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Dear Readers

It is our pleasure to present the new issue of the Montenegrin Journal of Sports Science and Medicine. This issue brings together a diverse collection of original research papers that reflect the broad and multidisciplinary nature of contemporary sport science.

The studies included in this issue address a wide range of relevant topics. They explore the relationship between muscle and tendon characteristics and sprint performance, the development of scientific research in handball, physiological responses to resistance training, and the validity of portable technologies used for performance assessment. Other contributions examine training load and sprint performance in football, the role of the school environment in the development of physical fitness, and the physical demands placed on referees in cerebral palsy football. The issue also highlights important educational and social aspects of sport through research on team teaching in physical education and legal anti-doping literacy. Finally, the physical factors associated with sprint performance in female football players are examined across different competitive levels. Together, these papers demonstrate the variety of questions currently being addressed in sport science, from laboratory measurements and athletic performance to education, regulation, and practical applications in sport.

We would like to express our sincere gratitude to all authors who selected our journal as a platform for presenting their research. Their commitment and high-quality work are essential to the continued development of the journal. We are equally grateful to our reviewers, whose time, expertise, and thoughtful comments play an important role in maintaining the scientific quality of every paper we publish.

We hope that our readers will find this issue informative, useful, and inspiring, and that the published studies will encourage further research and discussion within the international sport science community.

We would also like to take this opportunity to invite our readers, authors, reviewers, and colleagues to join us at the upcoming Montenegrin Sports Academy Conference which will be held in Budva, Montenegro, 8-11 April 2027. The conference is an excellent opportunity to present new research, exchange ideas, meet colleagues from different countries, and strengthen cooperation within the international sport science community. We would be delighted to welcome you to Montenegro and to share another inspiring scientific gathering together. More information about the conference is available at: https://csakademija.me/conference/

Editors-in-Chief
Professor Duško Bjelica
Professor Damir Sekulić

Montenegrin Journal of Sports Science and Medicine Expands Publication Capacity from 2027

We are pleased to announce an important development in the continued growth of the *Montenegrin Journal of Sports Science and Medicine (MJSSM)*.

Beginning in 2027, MJSSM will increase the number of articles published in each issue from 10 to 15. As the journal publishes two issues annually, this will increase our annual publication capacity from 20 to 30 articles.
This decision reflects the growing interest of researchers in publishing their work in MJSSM, as well as the increasing number of high-quality manuscripts submitted to the journal. The expansion will allow us to make a greater number of valuable studies available to our readers and the wider scientific community.

Our commitment to scientific quality, however, remains unchanged. All manuscripts will continue to undergo the journal's established editorial evaluation and peer-review procedures, with the same standards of scientific relevance, methodological quality, originality, and research integrity.

We see this development as another important step in the evolution of MJSSM and as a reflection of the trust placed in the journal by authors, reviewers, readers, and the international scientific community.

We sincerely thank our authors, reviewers, and Editorial Board members for their continued contribution to the journal's development and look forward to this new stage in 2027.

Editorial Team
Montenegrin Journal of Sports Science and Medicine

ORIGINAL SCIENTIFIC PAPER

Myotonometric Assessment of Achilles Tendon and Gastrocnemius Stiffness in Recreationally Active Young Adults: Reliability, Impact of Sex, and Links to Linear Sprint

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Abstract

This study examined the relationship between passive Achilles tendon (AT) and gastrocnemius (GAS) stiffness, measured by myotonometry, and 40-m sprint performance across acceleration and maximal velocity phases, while accounting for sex differences. Twenty-one student athletes (10 males, 11 females) underwent bilateral passive stiffness assessments of the AT and GAS using MyotonPRO, followed by 40-m sprint testing with 10, 20, 30, and 40 m splits. Reliability was assessed using the intraclass correlation coefficient (ICC) and coefficient of variation (CV). Sex differences were examined with independent t-tests. Partial correlations controlling for sex were used to assess associations between passive stiffness and sprint performance. Passive stiffness and sprint variables demonstrated excellent within-session reliability (ICC = 0.95–0.99; CV < 5%). Males showed significantly greater passive GAS stiffness bilaterally (p = 0.006–0.049) and faster sprint times at 30 m (p = 0.040) and 40 m (p < 0.001), while passive AT stiffness did not differ significantly between sexes. Partial correlations indicated that greater passive AT stiffness in both legs was associated with faster sprint times at 10 m (r = -0.46 and -0.58, p = 0.008 and 0.043) and 20 m (r = -0.49 and -0.58, p = 0.008 and 0.029). No associations were observed at 30 m or 40 m, nor between passive GAS stiffness and sprint performance. Myotonometry provides reliable measures of AT and GAS stiffness. Greater passive AT stiffness is associated with faster acceleration sprint performance independent of sex.

Keywords: *Achilles tendon; gastrocnemius; stiffness; myotonometry; sprint performance; sex differences*

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ACHILLES STIFFNESS AND SPRINT PERFORMANCE
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Introduction

The plantar flexor muscle-tendon unit (MTU), combining the triceps surae muscles and Achilles tendon (AT), plays a central role in ensuring efficient force transmission and body propulsion during all phases of linear sprinting. Its contribution begins at the start of the sprint, with the highest muscle

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Conflict of interest: None declared.

activity occurring in the final phase of the push-off (Mero & Komi, 1990), during which plantar flexor MTU transfers power generated in the proximal joints to the ground and simultaneously generates force. A high force-producing capacity of the plantar flexor muscles is therefore particularly desirable when the goal is a fast start (Crotty et al., 2024). After the initiation of the sprint, the acceleration phase aims to increase the forward momentum of the body's centre of mass. Previous research has shown that a significant portion of this momentum is provided by the plantar flexor MTU (Macchi et al., 2025), with the gastrocnemius muscle (GAS) serving as the primary propulsor (Pandy et al., 2021). Due to changing biomechanical demands, the role of the plantar flexor MTU shifts during the acceleration phase and takes on a very specific role during the maximum velocity phase (Willer et al., 2024). In this phase, shorter ground contact times and higher vertical ground reaction forces require the plantar flexor MTU to act more as an energy absorber and transmitter (Crotty et al., 2024). Its primary role is to efficiently absorb energy during the initial stance phase (eccentric or decelerating) and then transfer it during the later stance phase (concentric or propulsive) to maintain maximum sprinting velocity for as long as possible (Willer et al., 2024).

Several plantar flexor MTU characteristics have been identified as factors contributing to linear sprint performance, including greater specific strength, a higher proportion of fast-twitch fibre types, a smaller pennation angle, longer fascicles, and optimal muscle volume (Crotty et al., 2024). In addition, MTU stiffness, defined as "the ability of a muscle or tendon to resist deformation in response to the application of force" (Latash & Zatsiorsky, 1993), has attracted particular attention in recent decades. Increased stiffness of the AT and triceps surae is desirable for explosive contractions such as the sprint start and allows for more efficient use of the stretch-shortening cycle by improving force transmission and minimising energy loss, thus enhancing sprint performance (Bojsen-Møller et al., 2005; Mero et al., 1992). This is supported by studies showing that sprinters with stiffer GAS perform better in the 100 m sprint [9] and have higher AT stiffness than endurance runners (Arampatzis et al., 2007). Therefore, plantar flexor MTU stiffness appears to be an important factor in sports where sprinting speed is of particular importance.

Despite its relevance to speed, stiffness is rarely measured in practice as standard procedures are based on expensive and time-consuming ultrasound assessments (Pinel et al., 2021; Yamazaki et al., 2022). In recent years, myotonometry has become established as a practical alternative. This method assesses palpable muscle and tendon stiffness by recording the magnitude of radial tissue displacement in response to a perpendicularly applied mechanical impulse from the device (i.e., the myotonometer) (McGowen et al., 2023). Compared to conventional methods, myotonometry is faster and more accessible. Moreover, several studies have confirmed its reliability and validity for the assessment of AT and GAS stiffness (Pruyn et al., 2016; Schneebeli et al., 2020; Taş & Salkın, 2019; Volesky et al., 2025). However, there is limited evidence on the relationship between plantar flexor stiffness measured by myotonometry and linear sprint performance, which limits its application in an athletic performance context.

To address this gap, the present study investigated the relationship between AT and GAS stiffness, measured by myotonometry, and 40 m sprint performance. Given previous reports of sex-related differences in triceps surae and tendon properties (Taş & Salkın, 2019)[15], and the fact that sprint performance also differs between men and women, we additionally investigated sex differences and whether these relationships persist when controlling for sex. We hypothesised that males would demonstrate greater AT and GAS stiffness and faster sprint performance compared with females, and that greater AT and GAS stiffness would be associated with faster sprint performance across all phases.

Materials and methods

Design and Participants

A cross-sectional study with two visits was conducted. At the first visit the stiffness of the AT, and the medial and lateral part of the GAS (GAS_M and GAS_L, respectively) was assessed. The second visit included 40-m sprints and the assessment of 10-, 20-, 30- and 40-metre split times.

Ten male (23.3 ± 1.3 years; 180.9 ± 6.9 cm body height, and 82.9 ± 3.5 kg body mass) and 11 female (23.5 ± 1.6 years; 166.5 ± 5.4 cm body height, and 61.1 ± 6.5 kg body mass) student athletes volunteered to participate in the study (21 participants in total). They were classified as Tier 2 individuals, who train to compete in different sports at local-level approximately 3 times per week (McKay et al., 2022). Only participants that were free of acute or chronic lower limb injuries, musculoskeletal disorders, or other health limitations in the previous six months were included in the procedures. Participants were instructed to refrain from strenuous physical activity for at least 24 h prior to each testing session. Participants were informed about the procedures and gave informed consent to participate in the study. The methods and interventions were reviewed and approved by the University of Primorska's Commission for Ethics in Human Subjects Research (approval number: 4264-19-6/23).

Muscle and Tendon Stiffness Assessment

Stiffness was assessed by the same investigator using a non-invasive handheld myotonometer (MyotonPRO, Myoton AS, Estonia), which quantifies the mechanical properties of palpable soft tissue. The MyotonPRO delivers a short mechanical impulse to the tissue, which causes a natural, damped oscillation. The resistance of the tissue to this deformation, known as stiffness, is calculated from the resulting acceleration curve. Specifically, the tissue stiffness (expressed in $N{\cdot}m^{-1}$) is calculated by multiplying the maximum acceleration of the oscillation waveform by the mass of the probe and dividing by the maximum displacement of the tissue. Higher values therefore indicate a greater stiffness of the tissue (Schneider et al., 2015).

The AS and GAS stiffness of the left and right leg was assessed under passive conditions, with the order of leg testing randomized between participants. Throughout the manuscript, stiffness assessed under these conditions is referred to as "passive stiffness". Participants were barefoot and lay prone on a table. The knees were extended, the ankles relaxed, and hanging slightly over the edge to maintain a neutral foot position. They were instructed to remain completely relaxed to minimise active muscle contraction. Measurements were performed on GAS_M, GAS_L and AT (Figure 1). GAS passive stiffness was measured at the centre of the muscle belly (i.e., one third of the distance between the me-

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dial femoral condyle and the lateral malleolus and between the lateral femoral condyle and the medial malleolus, respectively). AT passive stiffness was measured 2 cm proximal to the superior aspect of the calcaneus (Taş & Salkın, 2019). The MyotonPRO probe was placed perpendicular to the tissue surface, and each site was measured with five mechanical impulses. If the variation between five pulses exceeded 8%, the measurement was repeated. Each site and leg were measured three times and the mean value was used for subsequent analysis.

Linear Sprint Performance Testing

To assess sprint performance, three linear 40-m sprints were performed in an athletics stadium under dry windless environmental conditions. Prior to the test, a standardised warm-up was performed, including 10 minutes of jogging and dynamic stretching, 10 repetitions of squats, push-ups, crunches, and vertical jumps, followed by two submaximal 40-m sprint trials. Three maximal sprint attempts were then performed with at least three-minute breaks in between. The distances of 10 m, 20 m, 30 m, and 40 m were precisely determined using a GWM 32 measuring tape (Bosch, Gerlingen, Germany) and marked with cones. A pair of single-beam laser timing gates (Brower, TCi-System B13283, Utah, USA) were positioned at the start and at each marked distance to ensure accurate timing. The first set of timing gates was placed 0.5 metres in front of the start line to prevent premature triggering of the start (Haugen & Buchheit, 2016). The start line was marked with the tape to standardise the start position in the two-point stance. The split times at distances 0–10 m (T_{10}), 0–20 m (T_{20}), 0–30 m (T_{30}), and 0–40 m (T_{40}) of the fastest 40 m sprint were recorded. Analysing the sprint performance over the 40 m distance made it possible to evaluate the phases of early acceleration (T_{10}), late acceleration (T_{20}), and maximum velocity (T_{30} and T_{40}) of the linear sprint.

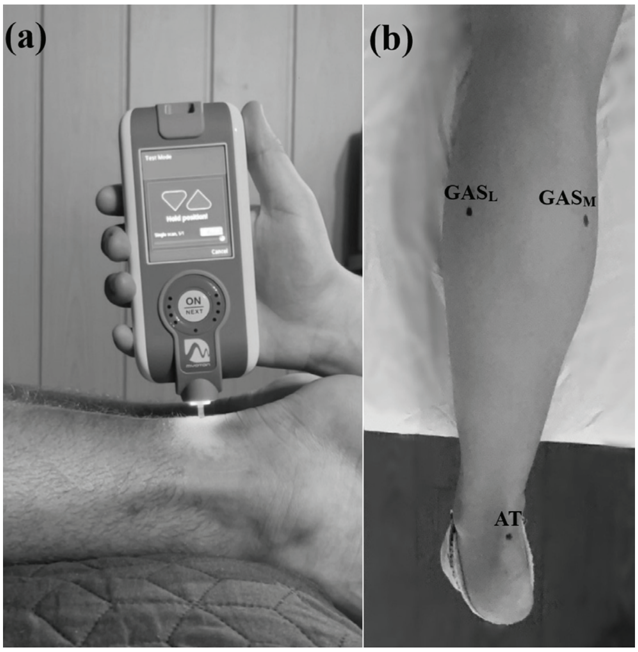

Figure 1. Myotonometry assessment (a) and anatomical measurement sites (b) for passive stiffness of the gastrocnemius muscle (GAS_L, GAS_M) and Achilles tendon (AT).

Statistical Analysis

The statistical analysis was performed with IBM SPSS Statistics (version 26). The descriptive data of the outcome variables are presented as mean ± standard deviation (SD). To assess the relative and absolute reliability of the outcome variables, the intraclass correlation coefficient (ICC; model 2.1) and the coefficient of variation (CV; as SD divided by mean and multiplied by 100) were calculated with 95% confidence intervals. The Shapiro-Wilk test was used to assess the normal distribution of the variables, whereas linearity and homoscedasticity were assessed via scatterplots. Differences between men and women were analysed using an independent samples t-test, with Levene's test used to check the assumption of homogeneity of variances between the sexes. To control for the influence of sex on the relationships between GAS_M, GAS_L, AT passive stiffness, and linear sprint split times, partial correlations were calculated. The correlations were interpreted as negligible ($r < 0.1$), weak ($r = 0.1–0.4$), moderate ($r = 0.4–0.7$), strong ($r = 0.7–0.9$) and very strong ($r = 0.9$) according to Akoglu (2018). All statistical tests were two-tailed, and statistical significance was set at $p < 0.05$.

