for this phenomenon is pro-inflammatory and anti-inflammatory cytokines (IL-6 and IL-10) that have high concentrations 48 hours after the first training session, which may play a role in DOMS (Hedderson et al., 2020).

In our study, massage appeared to be the best method for DOMS recovery. In other studies, massage appeared to be an effective treatment in reducing DOMS in ultramarathon runners (Visconti et al., 2015) and fighters (Demirhan et al., 2015). In this context, it has been suggested that massage helps to decrease cytokine levels, which in turn can minimize the inflammatory response expected by exercise (Nelson, 2013).

With regard to DOMS studies of women, a recent review study noted that 77 studies (63.6%) included men only, 13 studies (10.7%) women only, and 31 studies (25.6%) included both sexes (Nahon, Silva Lopes, 2021). In this sense, it can be observed that there are few studies that analyse DOMS in women. We speculate that DOMS caused by physical exercise may be one of the causes of women's low adherence to resistance exercises.

The lack of biochemical data, especially regarding the creatine kinase (CK) anti-inflammatory and pro-inflammatory cytokines concentration, is a limitation of our study, which we intend to include on the next one. Still, the loss of volunteers reduces statistical power. In favour, the main physical performance measurer is the pain perception, which limits the participation in further activities. The present protocol is of hard adhesion for non-athlete people, who are an important public for this kind of investigation, once they are more susceptible and have smaller tolerance to DOMS, compared to trained individuals.

CONCLUSION

The massage protocol used in this study proved itself effective on DOMS reduction throughout the days following the intense exercise session, distinguishing itself to the passive stretching, PNF and rest. PNF stretching was the second-best treatment for DOMS. Both scales of pain evaluation used proved themselves equivalent as for the DOMS intensity evaluation and could be relevant instrument to follow up intense physical training recover. We recommend the inclusion of ice baths in future DOMS-related studies.

AUTHOR CONTRIBUTIONS

Michelle Jalousie Kommers: Writing of the results and writing of the manuscript. Jonatas Deivyson Reis da Silva Duarte: Writing of the results and writing of the manuscript. Waléria Christiane Rezende Fett: Writing of the project and design of the study. Lauriane Cristina da Silva Rocha: Writing of the project, data collection and intervention. Camila Fernanda Costa e Cunha Moraes Brandão: Writing of the project, data analysis and writing of the results Carlos Alexandre Fett: Writing of the project and design of the study.

SUPPORTING AGENCIES

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

DATA AVAILABILITY STATEMENT

Data available on request.

REFERENCES

Afridi, B., Khan, H., Akkol, E. K., & Aschner, M. (2021). Pain Perception and Management: Where do We Stand? 14(5), 678-688. https://doi.org/10.2174/1874467213666200611142438

Damas, F., Phillips, S. M., Libardi, C. A., Vechin, F. C., Lixandrão, M. E., Jannig, P. R., Costa, L. A. R., Bacurau, A. V., Snijders, T., Parise, G., Tricoli, V., Roschel, H., & Ugrinowitsch, C. (2016). Resistance training-induced changes in integrated myofibrillar protein synthesis are related to hypertrophy only after attenuation of muscle damage. The Journal of Physiology, 594(18), 5209-5222. https://doi.org/10.1113/JP272472

Demirhan, B., Yaman, M., Cengiz, A., Saritas, N., & Günay, M. (2015). Comparison of Ice Massage versus Cold-Water Immersion on Muscle Damage and DOMS Levels of Elite Wrestlers. The Anthropologist, 19(1), 123-129. https://doi.org/10.1080/09720073.2015.11891646

Douglas, J., Pearson, S., Ross, A., & McGuigan, M. (2017). Eccentric Exercise: Physiological Characteristics and Acute Responses. Sports Medicine, 47(4), 663-675. https://doi.org/10.1007/s40279-016-0624-8

Fleckenstein, J., König, M., Vogt, L., & Banzer, W. (2017). The pain threshold of high-threshold mechanosensitive receptors subsequent to maximal eccentric exercise is a potential marker in the prediction of DOMS associated impairment. PLoS ONE, 12(10), 1-17. https://doi.org/10.1371/journal.pone.0185463

Gergin, O. O., Bayram, A., Gergin, İ. S., Aksu, R., Yay, A., Balcıoglu, E., Polat, S., Sarıca, Z. S., Yıldız, K., Gergin, O. O., Bayram, A., Gergin, İ. S., Aksu, R., Yay, A., Balcıoglu, E., & Polat, S. (2019). Comparison of myotoxic effects of levobupivacaine , bupivacaine and ropivacaine : apoptotic activity and acute effect on pro- inflammatory cytokines. Biotechnic & Histochemistry, 00(00), 1-9. https://doi.org/10.1080/10520295.2018.1548711

Haines, M., McKinley-Barnard, S. K., Andre, T. L., Gann, J. J., Hwang, P. S., & Willoughby, D. S. (2018). Skeletal muscle estrogen receptor activation in response to eccentric exercise up-regulates myogenic-related gene expression independent of differing serum estradiol levels occurring during the human menstrual cycle. Journal of Sports Science and Medicine, 17(1), 31-39.

Hedderson, W. C., Borsa, P. A., Fillingim, R. B., Coombes, S. A., Hass, C. J., & George, S. Z. (2020). Plasma concentrations of select inflammatory cytokines predicts pain intensity 48 hours post-shoulder muscle injury. Clin J Pain, 176(1), 139-148. https://doi.org/10.1097/AJP.0000000000000861

Heiss, R., Lutter, C., Freiwald, J., Hoppe, M. W., Grim, C., Poettgen, K., Forst, R., Bloch, W., Hüttel, M., & Hotfiel, T. (2019). Advances in Delayed-Onset Muscle Soreness (DOMS) - Part II: Treatment and Prevention. Sportverletzung-Sportschaden, 33(1), 21-29. https://doi.org/10.1055/a-0810-3516

Hotfiel, T, Seil, R., Bily, W., Bloch, W., Gokeler, A., Krifter, R. M., Mayer, F., Ueblacker, P., & Weisskopf, L. (2018). Nonoperative treatment of muscle injuries - recommendations from the GOTS expert meeting. https://doi.org/10.1186/s40634-018-0139-3

Hotfiel, Thilo, Freiwald, J., Hoppe, M. W., Lutter, C., Forst, R., Grim, C., Bloch, W., Hüttel, M., & Heiss, R. (2018). Advances in Delayed-Onset Muscle Soreness (DOMS): Part I: Pathogenesis and Diagnostics. Sportverletzung-Sportschaden, 32(4), 243-250. https://doi.org/10.1055/a-0753-1884