Results

Table 1 presents the descriptive statistics and within-session reliability for passive stiffness and linear sprint performance variables. The ICC and CV confirmed excellent relative (95% CI lower bound ≥ 0.89) and absolute reliability (95% CI upper bound ≤ 5.49%) across all outcome variables.

Sex comparisons are presented in Table 2. Men demonstrated significantly higher passive stiffness of the GAS_L and GAS_M on both legs ($p = 0.006–0.049$). No significant differences were observed in AT passive stiffness, although values tended to be higher in men ($p = 0.106–0.211$). In sprint performance, men were significantly faster in the maximum velocity phase (T_{30}: $p = 0.040$; T_{40}: $p < 0.001$), whereas differences in early and late acceleration did not reach statistical significance (T_{10}: $p = 0.099$; T_{20}: $p = 0.085$).

Table 1. Descriptive statistics of each repetition and the results of relative and absolute within-session reliability for the outcome variables on total sample.

Variable	Rep 1	Rep 2	Rep 3	ICC (95 CI)	CV in % (95 CI)
Left GAS_L stiffness ($N \cdot m^{-1}$)	300.7 ± 77.2	304.9 ± 78.1	304 ± 75.3	0.99 (0.99, 1.00)	2.19 (1.76, 2.92)
Left GAS_M stiffness ($N \cdot m^{-1}$)	285.4 ± 69.9	285.1 ± 70.5	284.4 ± 70.2	0.99 (0.99, 1.00)	2.11 (1.69, 2.81)
Left AT stiffness ($N \cdot m^{-1}$)	949 ± 145.7	967.4 ± 167.2	967.3 ± 167.6	0.95 (0.89, 0.98)	4.12 (3.31, 5.49)
Right GAS_L stiffness ($N \cdot m^{-1}$)	307 ± 90.6	310.1 ± 88.8	310.0 ± 87.0	0.99 (0.98, 1.00)	2.91 (2.34, 3.88)
Right GAS_M stiffness ($N \cdot m^{-1}$)	290 ± 74.2	290.3 ± 77.4	290.8 ± 80.5	0.99 (0.99, 1.00)	2.26 (1.82, 3.02)
Right AT stiffness ($N \cdot m^{-1}$)	915.9 ± 177.5	917.1 ± 178	918.4 ± 183.6	0.98 (0.96, 0.99)	2.82 (2.27, 3.76)
T_{10} (s)	2.13 ± 0.3	2.14 ± 0.3	2.15 ± 0.3	0.97 (0.94, 0.99)	2.52 (2.03, 3.37)
T_{20} (s)	3.43 ± 0.23	3.42 ± 0.23	3.45 ± 0.25	0.95 (0.89, 0.98)	1.70 (1.37, 2.27)
T_{30} (s)	4.74 ± 0.34	4.76 ± 0.35	4.76 ± 0.35	0.98 (0.96, 0.99)	1.00 (0.80, 1.33)
T_{40} (s)	6.06 ± 0.44	6.04 ± 0.45	6.05 ± 0.45	0.99 (0.97, 0.99)	0.93 (0.74, 1.23)

Note. GASL: lateral gastrocnemius; GASM: medial gastrocnemius; AT: Achilles tendon; T_{10}: 0 to 10 m split time; T_{20}: 0 to 20 m split time; T_{30}: 0 to 30 m split time; T_{40}: 0 to 40 m split time; N: Newtons; m: meters; s: seconds; ICC: intraclass correlation coefficient; 95CI = 95 % confidence interval; CV = coefficient of variation.

Table 2. Results of a t-test comparing outcomes between male and female athletes.

Variable	Female (n = 11)	Male (n = 10)	t-test	
			t	p
Left GAS_L stiffness ($N \cdot m^{-1}$)	262.5 ± 44.2	347.9 ± 81.5	-3.02	0.007
Left GAS_M stiffness ($N \cdot m^{-1}$)	247.5 ± 42.5	326.2 ± 72.8	-3.07	0.006
Left AT stiffness ($N \cdot m^{-1}$)	919.6 ± 131.2	1007 ± 176.4	-1.30	0.211
Right GAS_L stiffness ($N \cdot m^{-1}$)	268.4 ± 62.4	353.8 ± 94.1	-2.47	0.023
Right GAS_M stiffness ($N \cdot m^{-1}$)	259.1 ± 60.1	324.7 ± 82.0	-2.11	0.049
Right AT stiffness ($N \cdot m^{-1}$)	856.9 ± 99.4	983.4 ± 224.9	-1.70	0.106
T_{10} (s)	2.24 ± 0.33	2.03 ± 0.21	1.74	0.099
T_{20} (s)	3.51 ± 0.18	3.34 ± 0.25	1.81	0.085
T_{30} (s)	4.90 ± 0.31	4.59 ± 0.32	2.21	0.040
T_{40} (s)	6.35 ± 0.35	5.72 ± 0.26	4.57	<0.001

Note. p-values reported in the table are not adjusted for multiple testing across variables. GASL: lateral gastrocnemius; GASM: medial gastrocnemius; AT: Achilles tendon; T_{10}: 0 to 10 m split time; T_{20}: 0 to 20 m split time; T_{30}: 0 to 30 m split time; T_{40}: 0 to 40 m split time; N: Newtons; m: meters; s: seconds.

Partial correlations between passive stiffness and linear sprint performance are shown in Table 3. Significant moderate negative correlations were found between left AT passive stiffness and both T_{10} ($r = -0.58$; $p = 0.008$), and T_{20} ($r = -0.58$; $p = 0.008$). Similarly, significant moderate negative correlations were observed between right AT passive stiffness and T_{10} ($r = -0.46$; $p = 0.043$) and T_{20} ($r = -0.49$; $p = 0.029$). Correlations between AT passive stiffness and sprint performance during the maximum velocity phase were weaker and not significant. Moreover, no significant correlations were observed between GAS passive stiffness and sprint performance.

Table 3. Correlation between stiffness and linear sprint performance variables.

	Left leg			Right leg		
	GAS_L	GAS_M	AT	GAS_L	GAS_M	AT
T_{10}	-0.12 (-0.58, 0.25)	-0.11 (-0.51, 0.34)	-0.58 (-0.81, -0.19)**	0.06 (-0.39, 0.48)	-0.12 (-0.52, 0.33)	-0.46 (-0.74, -0.03)*
T_{20}	-0.09 (-0.50, 0.35)	0.03 (-0.41, 0.45)	-0.58 (-0.81, -0.19)**	0.08 (-0.36, 0.50)	0.01 (-0.42, 0.44)	-0.49 (-0.76, -0.07)*
T_{30}	-0.10 (-0.51, 0.35)	-0.02 (-0.45, 0.42)	-0.37 (-0.69, 0.08)	-0.01 (-0.44, 0.42)	-0.05 (-0.47, 0.39)	-0.40 (-0.71, 0.04)
T_{40}	0.08 (-0.37, 0.49)	0.17 (-0.29, 0.56)	-0.25 (-0.61, 0.21)	0.18 (-0.27, 0.57)	0.14 (-0.31, 0.54)	-0.13 (-0.53, 0.32)

Note. Values are partial correlation coefficients with 95 % confidence intervals controlling for sex. GAS_L: lateral gastrocnemius; GAS_M: medial gastrocnemius; AT: Achilles tendon; T_{10}: 0 to 10 m split time; T_{20}: 0 to 20 m split time; T_{30}: 0 to 30 m split time; T_{40}: 0 to 40 m split time. * $p < 0.05$, ** $p < 0.01$

Discussion

The present study investigated the reliability of myotonometry to assess plantar flexor MTU passive stiffness, sex differences in GAS and AT passive stiffness, and their relationship with linear sprint performance. The main findings were that (i) myotonometry showed excellent within-session reliability for both GAS and AT passive stiffness, (ii) males had greater GAS passive stiffness, while no sex differences were observed for AT passive stiffness, and (iii) after controlling for sex, greater AT passive stiffness was significant-

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ly correlated with faster performance in the early and late acceleration phases (10 and 20 m), but not in the maximal speed phase of the sprint.

Our results showed excellent relative and absolute reliability (ICC = 0.95–0.99; CV < 5%), confirming previous studies that reported excellent within-session reliability of myotonometry to quantify passive stiffness of left and right leg AT and GAS (McGowen et al., 2023). This emphasises the applicability of the method in sports practice as a viable alternative to ultrasound-based examinations, which are often costly and time-consuming.

Passive stiffness in our sample was similar to previously reported values, with GAS for females and males of ~240 to 270 and ~320 to 360 $N{\cdot}m^{-1}$, respectively, and AT of ~850 to 900 and ~850 to 1000 $N{\cdot}m^{-1}$, respectively (Pruyn et al., 2016; Schneebeli et al., 2020; Volesky et al., 2025). We found that males exhibited significantly higher GAS_L and GAS_M passive stiffness, whereas AT passive stiffness did not differ significantly between sexes. This is in partial agreement with previous work by Taş and Salkin (Taş & Salkın, 2019), who reported sex-specific differences in GAS and also AT passive stiffness. The lack of significant differences in AT stiffness in our sample may be explained by the relatively small sample size or the heterogeneous athletic background of the participants. Nonetheless, the significant differences in GAS passive stiffness and sprint performance emphasise the importance of considering sex as a confounding factor when examining stiffness using myotonometry. Furthermore, as males showed higher AT passive stiffness and also faster sprint performance, it could be hypothesised that the specific mechanical properties of the plantar flexor MTU are partly responsible for the already known differences in linear sprint performance between sexes (Galantine et al., 2023).

Taking sex into account, AT but not GAS passive stiffness, was associated with T_{10} and T_{20}. In particular, the early and late sprint acceleration phases were associated with higher AT passive stiffness, which is consistent with the biomechanical role of the AT as a key structure for efficient force transmission and energy storage-return during explosive push-off actions (Monte & Zamparoi, 2019). During the steps of the acceleration phase, a change in length of the plantar flexor MTU is primarily due to the changes in length of the soleus and GAS muscle fascicles (Lai et al., 2016), which may require a stiffer AT to enable efficient force transmission within the MTU. However, at higher sprint velocities, the change in muscle fascicle lengths of the plantar flexors is minimal (Lai et al., 2016), forcing the muscles to contract under lower velocity, which is biomechanically more optimal for generating high vertical ground reaction forces (Farris & Sawicki, 2011; Weyand et al., 2000). Thus, most of the change in MTU length of the plantar flexors is related to the change in AT, such that it must act as a more compliant spring, to utilise elastic strain energy (Kubo et al., 2011; Lichtwark & Wilson, 2007). The specificity of the associations with the acceleration phase in our study emphasises the functional importance of AT stiffness for sprint acceleration and not for maximal sprint velocity. However, it should be emphasised that this interpretation is speculative and cannot be directly inferred from the present cross-sectional results, therefore, further studies are needed to clarify whether a stiffer or more compliant AT is more desirable for sprint performance across distinct sprint phases.

From a practical perspective, this study provides several important applications. Firstly, myotonometry provides a reliable field-ready tool for monitoring tendon and muscle passive stiffness in athletes. For this purpose, it could be used to assess the mechanical properties of the plantar flexor MTU in the field, especially in sports where sprint performance plays a crucial role. Secondly, as higher AT passive stiffness has been associated with better acceleration performance, practitioners might consider utilising training modalities known to improve it, such as plyometric training (Ramírez et al., 2022), eccentric loading, or heavy resistance (Geremia et al., 2018) training. Given the observed sex differences in GAS passive stiffness and sprint performance, practitioners and researchers should consider sex when assessing athletes.

The results of this study should be interpreted with several limitations in mind. Firstly, the relatively small and heterogeneous sample of Tier 2 student athletes (McKay et al., 2022) limits the generalisability of the results to elite athletes and those active in sports disciplines with a high sprint density. Secondly, the cross-sectional design prevents causal conclusions from the results of our study. Third, only passive stiffness was measured, whereas stiffness during active muscle contractions could provide more biologically valid insights. To address these gaps, we suggest that future studies examine larger, more homogeneous samples, include elite-level athletes, and use a longitudinal design to determine whether exercise-induced changes in AT stiffness measured by myotonometry directly improve sprint performance.

Conclusion

Myotonometry is a reliable method for assessing AT and GAS passive stiffness in Tier 2 athletes (McKay et al., 2022). Regardless of sex, higher AT passive stiffness is associated with faster 10 and 20 m sprint performance, emphasising its functional importance for sprint acceleration. These findings support the use of AT passive stiffness in monitoring athletes and emphasise the potential value of stiffness-focused training interventions for sprint acceleration development.

Conflicts of Interest

The authors declare no conflict of interest.

References

Akoglu, H. (2018). Turkish Journal of Emergency Medicine User ' s guide to correlation coe ffi cients. *Turkish Journal of Emergency Medicine*, *18*, 91–93. https://doi.org/10.1016/j.tjem.2018.08.001

Arampatzis, A., Karamanidis, K., Morey-Klapsing, G., De Monte, G., & Stafilidis, S. (2007). Mechanical properties of the triceps surae tendon and aponeurosis in relation to intensity of sport activity. *Journal of Biomechanics*, *40*(9), 1946–1952. https://doi.org/10.1016/j.jbiomech.2006.09.005

Bojsen-Møller, J., Magnusson, S. P., Rasmussen, L. R., Kjaer, M., & Aagaard, P. (2005). Muscle performance during maximal isometric and dynamic contractions is influenced by the stiffness of the tendinous structures. *Journal of Applied Physiology*, *99*(3), 986–994. https://doi.org/10.1152/japplphysiol.01305.2004

Crotty, E. D., Furlong, L. A. M., & Harrison, A. J. (2024). Ankle and plantar flexor muscle–tendon unit function in sprinters: A narrative review. *Sports Medicine*, *54*(3), 585–606. https://doi.org/10.1007/s40279-023-01967-1

Farris, D. J., & Sawicki, G. S. (2011). Human medial gastrocnemius force–velocity behavior shifts with locomotion speed and gait. *Proceedings of the National Academy of Sciences of the United States of America*, *109*(3), 977–982. https://doi.org/10.1073/pnas.1107972109

Galantine, P., Sudlow, A., Peyrot, N., Vercruyssen, F., Bélard, C., Dalleau, G., & Duché, P. (2023). Force–velocity profile in sprinting: sex effect. *European Journal of Applied Physiology*, *123*(4), 911–921. https://doi.org/10.1007/s00421-022-05121-z

Geremia, J. M., Manfredini, B., Maarten, B., Bobbert, F., Rico, R., Juner, F., Marco, L., & Vaz, A. (2018). Effects of high loading by eccentric triceps surae training on Achilles tendon properties in humans. *European Journal of Applied Physiology*, *118*(8), 1725–1736. https://doi.org/10.1007/s00421-018-3904-1

Haugen, T., & Buchheit, M. (2016). Sprint Running Performance Monitoring: Methodological and Practical Considerations. *Sports Medicine*, *46*(5), 641–656. https://doi.org/10.1007/s40279-015-0446-0

Kubo, K., Ikebukuro, T., Yata, H., Tomita, M., & Okada, M. (2011). Morphological and mechanical properties of muscle and tendon in highly trained sprinters. *Journal of Applied Biomechanics*, *27*(4), 336–344. https://doi.org/10.1123/jab.27.4.336

Lai, A., Schache, A. G., Brown, N. A. T., & Pandy, M. G. (2016). Human ankle plantar flexor muscle-tendon mechanics and energetics during maximum acceleration sprinting. *Journal of the Royal Society Interface*, *13*(121). https://doi.org/10.1098/rsif.2016.0391

Latash, M. L., & Zatsiorsky, V. M. (1993). Joint stiffness: Myth or reality? *Human Movement Science*, *12*(6), 653–692. https://doi.org/10.1016/0167-9457(93)90010-M

Lichtwark, G. A., & Wilson, A. M. (2007). Is Achilles tendon compliance optimised for maximum muscle efficiency during locomotion? *Journal of Biomechanics*, *40*(8), 1768–1775. https://doi.org/10.1016/j.jbiomech.2006.07.025

Macchi, R., Hegyi, A., Giroux, C., Rabita, G., Nordez, A., Hollville, E., Couturier, A., Fornasier-Santos, C., Slawinski, J., Morin, J.-B., Lacourpaille, L., & Guilhem, G. (2025). Effects of resistance and speed on electromyographic activity of thigh and gluteal muscles in elite athletes throughout resisted sprint running. *Medicine & Science in Sports & Exercise*, *Febureary*. https://doi.org/10.1249/MSS.0000000000003689

McGowen, J. M., Hoppes, C. W., Forsse, J. S., Albin, S. R., Abt, J., & Koppenhaver, S. L. (2023). The utility of myotonometry in musculoskeletal rehabilitation and human performance programming. *Journal of Athletic Training*, *58*(4), 305–318. https://doi.org/10.4085/616.21

McKay, A. K. A., Stellingwerff, T., Smith, E. S., Martin, D. T., Mujika, I., Goosey-Tolfrey, V. L., Sheppard, J., & Burke, L. M. (2022). Defining training and performance caliber: A participant classification framework. *International Journal of Sports Physiology and Performance*, *17*(2), 317–331. https://doi.org/10.1123/ijspp.2021-0451

Mero, A., & Komi, P. V. (1990). Reaction time and electromyographic activity during a sprint start. *European Journal of Applied Physiology and Occupational Physiology*, *61*(1–2), 73–80. https://doi.org/10.1007/BF00236697

Mero, A., Komi, P. V., & Gregor, R. J. (1992). Biomechanics of sprint running: A review. *Sports Medicine*, *13*(6), 376–392. https://doi.org/10.2165/00007256-199213060-00002

Monte, A., & Zamparoi, P. (2019). Correlations between muscle-tendon parameters and acceleration ability in 20m sprints. *PLoS ONE*, *14*(3), 1–13. https://doi.org/10.1371/journal.pone.0213347

Pandy, M. G., Lai, A. K. M., Schache, A. G., & Lin, Y. C. (2021). How muscles maximize performance in accelerated sprinting. *Scandinavian Journal of Medicine and Science in Sports*, *31*(10), 1882–1896. https://doi.org/10.1111/sms.14021

Pinel, S., Kelp, N. Y., Bugeja, J. M., Bolsterlee, B., Hug, F., & Dick, T. J. M. (2021). Quantity versus quality: Age-related differences in muscle volume, intramuscular fat, and mechanical properties in the triceps surae. *Experimental Gerontology*, *156*, 1–11. https://doi.org/10.1016/j.exger.2021.111594

Pruyn, E. C., Watsford, M. L., & Murphy, A. J. (2016). Validity and reliability of three methods of stiffness assessment. *Journal of Sport and Health Science*, *5*(4), 476–483. https://doi.org/10.1016/j.jshs.2015.12.001

Ramírez, M., Sánchez, A. B., García, P. E., Jiménez, F., & Vicén, J. A. (2022). Effects of plyometric training on lower body muscle architecture, tendon structure, stiffness and physical performanc : A systematic review and meta-analysis. *Sports Medicine - Open*, *8*(40), 1–29. https://doi.org/10.1186/s40798-022-00431-0

Schneebeli, A., Falla, D., Clijsen, R., & Barbero, M. (2020). Myotonometry for the evaluation of Achilles tendon mechanical properties: A reliability and construct validity study. *BMJ Open Sport and Exercise Medicine*, *6*(e000726), 1–7. https://doi.org/10.1136/bmjsem-2019-000726

Schneider, S., Peipsi, A., Stokes, M., Knicker, A., & Abeln, V. (2015). Feasibility of monitoring muscle health in microgravity environments using Myoton technology. *Medical and Biological Engineering and Computing*, *53*(1), 57–66. https://doi.org/10.1007/s11517-014-1211-5

Taş, S., & Salkın, Y. (2019). An investigation of the sex-related differences in the stiffness of the Achilles tendon and gastrocnemius muscle: Inter-observer reliability and inter-day repeatability and the effect of ankle joint motion. *Foot*, *41*(July), 44–50. https://doi.org/10.1016/j.foot.2019.09.003

Volesky, K., Novak, J., Janek, M., Katolicky, J., Tufano, J. J., Steffl, M., Courel-Ibáñez, J., & Vetrovsky, T. (2025). Assessing the test-retest reliability of MyotonPRO for measuring achilles tendon stiffness. *Journal of Functional Morphology and Kinesiology*, *10*(1), 1–13. https://doi.org/10.3390/jfmk10010083

Weyand, P. G., Sternlight, D. B., Bellizzi, M. J., & Wright, S. (2000). Faster top running speeds are achieved with greater ground forces not more rapid leg movements. *Journal of Applied Physiology*, *89*(5), 1991–1999. https://doi.org/10.1152/jappl.2000.89.5.1991

Willer, J., Allen, S. J., Burden, R. J., & Folland, J. P. (2024). How humans run faster: The neuromechanical contributions of functional muscle groups to running at different speeds. *Scandinavian Journal of Medicine and Science in Sports*, *34*(8), 1–16. https://doi.org/10.1111/sms.14690

Yamazaki, K., Inoue, K., & Miyamoto, N. (2022). Passive and active muscle elasticity of medial gastrocnemius is related to performance in sprinters. *European Journal of Applied Physiology*, *122*(2), 447–457. https://doi.org/10.1007/s00421-021-04848-5

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ORIGINAL SCIENTIFIC PAPER

From the Court to the Laboratory: The Scientific Evolution of Handball through Global Research and Performance Outcomes

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Abstract

The objectives of this study were: (i) to analyze the evolution in the number of articles published on handball and the citations received; (ii) to determine whether there is a relationship between scientific production and the number of medals won in the Olympic Games and World Championships; (iii) to identify the research topics with the highest publication rates in handball; and finally, (iv) to identify the most cited articles, as well as the journals and countries that published the most on handball. Articles published between January 1, 1980, and December 31, 2024, were retrieved from the Web of Science Core Collection database. For each article, the following information was analyzed: authors; journal (year, volume, issue, pages, DOI); institution and country; funding agency; number of citations; and research topic. Absolute values and percentages were presented for articles and citations per year. Regression analyses calculated the coefficients of determination for the relationships between the number of articles and year, citations and year, and medals and publications by country. A total of 1,412 articles were analyzed. Significant relationships were found between year and number of articles (R^2=0.6625, p<0.001), year and citations (R^2=0.6697, p<0.001), and publications and medals by country (R^2=0.1575, p<0.01). The four countries that published the most articles were Spain, Germany, Norway, and Brazil. The main research topics were physical capacities – measurements, injuries and sports medicine, and physiological responses and adaptation (training programs). Five journals accounted for 19% of all publications.

Keywords: *Sports sciences, performance, physical fitness, physiology, medals*

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Conflict of interest: None declared.

Introduction

Team handball is a dynamic, high-intensity team sport that combines technical skill, tactical awareness, and physical fitness. Originating in Northern Europe in the early 20th century, it evolved from an outdoor 11-a-side game to the modern 7-a-side indoor version (Saavedra, 2018), it is the youngest of the major team sports (Constanti et al., 2008). It has been part of the Olympic Games since 1972 for men and 1976 for women, Considering the multifaceted nature of the sport, handball performance is influenced by a wide range of factors, including anthropometric characteristics, coordination, strength, endurance, nutrition, cognitive abilities, tactical understanding, social dynamics, and external conditions (Wagner et al., 2014). In recent decades, rule changes, such as faster restarts and goalkeeper substitutions—have made the game faster and more spectator-friendly (Þorgeirsson et al., 2022b). The popularity of this sport and its participation have been increasing, going from around 19 million players (International Handball Federation, 2014) to approximately 30 million, with 211 national federations and more than 28,000 clubs (IHF, 2025).

Bibliometric studies are systematic analyses of scientific literature aimed at identifying patterns, trends, and impacts within a specific field (Passas, 2024). In addition, bibliometrics serves descriptive, evaluative, and monitoring purposes in the analysis of research activity. Furthermore, bibliometric studies have practical applications in policy-making, resource allocation, and strategic planning. They support evidence-based decisions in research management, help guide the development of science and technology policies, and are essential for evaluating the progress and impact of research initiatives (Salinas-Ríos, & García-López, 2022). In the field of sports science, bibliometric studies have proliferated in recent years, either focusing on specific aspects such as the relative age effect (Bilgiç & Işın, 2002) or small-sided games (Endriani et al., 2024), or on specific sports such as adapted sport (Liu et al., 2022), judo (Rahmawati et al., 2024), squash (Liu et al., 2025), swimming (Morais et al., 2024), tennis (Kumar & Das, 2024) or volleyball (da Silva et al., 2023). Moreover, some research has conducted bibliometric analyses comparing Olympic sports (Millet et al., 2021). In that study, football was the sport with the highest number of citations, while the summer Olympic sports with the fewest citations included mountain biking, archery, diving, trampoline, and skateboarding. Among the six research topics analyzed (Physiology, Performance, Injuries – Medicine, Biomechanics – Equipment, Psychology, and Training and Testing), the first three were the most extensively studied. However, their distribution varied depending on the sport in question (Millet et al., 2021).

In relation to handball, the first bibliometric analysis (Prieto et al., 2015) examined publications up to 2012, identifying 373 articles indexed in the Web of Science and PubMed databases, with an increase in the number of publications between 2010 and 2012. The most frequently published disciplines were: (i) injuries (26.54%), (ii) physical capacities and conditions (17.96%), and (iii) physiological variables measurement (12.87%). Subsequently, another study that analyzed articles published between 2013 and 2018 in PubMed found that physical capacities and conditions was the most studied topic (19.14%) (Saavedra, 2018). A more recent study that analyzed articles published up to 2018 using the Web of Science database found 1,727 records, showing a significant increase in research related to handball (Pardo-Ibáñez et al., 2020) Although the research topics were not analyzed, the keywords used were examined, with the most frequent being handball (3.35%), Anterior Cruciate Ligament (ACL) (1.655) and sport (1.43%). Nevertheless, a later study conducted on all Olympic sports concluded that, in the case of handball, 50% of the articles could be ascribed to the field of physiology (Millet et al., 2021). If the publications are analyzed by country, it was found that up to 2012, the most scientifically productive countries were Norway (12.06% of the total articles), Germany (11.26%), and Spain (9.65%) (Prieto et al., 2015). Furthermore, interest in handball and bibliometric studies is also present in countries with less tradition, such as Chile (Hernández-Mosqueira et al., 2024), which demonstrates the growing interest in this sport beyond European countries. However, the main gap is that, beyond bibliometric studies (topics, countries, or authors), there are no studies that take into account bibliometric indicators alongside other performance indices.Therefore, the novelty of the present study lies in combining bibliometric indicators with performance outcomes (medals), providing a more comprehensive perspective on the development of handball research and its possible links with elite sport performance. In this way, in this context of multidisciplinary research and increased scientific production, and considering the need to better understand both the evolution of research and its potential implications for performance, the objectives of this study were: (i) to analyze the evolution in the number of articles published on handball and the citations received; (ii) to determine whether there is a relationship between scientific production and the number of medals won in the Olympic Games and World Championships; (iii) to identify the research topics with the highest publication rates in handball; and finally, (iv) to identify the most cited articles, as well as the journals and countries that published the most on handball..

Materials and methods

Literature search strategy

Articles published between January 1, 1980, and December 31, 2024, were retrieved using searches in the Web of Science Core Collection database. The terms used were handball in both the title and the abstract. No additional filters were applied. Only articles published in journals were considered. This database was chosen because it is used as the basis for calculating the impact factor in the Journal Citation Reports. All articles were included except those focused on beach handball. Beach handball was not considered because it has a different internal logic (number of players, match duration, final scoring system, etc.), which distinguishes it from "traditional" handball. Secondly, its international trajectory is more recent (the first World Championship was held in 2004, and it has never been an Olympic sport).The search was conducted between October 1 and October 10, 2025.

Data collection

After removing duplicate records, two of the authors (JMS, YE) independently screened the titles and abstracts. From each article, the following information was analyzed: authors; journal (year, volume, issue, pages, DOI); institution and country of each author; funding agency; and the

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number of citations of each paper. Finally, each article was assigned a research topic according to the following classification shown below. In cases where an article addressed two or more topics, it was assigned to the topic considered to be its main focus. In case of disagreement between the authors, it was resolved by consensus. The classification used for the topics was (alphabetically) (adapted from Devís-Devís et al., 2010; Prieto et al., 2015; Saavedra, 2018): (i) Biomechanics: studies that focus on body movements and the forces involved in technical actions. (ii) Body composition and somatotype: studies that focus on players' anthropometric and body composition characteristics and somatotypes. (iii) Injuries and sports medicine: studies that focus on the prevention, types, frequency, and treatment of injuries. (iv) Nutrition: studies that focus on diet, hydration, or supplementation. (v) Performance analysis: studies that focus on technical, tactical, or overall performance during matches. (vi) Physical capacities – measurements: studies that focus on strength, speed, endurance, or agility through tests designed to quantify players' abilities. (vii) Physiological responses and adaptation (training programs): studies that focus on how the body reacts and adapts to physiological stimuli or to specific training programs. (viii) Physiological variables – measurements: studies that focus on parameters such as heart rate, lactate concentration, or oxygen uptake during training, competition, or laboratory testing. (ix) Psychology and cognitive processes: studies that focus on motivation, concentration, decision-making, perception, and other psychological factors influencing performance. (x) Tactics: studies that focus on game strategies, offensive and defensive organization, and collective behavior patterns on the court. (xi) Others: studies not classified in any of the above groups.