Lau WY, Blazevich AJ, Newton MJ, Wu SS, N. K. (2015). Assessment of Muscle Pain Induced by Elbow-Flexor Eccentric Exercise. J Athl Train, 50(11), 1140-1148. https://doi.org/10.4085/1062-6050-50.11.05

Lee, Y. S., Bae, S. H., Hwang, J. A., & Kim, K. Y. (2015). The effects of kinesio taping on architecture, strength and pain of muscles in delayed onset muscle soreness of biceps brachii. Journal of Physical Therapy Science, 27(2), 457-459. https://doi.org/10.1589/jpts.27.457

McKinley-Barnard, S. K., Andre, T. L., Gann, J. J., Hwang, P. S., & Willoughby, D. S. (2018). Effectiveness of Fish Oil Supplementation in Attenuating Exercise-Induced Muscle Damage in Women During Midfollicular and Midluteal Menstrual Phases. Journal of Strength and Conditioning Research, 32(6), 1601-1612. https://doi.org/10.1519/JSC.0000000000002247

Nahon RL, Silva Lopes JS, M. de M. N. A. (2021). Physical Therapy in Sport Physical therapy interventions for the treatment of delayed onset muscle soreness (DOMS): Systematic review and meta-analysis. Phys Ther Sport, 52, 1-12. https://doi.org/10.1016/j.ptsp.2021.07.005

Nelson, N. (2013). Delayed onset muscle soreness: is massage effective? Journal of Bodywork and Movement Therapies, 17(4), 475-482. https://doi.org/10.1016/j.jbmt.2013.03.002

Sadacharan, C. M., & Seo, S. (2021). Effect of large versus small range of motion in the various intensities of eccentric exercise-induced muscle pain and strength. International Journal of Exercise Science, 14(7), 1-18.

Visconti, L., Capra, G., Carta, G., Forni, C., & Janin, D. (2015). Effect of massage on DOMS in ultramarathon runners: A pilot study. Journal of Bodywork and Movement Therapies, 19(3), 458-463. https://doi.org/10.1016/j.jbmt.2014.11.008

ORIGINAL ARTICLE

Predictors of performance on world-level arm wrestlers

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ABSTRACT

This study aims to explore predictors of performance ascertaining the optimal body composition for world-level arm wrestlers in a competitive environment. Athletes underwent body composition assessments and their final competition classifications were noted. Athletes had a pairwise comparison percentile groups for relative fat mass (FM%), scattered by country, fat-free mass (FFM%) clustered by final classification, and comparison of the final classifications, grouped by country. A total of 220 elite, male competitors from 33 countries showed a mixed classification by country for FM% percentiles (p = .089) with values ranging from the 10th percentile (FM = 7.1%) to above the 90th percentile (FM = 16.1%). Extreme values (FM = 4.5%) and country of origin did not predict the classification of the athletes, although the athletes´ ranking <75th did suggest a tendency towards classification (FFM% = 27.3%). Thus, world-level arm wrestlers revealed nutritional issues concerning values for body composition components in a competition environment.

Keywords: Performance analysis, Body composition, Wrestling, Wrestler profile.

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INTRODUCTION

Arm wrestling is a weight-sensitive sport branded by physical strength capabilities and perceptual skills (Akpınar et al., 2013; Bajkowski and Cynarski, 2024; Podrihalo et al., 2020). Several factors such as physical training, nutritional behaviour, health and body composition are crucial for predicting outcomes in weight-sensitive sports, combined with risk factors such as the effects of rapid weight loss on health and physical performance (Castor-Praga et al., 2021; Maksimovic et al., 2024; Ranisavljev et al., 2022).

Arm wrestling involves the action of forcing down the opponent's hand to the losing position on the surface of a special table (Akpınar et al., 2013; Yonca et al., 2017) and compete according to specific weight classes ("*Rules WAF*," 2024). It suggests that relationship between weight and body composition are the main factors in the improvement of performance in weight-sensitive sports (Bajkowski and Cynarski, 2024; Silva, 2019). Thus, we aimed to ascertain the best body composition profile for world-level arm wrestlers, taking into account predictors of performance in a competitive environment. Furthermore, we provided baseline reference data for coaches and athletes, embracing body composition, health and nutritional issues, and physical training programs.

MATERIALS AND METHODS

Subjects

All the volunteers were informed about the study, and signed a free and informed consent form, in accordance with the Helsinki Declaration (1964), and approved by the local Ethical Committee. The inclusion criteria consisted of selecting male athletes above 18 years old, only from the Senior division, during World Arm-wrestling Championships.

Interventions

Athletes underwent body composition assessment, applying a cross-validated equation (Evans et al., 2005) to obtain relative fat mass (FM%), based on the sum of abdomen, thigh, and triceps skinfolds thicknesses (3SKF), as a reference value: FM% = 8.997 + 0.24658*(3SKF) − 6.343*(gender) − 1.998*(race). The 3SKF sites were measure according to the international standards *("Isak - The International Society for the Advancement of Kinanthropometry,"* n.d.). The relative differences of FM provided values to fat free mas (FFM%). Measures comprised total body mass (BM) with a digital floor scale (seca 803, 0.1 kg); height, employing a vertical portable stadiometer (EST-223 Balmak, 0.1 cm); age of the athletes; measures of 3SKF using a Lange™ skinfold calliper (Beta Technology Inc., Cambridge, Maryland, USA, 10 g/mm^2 and an accuracy of 0.5 mm. Anthropometric values had control through technical error of measurement (TEM) verifying the intra-class correlation coefficient (ICC). The athletes' ranking after the awards provided reference values of physical performance.

Statistical analysis

Data outcomes represent the median and interquartile range (IQ = 25th-75th percentiles) to compare athletes' performance in the final classification groups: 1st, 2nd, 3rd, 4th, 5th, and Below (i.e., all those below 5th place). Body composition was analysed by percentile groups: <10th, <25th, <50th, <75th, <90th, >90th (above 90th), and estimated the relative FM and FFM. The data analysis used the Statistical Package for the Social Sciences (SPSS, Inc., Chicago, IL, USA, version 25.0). A Shapiro-Wilk test verified the distribution and the differences between the athletes' performance and evaluated percentile groups using a Kruskal-Wallis test with Bonferroni's post-hoc correction. A radial matrix (Acan, 2017) (chord diagram) permitted multiple comparisons between body composition and classification. A dot-plot diagram represented a cluster distribution of the final classification of the athletes, by country. A level of significance of $p < .05$ was used for all analyses.