Statistics

Absolute values and percentages were presented for the total number of articles per year and citations per year. A regression analysis was performed to calculate the coefficient of determination and the regression line for the number of articles and year, the number of citations and year, and finally, the number of medals and the number of articles by country. This approach allowed us to examine temporal trends in scientific production and citations, identifying patterns and the strength of these relationships over time. In addition, regression analysis was used to explore the association between the number of publications and performance outcomes (medals), providing a quantitative perspective on the potential link between research activity and sporting successAbsolute values and percentages were also presented for the journals in which the articles were published, as well as for the topics studied.

Results

From an initial search yielding 1,484 records in the Web of Science Core Collection, 48 articles were excluded for being conducted in beach handball; two for being conducted in Australian football; one for being conducted in Valencian pilota; four for being duplicate records; and 17 for being indexed as 2025 publications, resulting in a final dataset of 1,412 articles included for analysis. Figure 1 presents the regression analyses, showing coefficients of determination for the relationship between the number of articles and year (R^2=0.6625, p<0.001) and between citations and year (R^2=0.6697, p<0.001). The number of articles increases from 2020 onward, reaching its peak in 2022 with 176 articles, while citations also rise from 2020, reaching their highest value in 2024 with 3,536 citations.

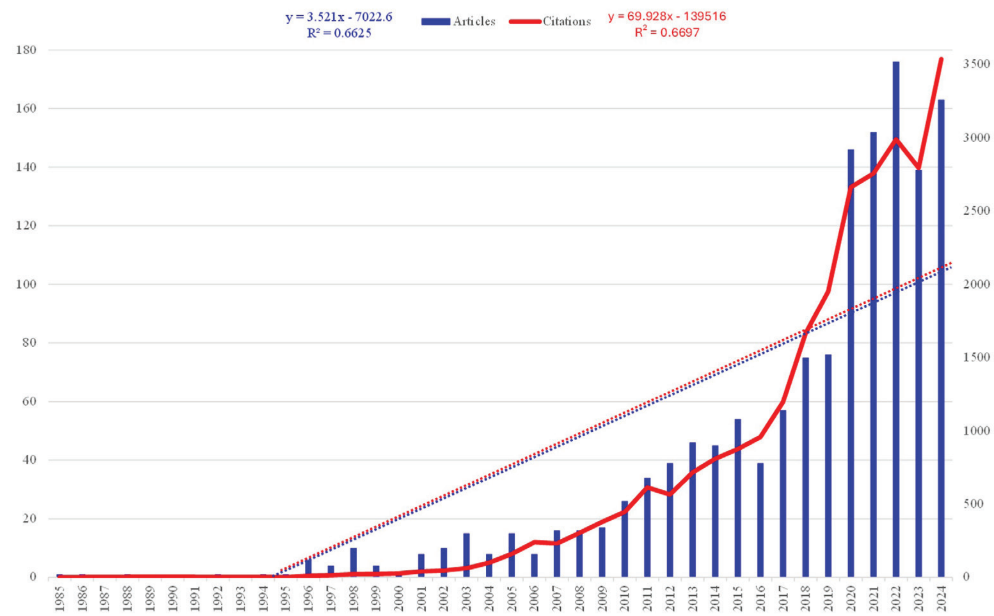

Figure 1. Evolution of the number of articles and citations from 1985 to 2024, and regression line and equation for articles/year and citations/year.

In terms of publications by country, the five countries with the highest number of articles were: (i) Spain, 297 articles (21.03%); (ii) Germany, 184 articles (13.03%); (iii) Norway, 138 articles (9.77%); (iv) Brazil, 112 articles (7.98%); and (v) Tunisia, 89 articles (6.30%), accounting for 58.06% of the total publications. Figure 2 presents the regression analysis showing a coefficient of determination for the relationship between (for the number of medals in Olympic Games and World Championships (men plus women) and the number of articles (R^2=0.1575, p<0.01). Countries that did not win any medals, as well as the USSR, were not included in the analysis.

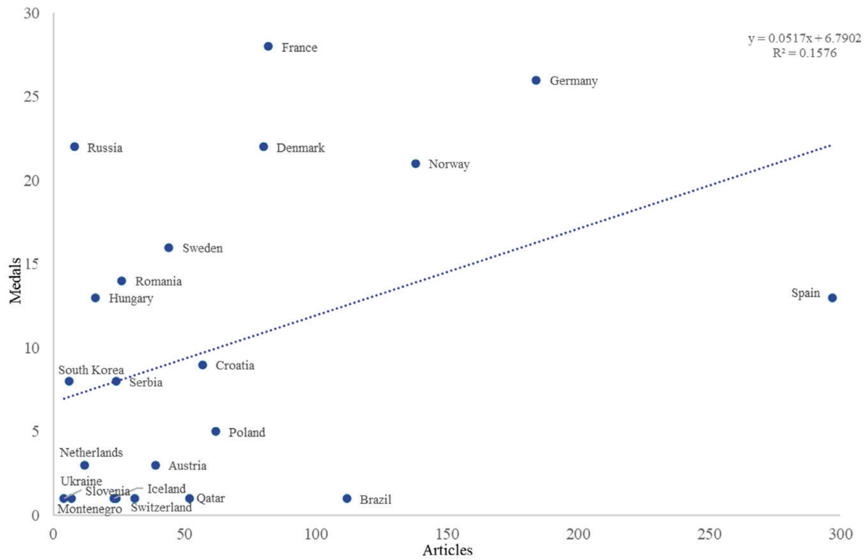

Figure 2. Relationship between the number of articles and the number of medals in the Olympic Games and World Championships by country.

Focusing on the topics studied, Table 1 indicates that the five most frequently researched were: (i) Physical capacities – measurements, 217 articles (15.37%); (ii) Injuries and sports medicine, 202 articles (14.31%); (iii) Physiological responses and adaptation (training programs), 178 articles (12.61%); (iv) Physiological variables – measurements, 143 articles (10.13%); and (v) Performance analysis, 103 articles (7.29%), accounting for 59.71% of the total publications. However, there was a considerable number of articles, 247 (17.49%), that could not be classified under any of the established topics.

Table 1. Distribution (total number and percentages) of articles according to the established topics.

Topic	Articles	
	n	%
Physical capacities - measurements	217	15.37
Injuries and sport medicine	202	14.31
Physiological responses and adaptation (training programs)	178	12.61
Physiological variables – measurements	143	10.13
Performance analysis	103	7.29
Psychology and cognitive process	98	6.94
Biomechanics	81	5.74
Body composition and somatotype	77	5.45
Nutrition	36	2.55
Tactics	30	2.12
Others	247	17.49
Total	1412	100.00

Table 2. The five most cited articles

Authors (year)	Title	Journal	Citations
Olsen, O.-E., Myklebust, G., Engebretsen, L., & Bahr, R. (2004).	Injury mechanisms for anterior cruciate ligament injuries in team handball: A systematic video analysis.	American Journal of Sports Medicine, 32(4), 1002–1012.	927
Koga, H., Nakamae, A., Shima, Y., Iwasa, J., Myklebust, G., Engebretsen, L., Bahr, R., & Krosshaug, T. (2010).	Mechanisms for noncontact anterior cruciate ligament injuries: Knee joint kinematics in 10 injury situations from female team handball and basketball	American Journal of Sports Medicine, 38(11), 2218–2225.	651
Myklebust, G., Engebretsen, L., Brækken, I. H., Skjolberg, A., Olsen, O.-E., & Bahr, R. (2003).	Prevention of anterior cruciate ligament injuries in female team handball players: A prospective intervention study over three seasons	Clinical Journal of Sport Medicine, 13(2), 71–78.	570
Myklebust, G., Maehlum, S., Holm, I., & Bahr, R. (1998).	A prospective cohort study of anterior cruciate ligament injuries in elite Norwegian team handball.	Scandinavian Journal of Medicine & Science in Sports, 8(3), 149–153.	317
Gorostiaga, E. M., Granados, C., Ibáñez, J., & Izquierdo, M. (2005).	Differences in physical fitness and throwing velocity among elite and amateur male handball players.	International Journal of Sports Medicine, 26(3), 225–232	289

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In terms of funding, 39.09% (552 out of 1,412 articles) were funded. The five funding agencies with the highest number of supported publications were: (i) the Spanish Government (Spain), 23 articles (1.63%); (ii) the Fundação para a Ciência e a Tecnologia (Portugal), 16 articles (1.13%); (iii) the Royal Norwegian Ministry of Culture (Norway), 16 articles (1.13%); (iv) the South-Eastern Norway Regional Health Authority (Norway), 15 articles (1.06%); and (v) the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (Brazil), 14 articles (0.99%).

Finally, the five that have published the most articles was: (i) Journal of Strength and Conditioning Research , 78 articles (5.52%); (ii) Journal of Human Kinetics, 65 articles (4.60%); (i) International Journal of Environmental Research and Public Health, 50 articles (3.54%); (iv) Journal of Sports Medicine and Physical Fitness, 39 articles (2.76%); and (v) Scandinavian Journal of Medicine and Science in Sports, 35 articles (2.48%), accounting for 18.91% of the total publications. The five most cited articles (Table 2) account for 2,754 citations, representing 10.51% of the total citations.

Discussion

The objectives of this study were: (i) to analyze the evolution in the number of articles published on handball and the citations received; (ii) to determine whether there is a relationship between scientific production and the number of medals won in the Olympic Games and World Championships; (iii) to identify the research topics with the highest publication rates in handball; and finally, (iv) to identify the most cited articles, as well as the journals and countries that published the most on handball. In general terms, there has been an increase in the number of articles and citations, especially since 2020. Similarly, the countries that publish the most are Spain, Germany, and Norway, with only a weak relationship between the number of publications and the number of medals won by countries. The most studied research topics focus on physical capacities – measurements, injuries and sports medicine. This reflects a current update in research on handball, helping to highlight both its strengths and weaknesses.

There was a relationship between the number of published articles and year (R^2=0.6625, p<0.001), as well as between the number of citations and year (R^2=0.6697, p<0.001). The increase in articles becomes more significant from 2020 onwards. These data appear to follow the trend observed in previous studies (Prieto et al., 2015; Saavedra, 2018), which reported a growth in publications related to handball. This may be due not only to researchers' increasing interest in the sport, but also to the rising number of journals indexed in the Journal Citation Reports. For example, in the Sport Sciences category, the number of indexed journals rose from 83 in 2018 to 116 in 2020, and to 134 in 2024. When analyzing the countries with the highest publication output, Spain, Germany, Norway, and Brazil lead, representing a shift compared to previous studies where the order was Norway, Germany, Spain, and France (Prieto et al., 2015). It could be assumed that this shift is driven by differences in available research funding (Beneke, 2013). However, this does not seem to be the case. Although among the top five institutions funding the most studies are one Spanish institution (Spanish Government), two Norwegian institutions (Royal Norwegian Ministry of Culture and South-Eastern Norway Regional Health Authority), and one Brazilian (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior), it is noteworthy that no German institution appears in the top five funding agencies. On the contrary, a Portuguese institution (Fundação para a Ciência e a Tecnologia) is listed among the top funders, even though Portugal is not among the countries with the highest publication output. However, the funding of handball-related studies does not even reach 40%. In this sense, research funding could perhaps be enhanced through greater involvement of the International Handball Federation and the European Federation, as occurs in other sports such as football (UEFA, 2025). In turn, the relationship between published articles and medals is low (R^2=0.1575, p<0.01). This seems to indicate that the publication of articles may be more closely related to other factors, such as the number of practitioners or the tradition in the practice of this sport, as shown by the fact that the countries winning the most medals are European, where handball originated.

The most frequently studied research topics were Physical capacities – measurements (15.37%), Injuries and sports medicine (14.31%), and Physiological responses and adaptation (training programs) (12.61%) (Table 2). These data reveal a shift in trend, as Injuries and sports medicine no longer occupy the leading position as they did up to 2012 (Prieto et al., 2015), while articles focusing on physiology continue to hold relevance as objects of study (Millet et al., 2021). This shift may reflect an increasing emphasis on performance-oriented and applied research, aimed at directly enhancing athletes' physical capacities and training adaptations. Such a trend suggests a closer alignment between scientific research and the practical demands of high-level handball performance. Although injuries and sports medicine no longer occupy the top position among the studied topics, it is worth noting that four of the most cited articles (Table 2) account for 9.30% of the total citations from 1,412 articles. However, it should be considered that the most recent of these four articles is more than 14 years old, making it reasonable to assume that, over time, newer articles will increase in citation count. It is worth highlighting the increase in Physiological responses and adaptation (training programs) (12.61%), which seems to indicate a growing interest in conducting applied research (Bishop 2008) through programs that enhance athletes' actual performance. It is also necessary to draw attention to the fact that articles within the research topic Psychology and cognitive processes are limited (6.94%), especially considering that cognitive processes are an integral part of performance in handball (Wagner et al., 2014; Kristjánsdóttir et al., 2019). Similarly, it is surprising that, despite handball being a team sport, only 2.12% of the articles examine tactical aspects, perhaps due to the complexity inherent in studying team sports (Espoz-Lazo, & Hinojosa-Torres, 2025). In any case, it is necessary to highlight that there is still a relatively high percentage (17.49%) of studies classified under the "Others" category, which reflects the heterogeneous and diverse interests within research.

Although there are no journals dedicated exclusively to handball, publications in five of them account for 18.9% of the total output: Journal of Strength and Conditioning Research, Journal of Human Kinetics, International Journal of Environmental Research and Public Health, Journal of Sports Medicine and Physical Fitness, and Scandinavian Journal of Medicine and Science in Sports. Two of these journals (Journal of Strength and Conditioning Research and Scandinavian Journal of Medicine and Science in Sports) were already in the top five when handball publications up to 2012 were analyzed (Prieto et al., 2015). This seems to indicate a diversification among journals which, although generally multidisciplinary, including some published in countries not traditionally linked to handball (for example, the Journal of Strength and Conditioning Research, published in the USA), are now paying greater attention to the sport.

This article has some limitations. First, the use of only one database may have resulted in the exclusion of certain articles; however, the Web of Science database was chosen, which can be considered the gold standard. Second, the classification of the selected research topics is not unanimous across bibliometric studies, which has made comparisons somewhat difficult in certain cases. Third, the use of citation-based metrics may be influenced by time-dependent bias. Older publications have had more time to accumulate citations, potentially over-representing their impact compared to more recent studies; for example, the five most cited articles were published between 1998 and 2010. Therefore, citation counts should be interpreted with caution, as they may not fully reflect the current relevance or scientific quality of newer research.

Conclusions

The conclusions of this study were as follows: (i) there was a clear increase in research related to handball, especially from 2020 onwards; (ii) the relationship between the countries that published the most (Spain, Germany, Norway, and Brazil) and the number of medals obtained in the Olympic Games and World Championships is weak; (iii) the research topics that developed the most were physical capacities – measurements, injuries and sports medicine (14.31%), and physiological responses and adaptation (training programs); (iv) five journals accounted for 19% of the total publications.Several practical implications can be drawn from this study. First, it seems necessary to sport governing bodies (e.g. International, European and national federations) and research institutions in handball to ensure that the scientific knowledge of a sport that has been part of the Olympic Games for more than 50 years continues to grow and be applied to practice. Second, studies in important areas such as psychology,cognitive process, and tactical analysis, it is recommended that researchers and coaches prioritize these fields. Third, there appears to be sufficient interest to potentially create special issues within scientific journals to make handball research more visible. Finally, future research should aim to develop more applied and interdisciplinary studies, particularly those that integrate physical, psychological, and tactical dimensions of performance, while also enhancing the translation of laboratory-based findings into real-world practice.

Conflicts of Interest

The authors declare no conflict of interest.

References

Beneke, R. (2013). Sport performance research: Sexy, underfunded, and with underutilized impact potential. International Journal of Sports Physiology and Performance, 8(4), 349–350. https://doi.org/10.1123/ijspp.8.4.349

Bilgiç, T., & Işın, A. (2022). Embarking on a journey: A bibliometric analysis of the relative age effect in sport science. German Journal of Exercise and Sport Research, 52(1), 154–165. https://doi.org/10.1007/s12662-021-00792-w

Bishop, D. (2008). An applied research model for the sport sciences. Sports Medicine, 38(3), 253–263. https://doi.org/10.2165/00007256-200838030-00005.

Costantini, D., Villepreux, P., & Mandigout, S. (2008). Intérêt des apports scientifiques dans la recherche de la performance en handball et en rugby Science & Sports, 23(1), 1–5. https://doi.org/10.1016/j.scispo.2007.12.009

da Silva, V., Forte, F. B., Diniz, I. B., García-de-Alcaraz, A., Palao, J. M., de Conti, G., Mesquita, I., Araripe, A. I., & Ricarte, G. (2023). Status of match analysis research in indoor and beach volleyball: A bibliometric analysis. Retos, 50, 838–848. https://recyt.fecyt.es/index.php/retos/article/view/99062

Devís-Devís, J., Valenciano, J., Villamón, M., & Pérez-Samaniego, V. (2010). Disciplines and themes of study in physical activity and sport science. Revista Internacional de Medicina y Ciencias de la Actividad Física y el Deporte, 10(37), 150–166.

Endriani, D., Gultom, S., Fahmi, M., Destya, M. R., & Md Nadzalan, A. B. (2024). Mapping the landscape of small-sided games in team sports: A bibliometric analysis and literature review. Journal Sport Area, 9(2), 170–185. https://doi.org/10.25299/sportarea.2024.vol9(2).16513

Espoz-Lazo, S., & Hinojosa-Torres, C. (2025). Modern handball: A dynamic system, orderly chaotic. Applied Sciences, 15(7), 3541. https://doi.org/10.3390/app15073541

Hernández-Mosqueira, C., Castillo-Quezada, H., Sandoval-Obando, E. E., Luna-Villouta, P., Bahamondes-Avila, C., & Molina Vásquez, R. (2024). Producción científica sobre balonmano en Chile: una revisión sistemática. Retos, 60, 1181–1193. https://doi.org/10.47197/retos.v60.107836

International Handball Federation. (2014). Handball. History and stories. Retrieved 15th April 2018, from http://techcrunch.comhttp://ihf.info/upload/Book/issue0001/index.html

International Handball Federation. (2025, November 3). Marketing. IHF. https://www.ihf.info/marketing-homepage

Kristjánsdóttir, H., Jóhannsdóttir, K.R., Pic, M., Saavedra, J.M. (2019). Psychological characteristics in women football players: skills, mental toughness, and anxiety. Scandinavian Journal of Psychology, 60: 609-615. https://doi.org/10.1111/sjop.12571.

Kumar, S., & Das, R. (2024). Biomechanical insights into the one-handed backhand drive in tennis: A bibliometric analysis. Physical Education Theory and Methodology, 24(6), [Artículo e236]. https://doi.org/10.17309/tmfv.2024.6

Liu, T., Wassell, N., Liu, J., & Zhang, M. (2022). Mapping research trends of adapted sport from 2001 to 2020: A bibliometric analysis. International Journal of Environmental Research and Public Health, 19(19), 12644. https://doi.org/10.3390/ijerph191912644

Liu, R., Kondrič, M., & Wang, J. (2025). A comprehensive bibliometric analysis of the sport of squash (1973–2024): Progress, collaboration, findings, and thematic evolution. Sports, 13(6), 157. https://doi.org/10.3390/sports13060157

Millet, G. P., Brocherie, F., & Burtscher, J. (2021). Olympic sports science—Bibliometric analysis of all summer

 DOI 10.26773/mjssm.260902

and winter Olympic sports research. Frontiers in Sports and Active Living, 3, 772140. https://doi.org/10.3389/fspor.2021.772140

Morais, J. E., Barbosa, T. M., Arellano, R., Silva, A. J., Sampaio, T., Oliveira, J. P., & Marinho, D. A. (2024). Race analysis in swimming: Understanding the evolution of publications, citations and networks through a bibliometric review. Frontiers in Sports and Active Living, 6, Article 1413182. https://doi.org/10.3389/fspor.2024.1413182

Pardo-Ibáñez, A., Madera Gil, J., & Pellicer-Chenoll, M. (2020). Bibliometric study of scientific production on handball. Movimento, 26, e26073. https://doi.org/10.22456/1982-8918.101908Passas, I. (2024). Bibliometric analysis: The main steps. Encyclopedia, 4, 1014–1025. https://doi.org/10.3390/encyclopedia4020065

Prieto, J., Gómez, M.-Á., & Sampaio, J. (2015). A bibliometric review of the scientific production in handball. Cuadernos de Psicología del Deporte, 15(3), 145–154. Universidad de Murcia. http://www.redalyc.org/articulo.oa?id=227042879014

Rahmawati, I., Tuasika, A. R. S., Widodo, A., Kusnanik, N., Hariyanto, A., Daulay, B., ... & Ayubi, N. (2024). Judo research trend in the last five decades: Bibliometric analysis and systematic review of Scopus journal database. Fizjoterapia Polska. https://doi.org/10.56984/8zg020cj5ym

Saavedra, J. M. (2018). Handball research: State of the art. Journal of Human Kinetics, 63(1), 5–8. https://doi.org/10.2478/hukin-2018-0001

Salinas-Ríos, K., & García López, A. J. (2022). Bibliometrics, a useful tool within the field of research. Journal of Basic and Applied Psychology Research, 3(6), 9-16. https://doi.org/10.29057/jbapr.v3i6.6829

UEFA. (2025). UEFA Research Grant Programme brochure 2025. UEFA Academy. https://uefaacademy.com/courses/rgp

Wagner, H., Finkenzeller, T., Würth, S., & von Duvillard, S.P. (2014). Individual and team performance in team-handball: A Review. Journal of Sports Science and Medicine, 13, 808-816.

Þorgeirsson, S., Pic, M., Lozano, D., Sigurgeirsson, O., Sekulic, D., & Saavedra, J. M. (2022). The difference between winners and losers in balanced handball games in the final 10 minutes. Montenegrin Journal of Sports Science and Medicine, 11(2), 37–43. https://doi.org/10.26773/mjssm.220905

ORIGINAL SCIENTIFIC PAPER

Metabolic Response to Low-Intensity Resistance Training with Blood Flow Optimization in the Limbs

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Abstract

The purpose of the study was to evaluate the blood lactate reactive response to low-intensity resistance training with and without blood flow optimization in the limbs. The sample consisted of 9 female and 16 male participants, all second-year students enrolled in the "Special Physical Training in Security Forces" study program at the Faculty of Sports, University of Presov, who had one year of strength training experience but no prior Blood Flow Optimization (BFO) resistance training experience. The study design consisted of two training weeks, during which blood lactate samples were collected from the fingertips before and after each training session and analyzed using the Biosen C-Line device. Resistance training involved bodyweight resistance exercises, structured into a 40-minute session consisting of 20 minutes of upper-body exercises and 20 minutes of lower-body exercises. During the first week, students exercised with KAATSU AirBands to optimize blood flow in their limbs, using the KAATSU C3 controller with a constant pressure of 250 SKU. During the second week, students performed the same training protocol without the KAATSU AirBands. The results show that resistance training caused significant changes in blood lactate concentration ($p < .05$). Among female students, lactate levels increased by 3.43 mmol/L after training without AirBands and by 5.43 mmol/L with AirBands. Among male students, the increase was 5.04 mmol/L without AirBands and 5.06 mmol/L with AirBands. The use of KAATSU AirBands during resistance training had no statistically significant effect on blood lactate concentrations ($p > .05$) in both male and female students.

Keywords: *metabolism, blood flow restriction, physical training, KAATSU, combat sports*

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Introduction

Resistance training with restricted blood flow in the limbs (BFR) has been a current scientific topic in recent years, focusing, in particular, on the functional and physiological responses of the human organism. Although extensive research exists on both BFR training and lactate measurements, there is still limited information on the combined use of these methods. The present study aims to examine how low-intensity Blood

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Flow Optimization (BFO) resistance training and conventional resistance training affect blood lactate levels.

Lactate is a crucial intermediary in numerous metabolic processes, serving as a particularly mobile fuel for aerobic metabolism and playing a vital role in wound repair and regeneration (Gladden, 2004). According to Jenkins (2005), lactate is the final product of anaerobic glucose metabolism and is formed by the reduction of pyruvate through the action of lactate dehydrogenase, and skeletal muscle contains five isoforms of this enzyme. The blood lactate level is determined by the ratio between its formation and its metabolism. At rest, muscles slowly produce and release lactate in the range from 0.7 to 2 mmol/L, which is maintained in the blood in a basic amount. In addition to muscles, cells of the skin, brain, intestinal mucosa, as well as blood elements, especially erythrocytes, participate in the lactate production. The blood transports the resulting lactate to the liver, where it is utilized for gluconeogenesis in the Cori cycle, and a smaller portion of the lactate is also utilized by the kidneys (McMorris & Hale 2006). The heart and brain actively take up lactate. According to Ide and Secher (2000), during intense exercise, the brain seems to take up lactate, and its oxygen uptake also increases.

Fukuta et al. (2024) found that the elevated blood lactate level was maintained after muscle blood flow restriction training, whereas the lactate level significantly decreased after conventional training. Zhu et al. (2025) have concluded that blood flow restriction training can induce significant muscle activation and metabolic stress, and increase blood lactate concentration at low loads and arterial occlusion pressures between 70% and 80%. This may be achieved by employing specialized compression devices applied to proximal limbs to partially occlude blood flow. This training causes venous occlusion and arterial inflow restriction, which induces a partially hypoxic environment that stimulates the secretion of anabolic hormones and enhances muscle activation at lower exercise intensities as well. The results suggest that concentric blood flow restriction training leads to pronounced acute changes in muscle size, a response that may be an essential factor in promoting muscle hypertrophy (Yasuda et al., 2012). Therefore, one-repetition maximum (1RM) has to be taken into account in the process of strength development. According to Wang et al. (2025), upper limb blood flow restriction training can significantly enhance bench press strength. Blood flow restriction training with 40%–70% 1RM and ≥60% AOP is more likely to promote immediate upper limb strength. Blood flow restriction training combined with maximal effort and ≥60% arterial occlusion pressure can increase the blood lactate value and subjective fatigue degree of the subjects.

The purpose of the study was to evaluate the organism's reactive response, especially capillary blood lactate levels measured before and after low-intensity resistance training combined with blood flow regulation in the limbs. We hypothesized that lactate levels following training with regulated limb blood flow would be significantly higher than those following low-intensity resistance training.

Materials and methods

Participants and design

The sample consisted of 9 female and 16 male second-year students enrolled in the "Special Physical Training in Security Forces" study program at the Faculty of Sports, University of Presov. Within the study program, students must demonstrate high levels of general and specific physical fitness as active participants in national combat sports contests. Table 1 shows the basic sample characteristics.

Procedures

The research design was divided into two weeks, during which lactate samples were taken before and 5 minutes after the training unit. The lactate samples were taken under medical supervision from capillary blood from the fingers, while observing hygiene requirements in a standard manner in a sitting position, with an individual adjustment of the depth of the lancet injection. The sample was taken without exerting effort to avoid mixing capillary blood with intercellular fluid. Lactate samples were taken into 20 µl Na-heparinised capillaries, which were subsequently placed in 1 ml containers with hemolysis solution and immediately subjected to analysis on the Biosen C-Line device, which works on the principle of the enzymatic-amperometric method using chip sensor technology. The device was calibrated before each evaluation of blood samples.

Training program

Before the study, students actively participated in a sample training unit and became familiar with the KAATSU training methodology. The resistance training program

Table 1. Sample characteristics

	n	Age	BH (cm)	IQR	BW (kg)	IQR	Muscle (kg)	IQR	Fat (kg)	IQR	Fat %
Females	9	20	161.6	7.0	55.2	5.6	22.4	1.3	14.9	7.4	26.9
Males	16	21	181.7	12.1	74.6	14.1	37.5	5.9	8.1	2.6	12.7

Note. n: number of subjects; BH: body height; BW: body weight; IQR: interquartile range.

Table 2. Resistance training program

	Upper limbs	Lower limbs	Sets and Reps	Rest
KAATSU Air Bands 250 SKU	Pushup	Squat	4 x 15	20 s.
	TRX Pullup	Fitball hamstring curls	4 x 15	20 s.
	Side Plank left and right	Calf raises	4 x 15	20 s.
		Plank	4 x 30 second	
No Bands	Pushups	Squats	4 x 15	20 s.
	TRX Pullups	Fitball hamstring curls	4 x 15	20 s.
	Side Plank left and right	Calf raises	4 x 15	20 s.
		Plank	4 x 30 second	

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consisted of upper- and lower-body exercises. Students performed body-weight exercises that combined dynamic and isometric modes of muscle work. The principles of proportionality and sequence were followed to minimize health risks. Students were instructed to perform all exercises using the correct technique and without restrictions. Table 2 shows the individual exercises, including the exact number of sets and repetitions.

A single resistance training session lasted 40 minutes and consisted of 20 minutes of upper-body exercises and 20 minutes of lower-body exercises. During the first week, students exercised with bands to regulate blood flow to the extremities, and a week later, under identical conditions, without bands.

Students enrolled in the study had one year of strength training experience but no prior KAATSU resistance training experience. The main difference between the training programs was the use of KAATSU AirBands and blood flow restriction, during which students experienced a sensation of muscle failure during the final repetitions of a set. When exercising without KAATSU AirBands, exercise intensity was determined by the subjective parameter of repetitions in reserve. Students were able to perform four more repetitions than the prescribed number in the intervention.