RESULTS

Two hundred and twenty top-level male competitors (aged 29.5 ± 5.6 years, height 179.1 ± 8.7 cm, body mass 89.4 ± 20.7 kg) from thirty-three countries, participated in this study. Technical error of measurement (TEM) (value (min-max); percentage value (min; max)) verified the intraclass correlation coefficient (ICC) provided by the two evaluators, through One-Way ANOVA per 20 subjects: TEM = 0.24 (0.13-0.37), 0.37 (0.22-0.64); percentage = 1.92 (0.19-2.81), 3.46 (2.18-6.19); ICC = 1.00, 0.86; respectively. The classification groups (n = 6) provided the effect size (f = 0.25), considering limits for α = .05, and determined the power analysis (1-β err prob = .82) of this study (Figure 1; Table 1).

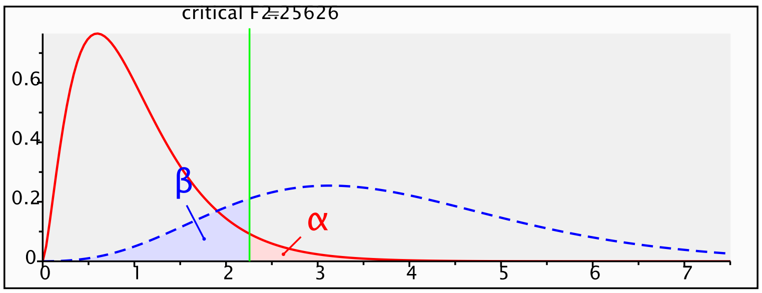


Figure 1. Central and noncentral distribution analysed by G*Power software.

Table 1. Protocol of power analysis.

F tests - ANOVA: Fixed effects, omnibus, one-way			
Analysis:	Post hoc: Compute achieved power		
Input:	Effect size f	=	0.25
	α Error probability	=	0.05
	Total sample size	=	220
	Number of groups	=	6
Output:	Noncentrality parameter λ	=	13.750000
	Critical F	=	2.2566566
	Numerator df	=	5
	Denominator df	=	214
	Power (1-β Error probability)	=	0.8196686

Note. F: the critical Type-I error value; df: degrees of freedom.

Athletes' participation by country (Figure 2) showed a mixed classification of FM% percentiles ($p = .089$) with values ranging from the 10th percentile (FM = 7.1%) to above the 90th percentile (FM = 16.1%).

To results involved controlling the mathematical effect of the confounding factors in the athletes' final classification. Height was not a factor ($p = .569$) but age was. Statistical differences were adjusted with Bonferroni's post-hoc correction ($p = .027$, $p > .164$, respectively) via the Kruskal-Wallis test (Figure 3, Table 2).

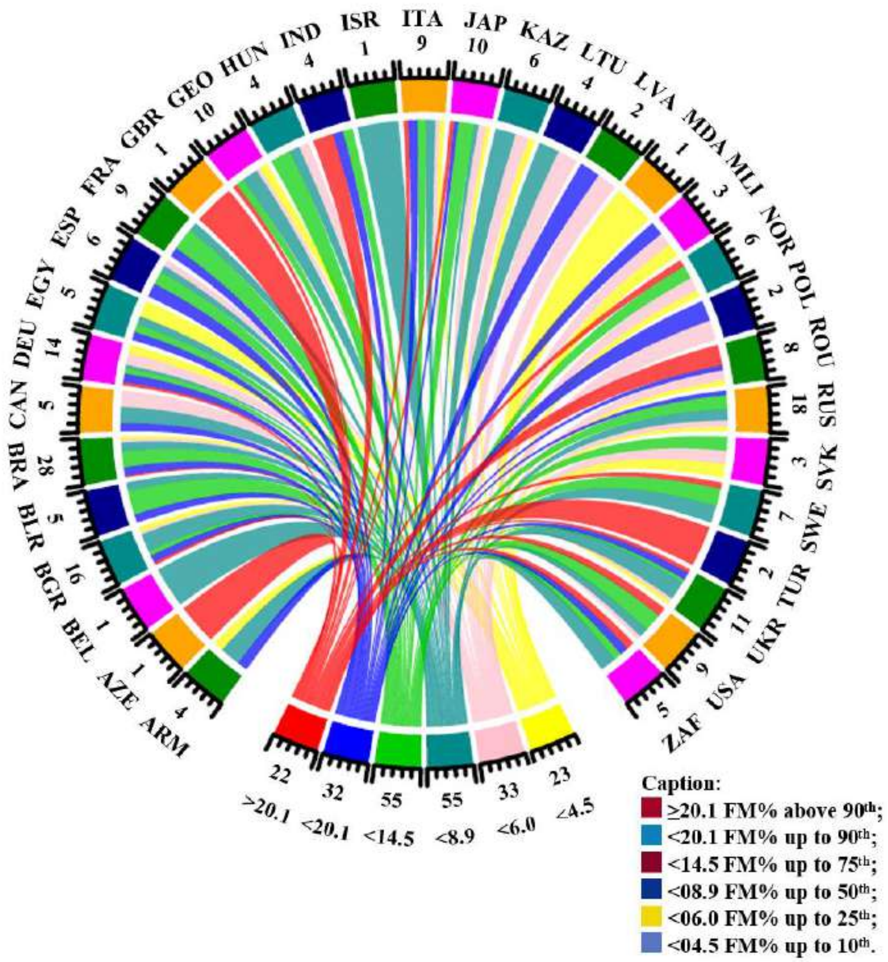
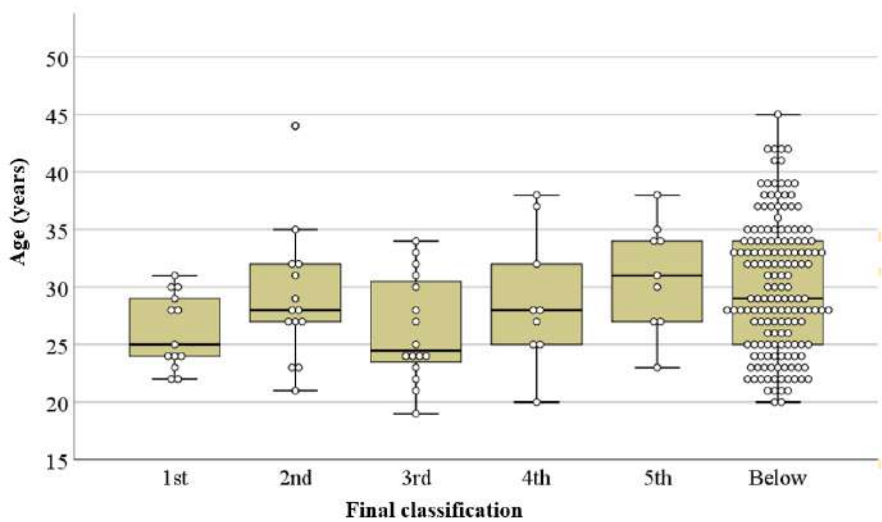


Figure 2. Interrelationship between the FM% percentiles according to the athletes´ participation, by country.