KAATSU training equipment with AirBands

The KAATSU C3 device was used, which is the third generation of the KAATSU Cycle product. The device consists of a controller and four pneumatic elastic bands (two 4 cm-wide arm bands and two 5 cm-wide leg bands). Figure 1 shows the placement of the bands, including the KAATSU C3 controller.

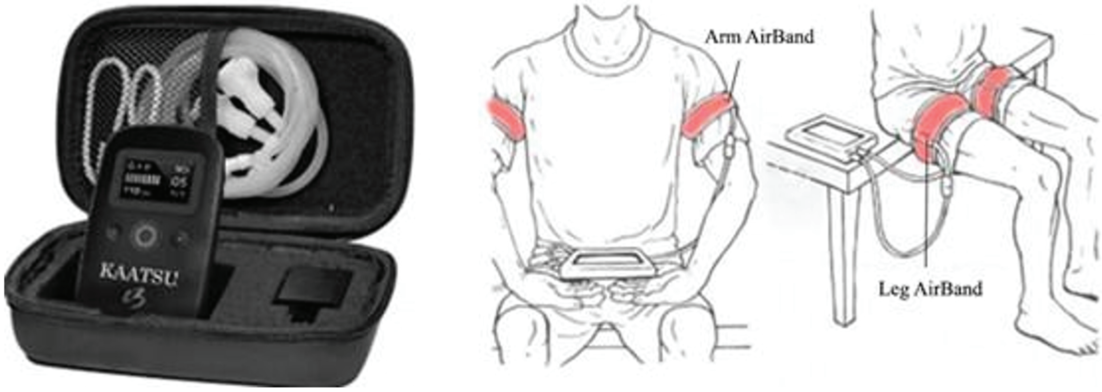

Figure 1. KAATSU C3 set

Each pressure level is expressed in Standard KAATSU Units (SKU), which can be adjusted in increments of 10 SKUs, ranging from 50 to 400. The Standard KAATSU Units, compared with blood pressure measured in millimetres of mercury (mmHg), measure compression against an air bladder inside the AirBand. During exercise, a constant AirBand pressure of 250 mmHg was applied, corresponding to approximately 45% of the blood flow in the brachial artery and 40% of the blood flow in the femoral artery, as verified by the Doppler ultrasonography using a Philips EPIQ system with a Philips L12-3 linear probe (Kokinda et al., 2024). The KAATSU AirBand tightness was adjusted individually for each student to achieve approximately 40–45% of arterial occlusion pressure (AOP).

Statistics

The Shapiro-Wilk test confirmed that the data were not normally distributed, so non-parametric methods were used. The Wilcoxon signed-rank test. was used to determine the differences in lactate concentrations between the pretest and posttest for both males and females. For each student, a difference score (Δ = pretest – posttest) was calculated and subsequently evaluated using the Wilcoxon signed-rank test. The effect size was determined using the coefficient r, which was calculated as the ratio of the Z-score to the square root of the sample size. Interpretation of the effect size was based on the criteria by Cohen (1988), with $r \geq 0.1$ indicating a small effect, $0.3 \leq r < 0.5$ a medium effect, and $r \geq 0.5$ a large effect.

Bioethical Committee

The presented procedures complied with the ethical standards of the AGEL Hospital Košice – Šaca a.s. and the University of Prešov (ECUP052024PO) for human experimentation in accordance with the Declaration of Helsinki. Each participant provided written informed consent voluntarily before participating in the study (Harriss, Jones, & MacSween, 2022).

Results

The absolute lactate concentrations before and after exercise for males and females, respectively, are graphically presented in Figures 2 and 3. The intraindividual assessment of lactate concentration among females shows that the most significant difference in lactate concentration between training with and without bands was recorded in subjects 3 and 4. Subject 3 did not experience any differences in lactate concentration after resistance training without bands. However, the application of bands caused a 5.72 mmol/L increase in lactate concentration after training. These subjects may have experienced increased local hypoxia and used anaerobic metabolism after the application of bands.

Figure 3 shows that seven male subjects experienced higher lactate concentrations after resistance training with bands. The remaining nine subjects had higher lactate concentrations after resistance training without bands. The intraindividual assessment showed that subject 13 experienced a 3.73 mmol/L increase in lactate concentration after resistance training with bands.

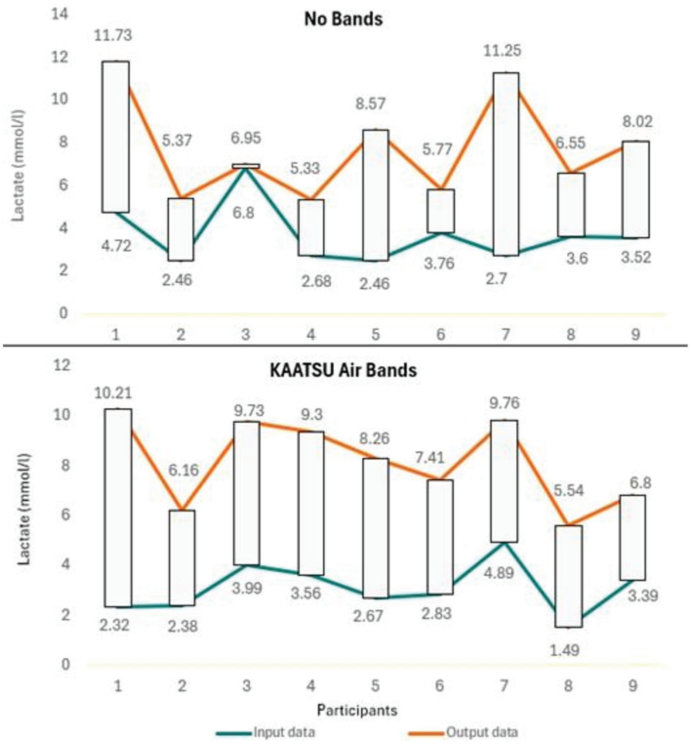

Figure 2. Blood lactate response: females

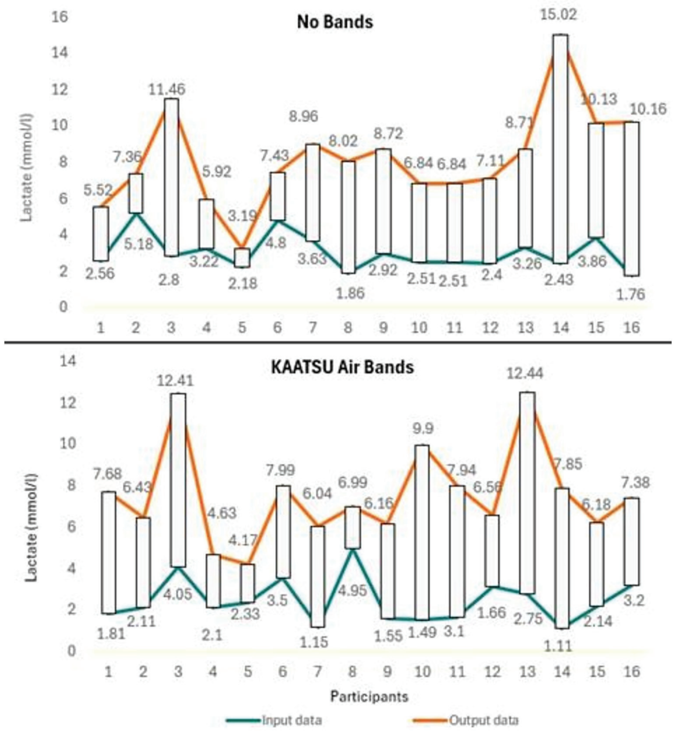

Figure 3. Blood lactate response: males

Comprehensive data evaluation has revealed that females experienced higher lactate concentrations after resistance training with bands. The median difference in lactate concentration was 1.31 mmol/L. The results of the Wilcoxon signed-rank test demonstrated a statistically significant ($p < .01$) increase in lactate concentration after exercise in both training programs, with a large effect size ($r = .89$). In the male group, a median difference in lactate concentration of 0.54 mmol/L was observed, with higher values recorded after training without bands. Similarly, in males, statistically significant ($p < .001$) increases in lactate levels after exercise were observed, with a large effect size ($r = .88$). The training program induced a reactive metabolic response in the organism. However, the difference in lactate concentration between resistance training with and without bands was not statistically significant (Table 3). However, no statistically significant difference was found between the program using bands and the program without bands ($p > .05$).

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Table 3. Lactate response to resistance training (mmol/L)

Females						
Wilcoxon signed-rank test	n	Median	IQR	Z	p	r
No Bands	9	Pre: 3.52	1.08	-2.67	.008	.89
		Post: 6.95	2.80			
KAATSU AB	9	Pre: 2.83	1.18	-2.67	.008	.89
		Post: 8.26	2.93			
Δ KAATSU vs. No Bands	9			-1.13	.260	.38
Males						
No Bands	16	Pre: 2.68	1.03	-3.52	.00044	.88
		Post: 7.72	2.70			
KAATSU AB	16	Pre: 2.12	1.54	-3.52	.00044	.88
		Post: 7.18	1.79			
Δ KAATSU vs. No Bands	16			-0.10	.918	.03

Note. n: number of subjects; IQR: interquartile range; AB: AirBands; Pre: pretest; Post: posttest; Z: Wilcoxon signed-rank test statistic; p: p-value; r: effect size; Δ: difference between post- and pre-exercise values

Discussion

The results of the study indicate that low-intensity blood flow optimized (BFO) resistance training does not induce a significantly higher metabolic response than bodyweight resistance training in both women and men. In young and physically fit athletes, the application of BFO alone without additional mechanical loading need not be a sufficient stimulus for increasing metabolic stress.

To maximize the metabolic response and potential for muscle adaptation, the optimization of training parameters with emphasis on the level of occlusive pressure, type, volume, and intensity of exercise appears to be decisive. Studies by Durand et al. (2003) and Kraemer et al. (2006) show that lactate production rates during concentric exercise are higher than during eccentric exercise. Resistance exercise with BFR stimulates muscle protein synthesis. However, the mechanisms underlying these effects are largely unknown (Gundermann et al., 2012). On the other hand, Loenneke et al. (2012) suggest that no measurable changes occur in whole blood lactate, indicating that significant changes in hydrogen ion concentration are unlikely to happen with BFR in the absence of exercise. The only two variables investigated that did change with BFR only were acute increases in real-time ultrasound-measured muscle thickness and a decrease in hematocrit determined plasma volume. These changes were maintained following the removal of the cuff, suggesting that the acute changes in muscle thickness were actual acute increases in muscle size and were not attributed to venous pooling. This acute change in size has also been observed following low-intensity BFR resistance training.

A study by Nancekievill et al. (2025) demonstrated that both males and females significantly increased their lean body mass and muscle strength. At 30% of 1-repetition maximum (1-RM) and blood flow restriction cuffs set to 60% of each individual's limb occlusion pressure, males improved strength to a greater extent than the females. According to Franz et al. (2020), blood flow restriction training is gaining popularity because it enables gains in muscle mass and strength despite using low mechanical loads combined with external venous occlusion. Using invasive measurements based on the principles of the arterial and venous catheters, the authors found that intravascular pressures increased more during low-intensity exercise. The analysis of arterial and venous blood gases revealed metabolic acidosis, accompanied by increased lactate production and elevated K+, Ca2+, and Na+. In their study, Fry et al. (2010) found that leg circumference was increased to a much larger extent in the BFR group. Obviously, leg circumference is not a direct measure of cell swelling. However, it should be noted that cell swelling is an anabolic proliferative signal in which proteins associated with osmosensing are activated.

A study by Pignanelli et al. (2021) summarized knowledge about skeletal muscle and cardiovascular adaptations. In athletes, higher performance levels and oxidative capacity are underlying factors of BFR training adaptations. Monitoring the applied pressure in the bands during every BFR training session is crucial in terms of minimizing the health risks and optimizing training effects. A study by Nitzsche et al. (2018) demonstrated that resistance training on the leg press with blood flow restriction without pressure control yielded significant differences in lactate concentration at low to moderate loads compared to training without BFR. However, the arterial occlusion pressure rate used in the study remains unclear. Bodybuilders often use cuffs to apply pressure to their limbs without targeted pressure regulation. In some cases, subjective feelings can aid in determining the optimal cuff compression and ultimately in achieving the desired effects. Freitas et al. (2000) compared the cuffs with and without pressure regulation. Their study revealed that both males and females exhibited similar metabolic responses, with males showing a higher blood lactate concentration than females. Xu et al. (2025) studied a sample of young male collegiate boxers and found that BFR training performed at 40% of arterial occlusion pressure enhanced upper-limb anaerobic power and fatigue resistance. The pressure rate in the cuffs is a frequently discussed topic, creating a platform for further research.

Strengths and Limitations of the study

The strengths of the study include the representation of both males and females, as well as the implementation of research in the educational environment for future experts in sports, which increases its practical relevance. At the same time, the training program presented provides a safe foundation for applying the BFO method, which appears to be a suitable complement to the sports training of students in security forces and combat sports.

Due to the specifics of bodyweight resistance training, it is not possible to accurately quantify exercise intensity using a percentage of 1RM. This may be considered a limitation of the present study, as it restricts the precise standardization and comparability of training load across participants. As confirmed by Zourdos et al. (2016), in resistance training, examining the number of "repetitions in reserve" is a more appropriate surrogate for assessing perceptual intensity than the traditional rating of perceived exertion. The students were able to perform approximately four more repetitions, corresponding to a low-to-moderate exercise intensity. On the other hand, when using KAATSU AirBands, students experienced a sensation of muscle failure during the final repetitions of the sets and were unable to perform any more repetitions.

An additional limitation of the study may be the timing at which lactate samples were collected. According to Machado et al. (2013), blood lactate reached its peak concentration at the fifth minute after the test across all protocols. However, it would be advisable to perform multiple samplings at different time intervals to capture the dynamics of lactate concentration increase and elimination.

Available literature suggests that pressures lower than approximately 50% of AOP may be insufficient to induce a substantial metabolic or neuromuscular response in trained individuals (Das & Paton, 2022; Zhu et al., 2025). Experimental data further indicate that lactate responses and muscle activation increase markedly only at 70–80% AOP, not at lower pressures (Zhu et al., 2025). This supports our observation that a pressure of approximately 40–45% AOP may not be sufficient to elicit a robust metabolic response in strength trained participants.

Conclusions

Blood flow manipulation, in conjunction with compression bands placed on the upper or lower limbs, may significantly affect the physiological processes associated with muscle fatigue and the organism's metabolic response. It appears that even during low-intensity resistance training, band pressure is the determining factor, as it can regulate arterial blood flow. We may conclude that students with high physical performance levels did not show significant differences in blood lactate concentrations between conventional resistance training and KAATSU training.