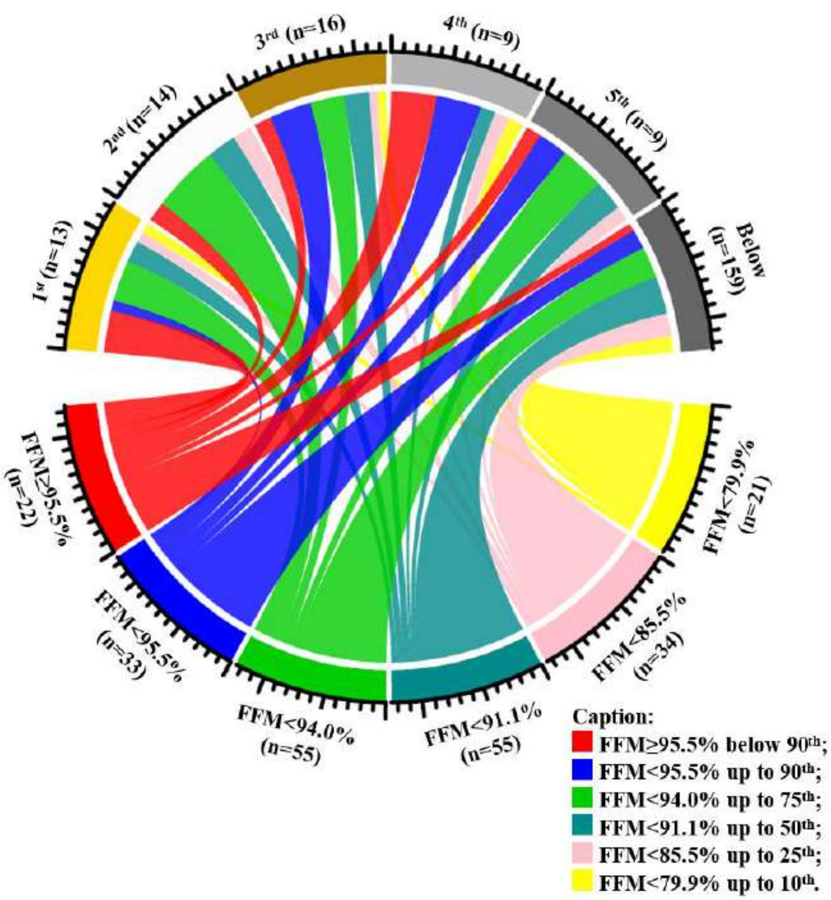
Note. Age: years (decimal); final classification: 1st-3rd: podium; Below: 6th place and below (until the 30th).

Figure 3. Post hoc Bonferroni correction by Independent-sample Kruskal-Wallis test.

Table 2. Pairwise comparison of Age by Classification adjusted by Bonferroni correction.

Age/Class.	Test Statistic	Standard Error	Standard Test Statistic	Sig.	Adj. Sig.
1-3	-2.050	23.722	-0.086	.931	1.000
1-2	-29.448	24.470	-1.203	.229	1.000
1-4	-31.158	27.549	-1.131	.258	1.000
1-6	-44.442	18.326	-2.425	.015	0.230
1-5	-57.491	27.549	-2.087	.037	0.553
3-2	27.397	23.250	1.178	.239	1.000
3-4	-29.108	26.471	-1.100	.272	1.000
3-6	-42.392	16.663	-2.544	.011	0.164
3-5	-55.441	26.471	-2.094	.036	0.543
2-4	-1.710	27.143	-0.063	.950	1.000
2-6	-14.994	17.711	0.847	.397	1.000
2-5	-28.044	27.143	-1.033	.302	1.000
4-6	-13.284	21.768	-0.610	.542	1.000
4-5	-26.333	29.949	-0.879	.379	1.000
6-5	13.049	21.768	0.599	.549	1.000

Note. Total N = 220; test statistic (12.611) DF = 5; asymptotic signal (2-sided test).



Note. FFM fat free mass; (1st - 5th, and Below) ranking distribution.

Figure 4. Interrelationship between final classification of the athletes according to relative fat free mass distribution.

Table 3. Athletes' final classification by fat free mass (FFM) percentiles.

Placing	<10	<25	<50	<75	<90	>90	Total
1st	1 (<79.9)	1 (<85.5)	2 (87.4-87.7)	4 (92.4-93.1)	1 (< 95.5)	4 (95.8-98.2)	13
2nd		2 (81.2-82.5)	3 (87.3-90.8)	7 (91.2-93.8)		2 (96.1-97.4)	14
3rd	1 (<79.9)	1 (<85.5)	3 (87.8-90.8)	4 (91.2-93.9)	5 (94.1-95.4)	2 (95.9-97.3)	16
4th	1 (<79.9)	1 (<85.5)	1 (<91.1)		3 (94.5-95.3)	3 (95.8-96.1)	9
5th		1 (<85.5)	2 (88.9-89.6)	3 (92.1-93.7)	2 (94.1-94.6)	1 (≥95.5)	9
Below 5th	19 (67.6-79.9)	27 (80.0-85.5)	44 (85.5-91.1)	37 (91.1-94.0)	23 (94.0-95.5)	9 (95.6-96.6)	159
Total	22	33	55	55	34	21	220

Note. Values are frequency and specific FFM percentage (min; max); Below: classification between 6th and 30th place; FFM percentiles according to final classification groups: <10th: up to 79.9% of fat free mass; <25th: up to 85.5%; <50th: up to 91.1%; <75th: up to 94.0%; <90th: up to 95.5%; >90th: Above.

Table 4. Pairwise comparison of FFM percentage by classification.

Sample 1-Sample 2	Test Statistic	Standard Error	Standard Test Statistic	Significance	Adjust Significance
6-2	19.655	17.745	1.108	.268	1.000
6-5	32.560	21.810	1.493	.135	1.000
6-1	37.380	18.362	2.036	.042	0.627
6-3	37.476	16.695	2.245	.025	0.372
6-4	41.782	21.810	1.916	.055	0.831
2-5	-12.905	27.195	-0.475	.635	1.000
2-1	17.725	24.517	0.723	.470	1.000
2-3	-17.821	23.294	-0.765	.444	1.000
2-4	-22.127	27.195	-0.814	.416	1.000
5-1	4.821	27.602	0.175	.861	1.000
5-3	4.917	26.522	0.185	.853	1.000
5-4	9.222	30.006	0.307	.759	1.000
1-3	-0.096	23.767	-0.004	.997	1.000
1-4	-4.402	27.602	-0.159	.873	1.000
3-4	-4.306	26.522	-0.162	.871	1.000

Note. Pairwise comparison of FFM percentage by ranking classification (1-5: 1st - 5th; 6: bellowed classification until the 30th place).

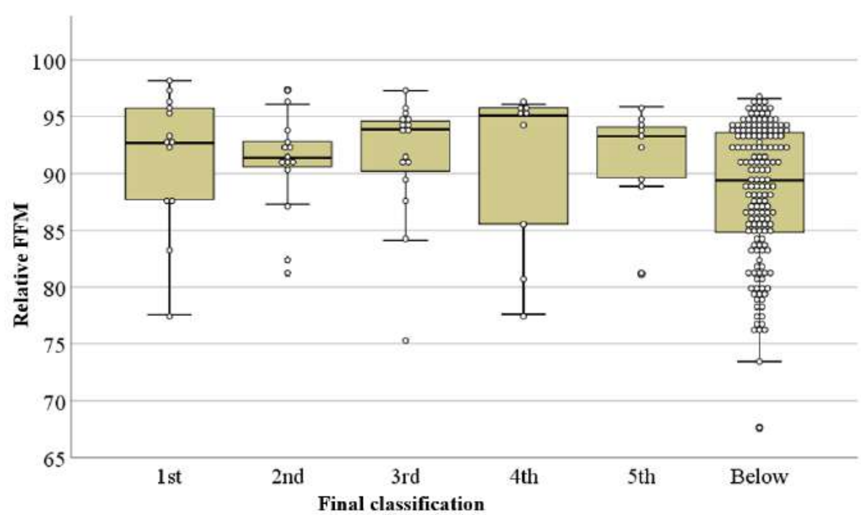
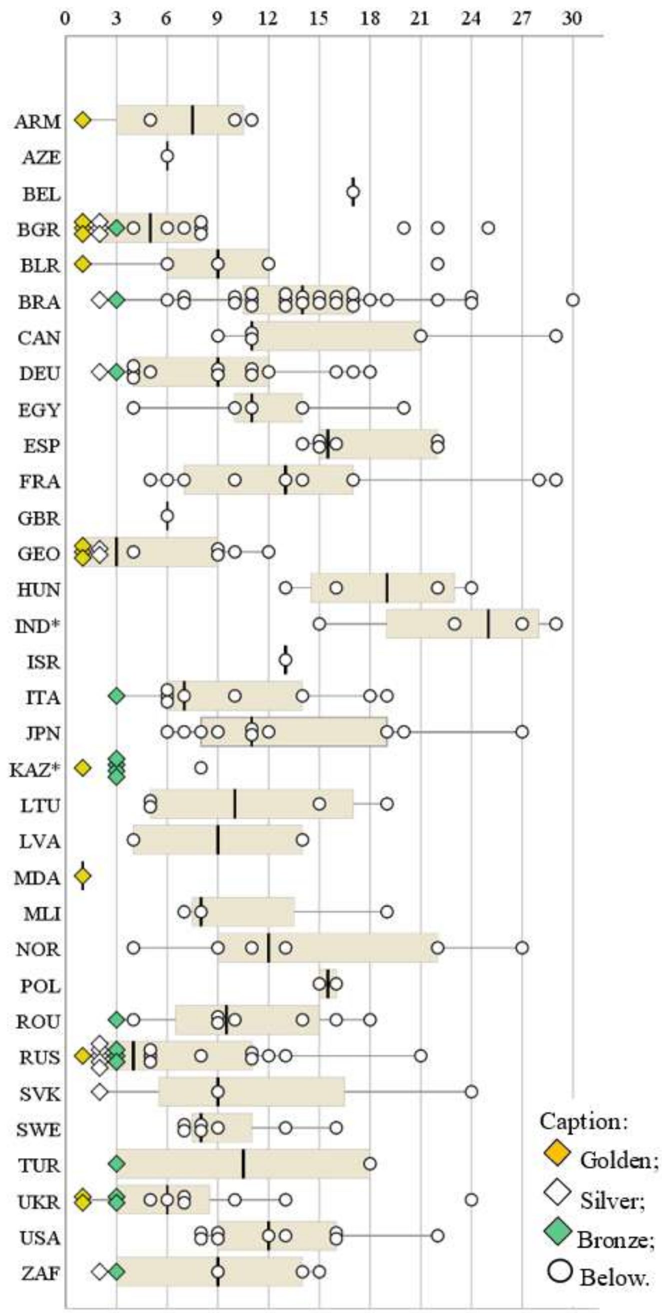


Figure 5. Post hoc Bonferroni correction by Independent-sample Kruskal-Wallis test of the FFM percentage; 1st-3rd: podium; Below: 6th place and below (until the 30th place).

Figure 4 shows the FFM% percentiles distributed by final classification. Values ranged from below 79.9% (up to the 10th percentile), to over 95.5% (the over 90th percentile), with a median of 91.1%. We discarded Differences (p = .025) found in the final classification groups after post-hoc correction (p > .372). Up to the 3rd place on the podium, athletes from the <10th percentile (FFM up to 79.9%) achieved two classifications (=9.1%). On the other hand, athletes with the >90th percentile (FFM over 95.5%) achieved eight classifications (=36.4%). We also found a trend in the <75th with 15 classifications (=27.3%) between <94.0% and >91.1%, compared to the <50th, which achieved 8 classifications (=14.5%) up to 3rd position. The Supplement displays FFM values according to the final classification of the athletes (Tables 3-4; Figure 5).