The training sessions presented have minimal mechanical and metabolic effects on the organism, creating the prerequisites for more optimal manipulations with the volume and intensity of specific training stimuli. The training controlled in this manner is a suitable complement to combat sports and practical tests during studies. Further strength development with a significantly higher metabolic response requires additional verification of the training methodology, focusing on increasing exercise intensity and the corresponding arterial occlusion pressure exerted by the bands on the human vascular system.

It may be concluded that a band with arterial pressure at a level of up to 50% occlusion is a safe option for low-intensity resistance training in healthy and trained athletes. It is essential to analyze additional indicators, especially heart rate, level of muscle tissue oxygenation, and performance indicators, according to the sports specialization.

Hypothesis testing showed that lactate concentrations following training with regulated limb blood flow were not significantly higher than those following low-intensity training without KAATSU AirBands.

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Conflicts of Interest

The authors declare no conflict of interest.

References

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Lawrence Erlbaum Associates.

Das, A., & Paton, B. P. (2022). Is there a minimum effective dose for vascular occlusion during blood flow restriction training? *Frontiers in Physiology, 13*. https://doi.org/10.3389/fphys.2022.838115.

Durand, R. J., Castracane, V. D., Hollander, D. B., Tryniecki, J. L., Bamman, M. M., O'Neal, S., Hebert, E. P., & Kraemer, R. R. (2003). Hormonal responses from concentric and eccentric muscle contractions. *Medicine & Science in Sports & Exercise*, *35*(6), 937–943. https://doi:10.1249/01.MSS.0000069522.38141.0B

Freitas, E. D. S., Galletti, B. R. A., Koziol, K. J., Miller, R.M., Heishman, A. D., Black, C. D., Bemben, D., & Bemben, M. G. (2020). The Acute Physiological Responses to Traditional vs. Practical Blood Flow Restriction Resistance Exercise in Untrained Men and Women. *Frontiers in Physiology*, *11*. https://doi:10.3389/fphys.2020.577224

Fry, C. S., Glynn, E. L., Drummond, M. J., Timmerman, K. L., Fujita, S., Abe, T., Dhanani, S., Volpi, E., & Rasmussen, B. B. (2010). Blood flow restriction exercise stimulates mTORC1 signaling and muscle protein synthesis in older men. *Journal of Applied Physiology*, *108*(5), 1199–1209. https://doi: 10.1152/japplphysiol.01266.2009

Fukuta, H. (2024). Effect of One Session of Muscle Blood Flow Restriction Training Versus Normal Training on Blood Lactate Level. *Progress in Rehabilitation Medicine, 9*. https://doi:10.2490/prm.20240017

Gladden, L. B. (2004). Lactate metabolism: a new paradigm for the third millennium. *The Journal of Physiology*, *558*(1), 5–30. https://DOI: 10.1113/jphysiol.2003.058701

Gundermann, D. M., Fry, C. S., Dickinson, J. M., Walker, D. K., Timmerman, K. L., Drummond, M. J., Volpi, E., & Rasmussen, B. B. (2012). Reactive hyperemia is not responsible for stimulating muscle protein synthesis following blood flow restriction exercise. *Journal of Applied Physiology, 112*(9), 1520–1528. https://DOI: 10.1152/japplphysiol.01267.2011

Harriss, D. J., Jones, C., & MacSween, A. (2022). Ethical Standards in Sport and Exercise Science Research. *International Journal of Sports Medicine*, *43*(13), 1065–

 DOI 10.26773/mjssm.260903

1070. https://doi:10.1055/s-0031-1287829

Ide, K., Secher, N. (2000). Cerebral blood flow and metabolism during exercise. *Progress in Neurobiology*, *61*(4), 397–414. https://doi: 10.1016/s0301-0082(99)00057-x

Jenkins, S. P. R. (2005). *Sports Science Handbook: The Essential Guide to Kinesiology*: MultiScience.

Kokinda M, Fečík M, Kozák T, Bujdoš M. Objektivizácia regulovaného prietoku krvi na končatinách z pohľadu tlaku v manžetách. *Acta Facultatis Exercitationis Corporis Universitatis Presoviensis*. Prešov: Vydavateľstvo PU; 2024. ISBN: 978-80-555-3416-9. p. 26–32.

Kraemer, R. R., Hollander, D. B., Reeves, G. V., Francois, M., Ramadan, Z. G., Meeker, B., Tryniecki, J. L., Hebert, E. P., & Castracane, V. D. (2006). Similar hormonal responses to concentric and eccentric muscle actions using relative loading. *European Journal of Applied Physiology*, *96*(5), 551–557. https://doi:10.1007/s00421-005-0094-4

Loenneke, P. J., Abe, T., Wilson, M. J., Ugrinowitsch, C., Bemben, G. M. (2012). Blood flow restriction: How does it work? *Frontiers in Physiology, 3*. https://doi:10.3389/fphys.2012.00392

Machado, F. A., Kravchychyn, A. C. P., Peserico, C. S., da Silva, D. F., & Mezzaroba, P. V. (2013). Effect of stage duration on maximal heart rate and post-exercise blood lactate concentration during incremental treadmill tests. *Journal of Science and Medicine in Sport,* 16(3), 276–280. https://doi.org/10.1016/j.jsams.2012.08.003

McMorris, T., & Hale, T. (2006). *Coaching Science: Theory into Practice*: John Wiley & Sons.

Nancekievill, D., Seaman, K., Bouchard, D. R., Thomson, A. M., & Sénéchal, M. (2025). Impact of exercise with blood flow restriction on muscle hypertrophy and performance outcomes in men and women. *PLoS ONE*, *20*(1). https://doi:10.1371/journal.pone.0301164

Nitzsche, N., Schulze, R., Weigand, F., Hummer, N., & Schulz, H. (2018). Comparison of an Acute Resistance Training on the Lactate Concentration with and without Blood Flow Restriction at Different Loads. *German Journal of Sports Medicine, 69*(11), 337–342. https://doi:10.5960/dzsm.2018.351

Pignanelli, C., Christiansen, D., & Burr, F. J. (2021). Blood flow restriction training and the high-performance athlete: science to application. *Journal of Applied Physiology*, *130*(4), 1163–1170. https://doi:10.1152/japplphysiol.00982.2020

Wang, J., Xu, L., Liu, H., & Jiang, L. (2025). The immediate effects of blood flow restriction training on upper limb muscle strength and fatigue level: a meta-analysis. *Frontiers in Physiology*, *16*. https://doi:10.3389/fphys.2025.1521145

Xu, Q., Fei, J., Mao, R., Liu, L., & Fei, C. (2025). Effects of BFR-RST on upper limb performance in boxers: a study based on physiological indices, anthropometric measurement indices, anaerobic power, and punching performance. *Frontiers in Physiology*, *16*. https://doi:10.3389/fphys.2025.1453153

Yasuda, T., Loenneke, P. J., Thiebaud, S. R., & Abe, T. (2012). Effects of blood flow restricted low-intensity concentric or eccentric training on muscle size and strength. *PLoS ONE*, *7*(12). https://doi:10.1371/journal.pone.0052843

Zhu, H., Tan, Z., Zhang, N., Li, Y., & Qi, H. (2025). Acute effects of blood flow restriction training at various arterial occlusion pressures on muscle activation, blood lactate responses, and RPE in healthy adult males. *Frontiers in* Physiology, *10*. https://doi:10.3389/fphys.2025.1620294

Zourdos, M. C., Klemp, A., Dolan, C., Quiles, J. M., Schau, K. A., Jo, E., Helms, E., Esgro, B., Duncan, S., & Garcia Merino, S. (2016). Novel resistance training-specific RPE scale measuring repetitions in reserve. *Journal of Strength and Conditioning Research.* https://doi.org/10.1519/JSC.0000000000001049

ORIGINAL SCIENTIFIC PAPER

Laboratory-Grade Accuracy on a Budget: Concurrent Validity of CC Athletics Portable Force Plates for Vertical Jump Analysis

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Abstract

Vertical jump assessments are widely used to evaluate athletic performance. As demand grows for field-ready systems with laboratory-grade accuracy, portable devices like the CC Athletics PlateMate force plates offer affordable and accessible solutions. This study examined the concurrent validity of PlateMate compared to a gold-standard AMTI force plate during squat jump (SJ), countermovement jump (CMJ), and countermovement jump with arm swing (CMJH). Seventeen recreationally active participants performed five trials per jump while force data were recorded simultaneously from both systems. Agreement was evaluated using Bland–Altman plots, RMSE, Pearson's r, ICC, CV%, and SEM. Across conditions, raw force-time signals and most derived metrics showed excellent agreement ($r \geq 0.95$; ICC > 0.93), with RMSE under 50 N and SEM for jump height between 0.2–0.9 cm. PlateMate demonstrated strong feasibility as a practical, low-cost alternative to laboratory force plates for field-based vertical jump testing.

Keywords: *ground reaction force; jump testing; countermovement jump; squat jump; sports performance; jump assessment*

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Introduction

Vertical jump is a well-established method in sports and rehabilitation to evaluate athletic performance (Claudino et al., 2017). However, relying solely on outcome metrics, such as jump height, can overlook important details on how that height is achieved, including force production and movement mechanics (Anicic et al., 2023; Hubley & Wells, 1983). Additionally, force-time analysis can provide valuable insights into lower limb injury mechanisms (Lichtwark et al., 2024), further amplifying the need for comprehensive vertical jump analysis (Mandic et al., 2016). Given this pivotal role that vertical jumps play in assessing athletic capacity, the need for reliable and accurate measurements cannot be overstated (Hori et al., 2009). Studies have demonstrated that even minor measurement variations can affect the reliability of jump metrics. For example, small errors in take-off phase estimation (ex. 3 ms) can lead to inaccuracies in calculated vertical velocity, displacement or jump height, later affecting informed decisions in sport (Hori et al., 2009; McMahon et al., 2018; Kibele, 1998).

Force plates are widely recognized as the "gold standard" for accurate vertical jump measurements (Cormie et al., 2009; Chavda et al., 2017). These plates capture vertical ground re-

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action forces, which reflect an athlete's power output, and can be further analyzed to extract a wide range of variables (Anicic et al., 2023; Hori et al., 2009). However, despite their accuracy, force plates are typically confined to laboratory settings due to their lack of portability and high cost (Aleksic et al., 2024). Portable force plates, like those from VALD (Collings et al., 2024), have demonstrated validity for field settings; however, their high cost, including software subscription, limits their accessibility for many sports practitioners. Alternatively, less sophisticated equipment is often used in field settings, such as contact mats (e.g., the Just Jump mat), Vertec systems (Leard et al., 2007), or smartphone applications like MyJump (Balsalobre-Férnandez et al., 2015). While these tools are more accessible, their utility is limited by the range of metrics they capture often focusing solely on jump height without offering the deeper insights which are available from laboratory equipment (Aleksic et al., 2024).

Advances in technology continue to drive the development of new measurement tools aimed at bridging the gap between laboratory accuracy and field practicality. In this context, the PlateMate (CC Athletics, Odense, Denmark) force plates represent a promising innovation, particularly due to their portability and no subscription costs related to the software. They enable real-time analysis of jump performance, capturing a comprehensive array of over 45 variables. Additionally, users have the option to export raw data, providing flexibility for in-depth analysis and integration with other systems.

The aim of this study was to assess the level of agreement between PlateMate and the established AMTI force plates (AMTI, Watertown, MA, USA) across key variables of squat jump (SJ), countermovement jump (CMJ) and countermovement jump with arm swing (CMJH). This comparison will contribute to validating PlateMate's suitability as a field-ready tool for accurate vertical jump assessments, potentially expanding the options available to sports scientists, coaches, and practitioners in diverse training and competition environments.

Materials and Methods

Experimental Session

The study involved seventeen healthy male (n=12) and female (n=5) participants, categorized as recreational athletes ($\bar{x} \pm$ SD: Age = 25.6 ± 4.8 years; Height = 180.2 ± 11 cm; Body Mass = 75.7 ± 14.8 kg). All participants were familiar with the proper SJ, CMJ and CMJH jumping techniques prior to this research and their participation was voluntary. Ethical approval was granted by the University's Institutional Ethical Review Board (#02-848/23-2; 5th May 2023), and written informed consent was obtained from all participants in accordance with the Declaration of Helsinki. The required sample size was computed in G*Power (ver. 3.1.9.7; Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany) and yielded 9 subjects for statistical power (1-β) of 0.8, significance level (α) of 0.05, and correlation of 0.8.

Experimental Protocol

Prior to experiment, participants completed a standardized warm-up protocol which included 3 min of cycling and dynamic stretching, followed by 2–3 familiarization jump trials. After the warm-up, participants were instructed to step onto a calibrated force plate system. The experimental set-up is illustrated in Figure 1. For data synchronization purposes, PlateMate was positioned on top of AMTI force plates, with both systems zeroed prior to use, following the methodology described in Collings et al. (2024). Both systems were simultaneously started via a manual trigger. After stepping on the platforms, the participants were asked to stand still for 2 s, jump as high as possible after the "go" signal, and then remain stationary for another 2 s. Each participant completed a total of 15 jump trials: five SJs, five CMJs and five CMJHs, with a 60 s rest interval between trials and 120 between jump types (Gathercole et al., 2015a). The order of jumps was randomized to avoid bias (Anicic et al., 2023). For all jumps, participants chose their preferred squat depth (Petronijevic et al., 2018).

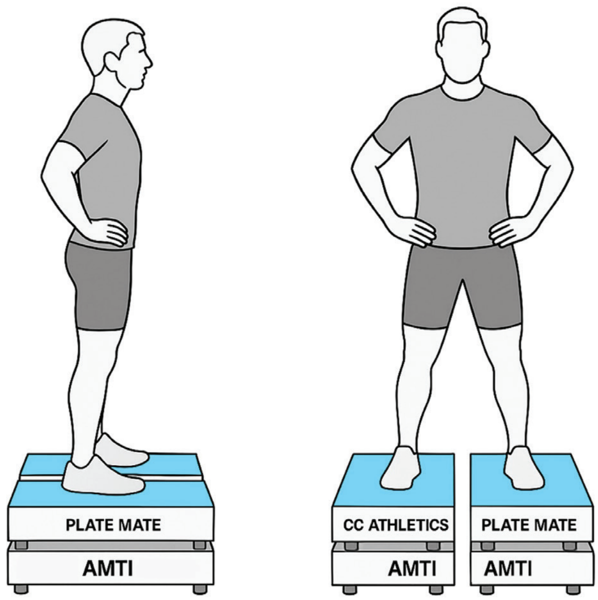

Figure 1. Experimental set-up.