*Note. Diamond-shaped graph: podium classification 1st to 3rd place; * Kruskal-Wallis test.*

Figure 6. Athletes' classification by country.

Final competition results showed that sixty athletes participated on just one day, thirty-five of whom competed with their left arm the day before. Another five athletes competed on four consecutive days, alternating arms, and in two divisions. In this regard, the classification of the athletes showed that fifteen countries achieved podium finishes (Figure 6). The largest team in this study was Brazil (n = 28, 12.7%), followed by Russia (n = 18, 8.2%), Bulgaria (n = 16, 7.3%), Germany (n = 14, 6.4%), Ukraine (n = 11, 5.0%), Georgia (n = 10, 4.5%) and Japan (n = 10, 4.5%) (Table 5). The classification of athletes by country of origin did not produce predictive results among those athletes achieving first place in the ranking. Only KAZ (6 athletes) versus IND (4 athletes) showed differences in classification through the Kruskal-Wallis independent sample test (p = .049) (Table 6).

Table 5. Athlete's classifications among the 33 countries.

Country	Athletes	Percentage	Cumulative percentage	Country	Athletes	Percentage	Cumulative percentage
ARM	4	1.8	1.8	JPN	10	4.5	60.5
AZE	1	0.5	2.3	KAZ	6	2.7	63.2
BEL	1	0.5	2.7	LTU	4	1.8	65.0
BGR	16	7.3	10.0	LVA	2	0.9	65.9
BLR	5	2.3	12.3	MDA	1	0.5	66.4
BRA	28	12.7	25.0	MLI	3	1.4	67.7
CAN	5	2.3	27.3	NOR	6	2.7	70.5
DEU	14	6.4	33.6	POL	2	0.9	71.4
EGY	5	2.3	35.9	ROU	8	3.6	75.0
ESP	6	2.7	38.6	RUS	18	8.2	83.2
FRA	9	4.1	42.7	SVK	3	1.4	84.5
GBR	1	0.5	43.2	SWE	7	3.2	87.7
GEO	10	4.5	47.7	TUR	2	0.9	88.6
HUN	4	1.8	49.5	UKR	11	5.0	93.6
IND	4	1.8	51.4	USA	9	4.1	97.7
ISR	1	0.5	51.8	ZAF	5	2.3	100.0
ITA	9	4.1	55.9	**Total**	**220**	**100.0**	

Table 6. Athletes final classification by country of origin.

Country	1st	2nd	3rd	4th	5th	Below	Total
ARM	1(25.0%)				1(25.0%)	2(50.0%)	4
AZE						1(100.0%)	1
BEL						1(100.0%)	1
BGR	3(18.8%)	3(18.8%)	1(6.3%)	1(6.3%)		8(50.0%)	16
BLR	1(20.0%)					4(80.0%)	5
BRA		1(3.6%)	1(3.6%)			26(92.9%)	28
CAN						5(100.0%)	5
DEU		1(7.1%)	1(7.1%)	3(21.4%)	1(7.1%)	8(57.1%)	14
EGY				1(20.0%)		4(80.0%)	5
ESP						6(100.0%)	6
FRA					1(11.1%)	8(88.9%)	9
GBR						1(100.0%)	1
GEO	3(30.0%)	2(20.0%)		1(10.0%)		4(40.0%)	10
HUN						4(100.0%)	4

Country	1st	2nd	3rd	4th	5th	Below	Total
IND*						4(100.0%)	4
ISR						1(100.0%)	1
ITA			1(11.1%)			8(88.9%)	9
JPN						10(100.0%)	10
KAZ*	1(16.7%)		4(66.7%)			1(16.7%)	6
LTU					2(50.0%)	2(50.0%)	4
LVA				1(50.0%)		1(50.0%)	2
MDA	1(100.0%)						1
MLI						3(100.0%)	3
NOR				1(16.7%)		5(83.3%)	6
POL						2(100.0%)	2
ROU			1(12.5%)	1(12.5%)		6(75.0%)	8
RUS	1(5.6%)	5(27.8%)	3(16.7%)		3(16.7%)	6(33.3%)	18
SVK		1(33.3%)				2(66.7%)	3
SWE						7(100.0%)	7
TUR			1(50.0%)			1(50.0%)	2
UKR	2(18.2%)		2(18.2%)		1(9.1%)	6(54.5%)	11
USA						9(100.0%)	9
ZAF		1(20.0%)	1(20.0%)			3(60.0%)	5
Total	13(5.9%)	14(6.4%)	16(7.3%)	9(4.1%)	9(4.1%)	159(72.3%)	220

*Note. Placing: individual classification; Below: classification from 6th to 30th place; * Kruskal-Wallis test.*

DISCUSSION

This study reveals a unique scenario of the body composition of world arm wrestlers in a competitive environment. The interrelationships found in the components FM% and FFM% head the main factors of influence. The FM% showed variability in proportion to the number of athletes, scattered by country. Notably, the FFM% showed uniformity in terms of podium ranking (Silva, 2019). However, several factors may also impact the optimal performance in elite arm wrestlers in respect of health issues, and nutritional behaviour.

The study reported that body composition exerted a strong influence in weight-sensitive sports (Bajkowski and Cynarski, 2024; Sengeis et al., 2019). The FM% in the 75th percentile group (Figure 2) and above may have overestimated the weight class groups, amounting to a difference of as much as 11.1% (i.e., 90 kg; 100 kg) according to the body mass ("*Rules WAF,*" 2024). Indeed, the FM% can place a burden on physical performance (Giovanelli et al., 2023; Silva, 2019). This situation strongly suggests that many athletes could compete in lower weight classes.

From nutrition status, athletes may also be exposed to risk factors due to low FM%, such as relative energy deficiency in sport (RED-S). This syndrome usually affects weight-sensitive or gravitational sports, owing to either intentional or unintentional low energy availability (LEA) or as a consequence of overtraining (Dipla et al., 2020). The former can start through the failure to observe the dietary needs required to adhere to an athlete's program (Amawi et al., 2024). On the other hand, overtraining can reduce the metabolism ratio relative to the FFM, and cause regression to LEA(Logue et al., 2020). It also leads to a deficiency in testosterone production, low bone turnover, and higher cortisol levels (Angelidi et al., 2024). Consequently, this syndrome increases the risk factors for injury, including damage to musculoskeletal tissue, and reduces bone mineral density, regardless of gender (Dipla et al., 2020; Silva, 2019).

The FFM% outcomes suggest consistency with athletes´ classifications. Strength training programs help to improve the BM ratio, increasing strength mainly in experienced male athletes, but not always with changes in FM% (Bartolomei et al., 2014). Several athletes demonstrated optimum fitness in the 75th FFM% (<94.0% and >91.1%) up to third place (Figure 4). Among other reasons, many arm wrestlers did not appreciate how to increase FFM (muscle mass) and reduce body mass in order to compete against opponents with lower body mass (Andreato et al., 2012; Drid et al., 2015).

Arm wrestlers practice weight cutting up to 24 hours before competition (Barley and Harms, 2021; Brandt et al., 2018; Castor-Praga et al., 2021; Sengeis et al., 2019). However, the sport's international rules strongly discourage this practice, classifying athletes in the same weight class that applied during the season ("Rules WAF*," 2024)*. Athletes who pursue this behaviour can achieve their goals in a period of weight loss, inserted between periods of strength training, with a weekly weight loss target of 0.7% of body weight, whereas athletes who simply seek to maintain their muscle mass might adjust their weekly weight-loss rate to 0.5-1.0% of their body weight (Ruiz-Castellano et al., 2021). Knowledge of body composition helps control the macronutrient distribution of the diet, and vice versa, to achieve healthy limits of performance (Martín-Rodríguez et al., 2024).

Sources of energy metabolism in arm wrestling embody the strength capability of the upper limbs (Akpınar et al., 2013), including several other skills: explosive power, and between maximum power and strength endurance (Voronkov et al., 2014). Despite the fact that athletes may compete over several days, activities that generate micro-trauma in different or opposing limbs or muscle groups can assist with protein resynthesis through the mediation of satellite and proliferation cells (Abaïdia et al., 2017). In this regard, high-intensity activities could help the neuromuscular recovery process on the day after the competition (Abaïdia et al., 2017). Accordingly, this recovery effect may be associated with the system of competition in which all divisions always start with only the left arm on the first day and the right arm the day after ("*Rules WAF*," 2024).

Classification up to thirtieth place in the ranking (Figure 6) followed a system of competition known as double knockout. Traditionally, the ideal is to reach the Knockout Classification of the quarter-finals (Mcgarry and Schutz, 1997). This system allows for a tie in the final, where athletes can compete in as many as eight matches for final classification. The weight classes can run for more than an hour, stopping in the late morning and restarting for the semifinals after about 3 hours. It is possible for the athletes to compete in different divisions on alternate days, depending on age, para-sport, and in stand-up for competition in the senior division (Silva, 2019). From a practical standpoint, lower FM content increases power and strength, essential to recover the athletes' performance (Martín-Rodríguez et al., 2024). Nevertheless, we also found finalists that were evaluated as over the weight, overstepping the boundaries between the classes.

Limitations and strength

This study has several limitations due to its cross-sectional design. It was not possible to monitor athletes during training, so it assumed that competing athletes were in the same weight class in which they classified during the season. It did not provide a physical test for strength, very useful for comparing body composition and performance. It still remains to compare adult male categories with all other age groups, also distributed by para-athlete's classifications, as well as all of these groups in the female division.

The strong point of this work is the sample size of athletes evaluated, performing in a competitive environment, compared with others similar studies.

CONCLUSIONS

The final classification of the athletes revealed a wide diversity of countries making the podium. In the analysis of body composition, the FM% suggests that several athletes could compete in lower weight classes, which may account for the absence of differences between FFM% with performance in competition. Thus, world-level arm wrestlers revealed nutritional issues concerning values for body composition components in a competition environment.

AUTHOR CONTRIBUTIONS

Conceptualization, M.A.P. and F.L.L.; methodology, M.A.P., F.L.L., T.F.L., and G.G.J.; software, M.A.P.; formal analysis, M.A.P. and F.L.L.; investigation, M.A.P., F.L.L., M.S., V.T., and G.G.J.; resources, M.A.P., and G.G.J.; data curation, M.A.P., F.L.L., M.S., V.T.; writing-original draft preparation, M.A.P., F.L.L., and T.F.L.; writing-review and editing, M.A.P., and F.L.L.; visualization, M.A.P., T.F.L., and F.L.L.; project administration, M.A.P., and G.G.J.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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REFERENCES

Abaïdia, A.-E., Delecroix, B., Leduc, C., Lamblin, J., McCall, A., Baquet, G., Dupont, G., 2017. Effects of a Strength Training Session After an Exercise Inducing Muscle Damage on Recovery Kinetics. J. Strength Cond. Res. 31, 115-125. https://doi.org/10.1519/JSC.0000000000001479

Acan, H., 2017. On a uniformly random chord diagram and its intersection graph. Discrete Math. 340, 1967-1985. https://doi.org/10.1016/j.disc.2016.11.004

Akpınar, S., Zileli, R., Senyüzlü, E., Tunca, S.A., 2013. Predictores Antropológicos y Perceptuales que Afectan la Clasificación en la Competencia de Fuerza. Int. J. Morphol. 31, 832-838. https://doi.org/10.4067/S0717-95022013000300009

Amawi, A., AlKasasbeh, W., Jaradat, M., Almasri, A., Alobaidi, S., Hammad, A.A., Bishtawi, T., Fataftah, B., Turk, N., Saoud, H.A., Jarrar, A., Ghazzawi, H., 2024. Athletes' nutritional demands: a narrative review of nutritional requirements. Front. Nutr. 10. https://doi.org/10.3389/fnut.2023.1331854

Andreato, L.V., Franchini, E., Moraes, S.M.F. de, Esteves, J.V.D.C., Pastório, J.J., Andreato, T.V., Gomes, T.L. de M., Vieira, J.L.L., 2012. Morphological profile of Brazilian Jiu-Jitsu elite athletes. Rev. Bras. Med. Esporte 18, 46-50. https://doi.org/10.1590/S1517-86922012000100010

Angelidi, A.M., Stefanakis, K., Chou, S.H., Valenzuela-Vallejo, L., Dipla, K., Boutari, C., Ntoskas, K., Tokmakidis, P., Kokkinos, A., Goulis, D.G., Papadaki, H.A., Mantzoros, C.S., 2024. Relative Energy Deficiency in Sport (REDs): Endocrine Manifestations, Pathophysiology and Treatments. Endocr. Rev. bnae011. https://doi.org/10.1210/endrev/bnae011

Bajkowski, D., Cynarski, W.J., 2024. Testing factors influencing handgrip strength and reaction time to visual stimulus in selected martial arts. J. Kinesiol. Exerc. Sci. 34, 46-59. https://doi.org/10.5604/01.3001.0054.3260

Barley, O.R., Harms, C.A., 2021. Profiling Combat Sports Athletes: Competitive History and Outcomes According to Sports Type and Current Level of Competition. Sports Med. - Open 7, 63. https://doi.org/10.1186/s40798-021-00345-3

Bartolomei, S., Hoffman, J.R., Merni, F., Stout, J.R., 2014. A Comparison of Traditional and Block Periodized Strength Training Programs in Trained Athletes. J. Strength Cond. Res. 28, 990-997. https://doi.org/10.1519/JSC.0000000000000366

Brandt, R., Bevilacqua, G.G., Coimbra, D.R., Pombo, L.C., Miarka, B., Lane, A.M., 2018. Body weight and mood state modifications in mixed martial arts: an exploratory pilot. J. Strength Cond. Res. 32, 2548-2554. https://doi.org/10.1519/JSC.0000000000002639

Castor-Praga, C., Lopez-Walle, J.M., Sanchez-Lopez, J., 2021. Multilevel Evaluation of Rapid Weight Loss in Wrestling and Taekwondo. Front. Sociol. 6, 637671. https://doi.org/10.3389/fsoc.2021.637671

Dipla, K., Kraemer, R.R., Constantini, N.W., Hackney, A.C., 2020. Relative energy deficiency in sports (RED-S): elucidation of endocrine changes affecting the health of males and females. Hormones. https://doi.org/10.1007/s42000-020-00214-w

Drid, P., Casals, C., Mekic, A., Radjo, I., Stojanovic, M., Ostojic, S.M., 2015. Fitness and Anthropometric Profiles of International vs. National Judo Medalists in Half-Heavyweight Category. J. Strength Cond. Res. 29, 2115-2121. https://doi.org/10.1519/JSC.0000000000000861

Evans, E.M., Rowe, D.A., Misic, M.M., Prior, B.M., Arngrímsson, S.Á., 2005. Skinfold Prediction Equation for Athletes Developed Using a Four-Component Model. Med. Sci. Sports Exerc. 37, 2006-2011. https://doi.org/10.1249/01.mss.0000176682.54071.5c

Giovanelli, L., Biganzoli, G., Spataro, A., Malacarne, M., Bernardelli, G., Spada, R., Pagani, M., Biganzoli, E., Lucini, D., 2023. Body composition assessment in a large cohort of Olympic athletes with different training loads: possible reference values for fat mass and fat-free mass domains. Acta Diabetol. 61, 361-372. https://doi.org/10.1007/s00592-023-02203-y

Isak - The International Society for the Advancement of Kinanthropometry. [WWW Document], n.d. Retrieved from [Accessed 2024, July 29]: https://www.isak.global/Home/Index

Logue, D.M., Madigan, S.M., Melin, A., Delahunt, E., Heinen, M., Donnell, S.-J.M., Corish, C.A., 2020. Low Energy Availability in Athletes 2020: An Updated Narrative Review of Prevalence, Risk, Within-Day Energy Balance, Knowledge, and Impact on Sports Performance. Nutrients 12, 835. https://doi.org/10.3390/nu12030835

Maksimovic, N., Cvjeticanin, O., Rossi, C., Manojlovic, M., Roklicer, R., Bianco, A., Carraro, A., Sekulic, D., Milovancev, A., Trivic, T., Drid, P., 2024. Prevalence of metabolic syndrome and its association with rapid weight loss among former elite combat sports athletes in Serbia. BMC Public Health 24, 245. https://doi.org/10.1186/s12889-024-17763-z

Martín-Rodríguez, A., Belinchón-deMiguel, P., Rubio-Zarapuz, A., Tornero-Aguilera, J.F., Martínez-Guardado, I., Villanueva-Tobaldo, C.V., Clemente-Suárez, V.J., 2024. Advances in Understanding the Interplay between Dietary Practices, Body Composition, and Sports Performance in Athletes. Nutrients 16, 571. https://doi.org/10.3390/nu16040571

Mcgarry, T., Schutz, R.W., 1997. Efficacy of traditional sport tournament structures. J. Oper. Res. Soc. 48, 65-74. https://doi.org/10.1057/palgrave.jors.2600330

Podrihalo, O.O., Podrigalo, L.V., Bezkorovainyi, D.O., Halashko, O.I., Nikulin, I.N., Kadutskaya, L.A., Jagiello, M., 2020. The analysis of handgrip strength and somatotype features in arm wrestling athletes with different skill levels. Phys. Educ. Stud. 24, 120-126. https://doi.org/10.15561/20755279.2020.0208

Ranisavljev, M., Kuzmanovic, J., Todorovic, N., Roklicer, R., Dokmanac, M., Baic, M., Stajer, V., Ostojic, S.M., Drid, P., 2022. Rapid Weight Loss Practices in Grapplers Competing in Combat Sports. Front. Physiol. 13. https://doi.org/10.3389/fphys.2022.842992

Ruiz-Castellano, C., Espinar, S., Contreras, C., Mata, F., Aragon, A.A., Martínez-Sanz, J.M., 2021. Achieving an Optimal Fat Loss Phase in Resistance-Trained Athletes: A Narrative Review. Nutrients 13, 3255. https://doi.org/10.3390/nu13093255

Rules WAF, 2024. Retrieved from [Accessed 2024, July 29]: http://www.waf-armwrestling.com/

Sengeis, M., Müller, W., Störchle, P., Führhapter-Rieger, A., 2019. Body weight and subcutaneous fat patterning in elite judokas. Scand. J. Med. Sci. Sports 29, 1774-1788. https://doi.org/10.1111/sms.13508

Silva, A.M., 2019. Structural and functional body components in athletic health and performance phenotypes. Eur. J. Clin. Nutr. 73, 215-224. https://doi.org/10.1038/s41430-018-0321-9

Voronkov, A.V., Nikulin, I.N., Sobyanin, F.I., 2014. On the improvement of the control force readiness of students engaged arm sport. Phys. Educ. Stud. 18, 3-7. https://doi.org/10.6084/m9.figshare.917169

Yonca, S.S., Engin, Ç.B., Serdar, Y.A., Mustafa, K., Yüksel, S., 2017. The Effects of Unit Exercises on the Hand Grip Strength of Arm Wrestlers. https://doi.org/10.11114/jets.v5i6.2425