Data Processing

Vertical ground reaction force (vGRF) data was recorded using dual fixed (AMTI BP600400, Watertown, MA, USA) and portable (PlateMate, CC Athletics, Odense, Denmark) three-dimensional force platforms, sampling at 1000Hz and 960Hz, respectively. The vGRF data obtained from both platforms was processed in MATLAB (Statistics Toolbox Release 2025a, The MathWorks, Inc., Natick, MA, USA). Sig-

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nals from both platforms were processed using an identical pipeline with a 2nd-order zero-phase (forward-backward) Butterworth low-pass filter and a cutoff frequency of 50 Hz. The zero-phase implementation eliminated phase distortion at key temporal events such as movement onset and take-off (Winter, 2009). The 50 Hz cutoff was selected following visual inspection of unfiltered and filtered force-time traces for each platform individually, confirming adequate noise attenuation without loss of movement-relevant signal characteristics. Applying a uniform filter across both systems supported methodological comparability between platforms.

Participant's body weight was established during the 2 s motionless period prior to the beginning of each jump. For both the CMJ and CMJH, the onset of the downward movement was marked by a threshold set at five times the standard deviation (SD) of the recorded body weight. When the vGRF dropped below this threshold, it signified the start of the unweighting phase (McMahon et al., 2018). The braking phase was then determined as the interval between the point of minimum vGRF and the return of vGRF to a level that corresponded to the deepest part of the countermovement (i.e., lowest squat position). For all jump conditions, the take-off phase was marked as the point when vGRF exceeded the participant's body weight and continued until it dropped below a threshold of 5*SD of the force recorded during the flight phase, averaged over a 300 ms period. The flight phase was identified as the interval between take-off and landing, during which the vGRF remained near zero. Finally, the landing phase commenced when the vGRF exceeded a 5N threshold value and continued until stabilizing at body weight again.

Variables

The study focused on a refined set of 15 variables for SJ and 24 variables for CMJ and CMJH, selected as the most relevant for vertical jump performance assessment in applied settings (Anicic et al., 2023; Bishop et al., 2022). A relatively broader set was retained because one of the practical strengths of the PlateMate system is its ability to generate and export numerous force-time metrics, allowing coaches and practitioners to look deeper into jump performance. To preserve clarity and readability of the manuscript, only a core subset of key outcome variables is presented in the primary results tables, whereas the descriptive and validity results for the remaining variables are reported in Supplementary Tables S1 and S2. The complete list of analyzed variables is presented in Table 1.

Table 1. Definition of vertical jump variables examined in this study.

Phase	Variable	Description	Unit
Weighing Phase	BW	Body Weight	N
	BM	Body Mass	kg
Unweighting Phase	dt_Fmin	Time from movement onset to the minimum force during the unweighting phase.	s
	dt_UP	Duration of the unweighting phase.	s
	Fmin_UP	Minimum force during the unweighting phase.	N
	Favg_UP	Average force during the unweighting phase.	N
Braking Phase	dt_BP	Duration of the braking phase (time from the end of unweighting to the lowest center of mass position)	s
	hmin_BP	Minimum center of mass displacement during the braking phase.	m
	Fmax_BP	Maximum force recorded during the braking phase.	N
	Favg_BP	Average force during the braking phase.	N
Propulsion (push-off) Phase	dt_PP	Duration of the propulsion phase (time from the lowest center of mass position to push-off).	s
	vto	Velocity at take-off.	$m \cdot s^{-1}$
	Fmax_PP	Maximum force during the propulsion phase.	N
	Favg_PP	Average force during the propulsion phase.	N
	J_PP	Impulse (force x time) during the propulsion phase.	N·s
Flight Phase	dt_FP	Duration of the flight phase (time from push-off to landing).	s
	hmax_FP	Maximum height achieved during the flight phase.	m
Landing Phase	F1_LP	First peak vertical ground reaction force during the landing phase (initial impact peak).	N
	F2_LP	Second peak force during landing (eccentric braking).	N
	dt_F1_LP	Duration of the eccentric part of the landing phase.	s
	dt_F2_LP	Duration of the concentric part of the landing phase.	s
Performance Metrics	RSImod	Reactive strength index modified (Jump height / Time to take-off)	m/s
	hmax_vto	Maximum height calculated from take-off velocity method.	m
	hmax_IMP	Maximum height calculated from impulse-momentum method.	m

Note: kg = kilogram; N = Newtons; s = seconds; m = meters; $m \cdot s^{-1}$ = meters per second; N·s = Newton-seconds.

Statistical analysis

Descriptive statistics were calculated for all SJ, CMJ and CMJH variables. To evaluate the level of agreement between the two systems (i.e., AMTI and PlateMate), the force-time traces were first compared using Bland–Altman analysis (Bland & Altman, 1986), root mean square error (RMSE) and Pearson's correlation coefficient (r). Correlation thresholds were interpreted based on Hinkle et al. (2003) as follows: r <

0.3 (negligible), r = 0.3–0.5 (low), r = 0.5–0.7 (moderate), r = 0.7–0.9 (high), and r = 0.9–1.0 (very high). The force-time traces were examined separately for each plate (i.e., left and right) and for both plates combined.

Subsequently, consistency of key SJ, CMJ and CMJH variables was compared between the two systems by calculating the intraclass correlation coefficient (ICC 3,1), coefficient of variation (CV%) and standard error of measurement (SEM). Additionally, mean difference (MD) and Pearson's correlation coefficient (r) were computed to further assess the agreement between the systems. Statistical significance was determined a priori at $p < 0.05$. The Bland-Altman analyses, RMSE, and r calculations were conducted using the MATLAB toolbox (Klein, 2023), while all other statistical analyses were performed using the SPSS software (IBM SPSS Version 20.0, Chicago, IL, USA).

Table 2. Descriptive statistics for key SJ, CMJ and CMJH variables obtained from AMTI and PlateMate

		SJ		
		AMTI	PlateMate	AMTI vs PlateMate
Phase	Variable (Unit)	Mean ± SD	Mean ± SD	MD
Weighing Phase	BW (N)	761.00 ± 141.19	760.84 ± 142.55	0.15
	BM (kg)	77.57 ± 14.39	77.56 ± 14.53	0.02
Propulsion Phase	dt_PP (s)	0.35 ± 0.04	0.35 ± 0.04	0.00
	Fmax_PP (N)	1771.90 ± 390.81	1742.17 ± 388.47	29.73
Flight Phase	hmax_FP (m)	0.28 ± 0.06	0.28 ± 0.06	0.00
Performance Metrics	RSImod (m/s)	0.78 ± 0.17	0.65 ± 0.19	0.13
			CMJ	
Weighing Phase	BW (N)	756.44 ± 139.19	747.92 ± 139.12	8.52
	BM (kg)	77.11 ± 14.19	76.24 ± 14.18	0.87
Unweighting Phase	dt_UP (s)	0.32 ± 0.05	0.33 ± 0.05	0.00
Braking Phase	dt_BP (s)	0.17 ± 0.03	0.17 ± 0.03	0.00
	Fmax_BP (N)	1802.70 ± 396.86	1783.49 ± 395.48	19.21
Propulsion Phase	dt_PP (s)	0.28 ± 0.02	0.28 ± 0.02	0.00
	Fmax_PP (N)	1830.21 ± 398.52	1809.39 ± 397.49	20.83
Flight Phase	hmax_FP (m)	0.33 ± 0.07	0.33 ± 0.07	0.00
Performance Metrics	RSImod (m/s)	0.42 ± 0.10	0.41 ± 0.11	0.00
			CMJH	
Weighing Phase	BW (N)	757.42 ± 141.76	749.52 ± 141.26	7.90
	BM (kg)	77.21 ± 14.45	76.40 ± 14.40	0.81
Unweighting Phase	dt_UP (s)	0.34 ± 0.06	0.34 ± 0.06	0.00
Braking Phase	dt_BP (s)	0.18 ± 0.05	0.18 ± 0.05	0.00
	Fmax_BP (N)	1622.29 ± 377.85	1607.70 ± 377.12	14.58
Propulsion Phase	dt_PP (s)	0.29 ± 0.04	0.29 ± 0.04	0.00
	Fmax_PP (N)	1871.32 ± 444.19	1845.14 ± 442.69	26.18
Flight Phase	hmax_FP (m)	0.38 ± 0.08	0.38 ± 0.08	0.00
Performance Metrics	RSImod (m/s)	0.46 ± 0.11	0.46 ± 0.12	0.00

Note: SD- Standard Deviation; MD- Mean Difference.

Table 3. Bland-Altman comparison between AMTI and PlateMate raw force-time signals.

		Bias (min÷max)	LoA lower (min÷max)	LoA upper (min÷max)	RMSE (min÷max)	Pearson's r (95% CI)
BOTH	SJ Force-time (N)	11 (-15 ÷ 58)	-82 (-307 ÷ -3)	105 (22 ÷ 401)	50 (10 ÷ 184)	0.988 (0.980 ÷ 0.996)
	CMJ Force-time (N)	10 (-3 ÷ 25)	-54 (-200 ÷ -4)	73 (17 ÷ 203)	35 (9 ÷ 103)	0.997 (0.995 ÷ 0.999)
	CMJH Force-time (N)	9 (-49 ÷ 25)	-67 (-629 ÷ -7)	85 (5 ÷ 673)	41 (8 ÷ 333)	0.993 (0.988 ÷ 0.998)
LEFT	SJ Force-time (N)	6 (-79 ÷ 95)	-108 (-247 ÷ 5)	121 (-21 ÷ 351)	70 (11 ÷ 161)	0.951 (0.938 ÷ 0.964)
	CMJ Force-time (N)	7 (-70 ÷ 122)	-119 (-306 ÷ -10)	134 (36 ÷ 550)	72 (21 ÷ 250)	0.973 (0.965 ÷ 0.980)
	CMJH Force-time (N)	7 (-107 ÷ 128)	-153 (-421 ÷ -11)	166 (46 ÷ 632)	89 (26 ÷ 287)	0.954 (0.942 ÷ 0.967)
RIGHT	SJ Force-time (N)	22 (-13 ÷ 49)	-37 (-155 ÷ 6)	81 (15 ÷ 199)	39 (8 ÷ 93)	0.987 (0.980 ÷ 0.995)
	CMJ Force-time (N)	18 (-3 ÷ 43)	-28 (-90 ÷ 1)	63 (8 ÷ 159)	31 (5 ÷ 73)	0.996 (0.994 ÷ 0.998)
	CMJH Force-time (N)	16 (-36 ÷ 39)	-34 (-295 ÷ -4)	67 (6 ÷ 349)	33 (4 ÷ 166)	0.992 (0.986 ÷ 0.998)

Note: LoA lower/ upper– Lower/ Upper Limits of Agreement; min- Minimum; max- Maximum; RMSE- Root Mean Square Error; Pearson's r- Pearson's Correlation Coefficient; 95% CI- 95% Confidence Interval.

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Results

Descriptive statistics for the key variables pertaining to SJ, CMJ and CMJH are presented in Table 2. The complete descriptive statistics for all analyzed variables are provided in Supplementary Table S1.

Table 3 and Figure 2 present the comparison between vGRF force-time traces from the AMTI and PlateMate, for each plate separately (i.e., left and right), and for both plates combined.

Validity measures for key variables are summarized in Table 4 for SJ, CMJ and CMJH. The full validity statistics for all analyzed variables are provided in Supplementary Table S2.

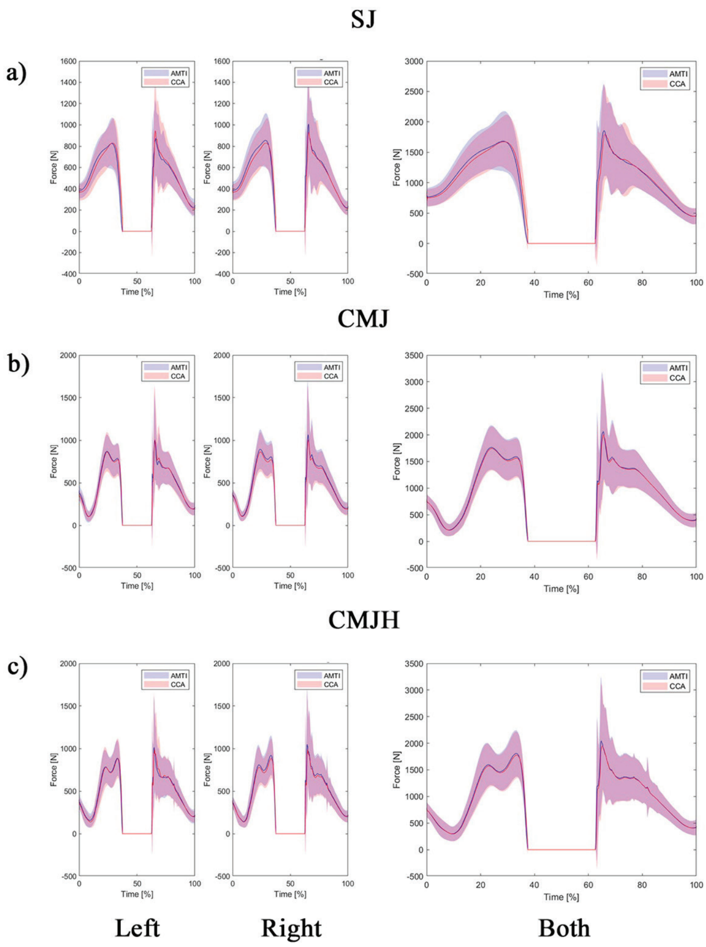

Figure 2. Comparison between AMTI and PlateMate force plate vertical ground reaction force-time traces. Left panel represents the signals for left and right plates individually. Right panel represents the signal for both plates collectively. The solid blue lines represent data from the AMTI system, and the red lines represent data from the PlateMate force plate system. The shaded areas represent variability (95% confidence intervals).

Table 4. Validity statistics for key SJ, CMJ and CMJH variables obtained from AMTI and PlateMate

		SJ			
Phase	Variable (Unit)	ICC (95% CI)	CV%	SEM	r
Weighing Phase	BW (N)	0.998 (0.998 ÷ 0.999)	1.02	7.79	0.997*
	BM (kg)	0.998 (0.998 ÷ 0.999)	1.02	0.80	0.699*
Propulsion Phase	dt_PP (s)	0.996 (0.995 ÷ 0.998)	1.00	0.00	0.993*
	Fmax_PP (N)	0.999 (0.999 ÷ 0.999)	0.46	8.03	0.999*
Flight Phase	hmax_FP (m)	0.999 (0.999 ÷ 0.999)	0.27	0.00	0.999*
Performance Metrics	RSImod (m/s)	0.821 (0.739 ÷ 0.877)	13.80	0.10	0.997*
		CMJ			
Weighing Phase	BW (N)	0.999 (0.999 ÷ 0.999)	0.36	2.74	0.999*
	BM (kg)	0.999 (0.999 ÷ 0.999)	0.36	0.28	0.999*
Unweighting Phase	dt_UP (s)	0.999 (0.998 ÷ 0.999)	0.80	0.00	0.998*
Braking Phase	dt_BP (s)	0.999 (0.999 ÷ 0.999)	0.67	0.00	0.998*
	Fmax_BP (N)	0.999 (0.999 ÷ 0.999)	0.37	6.62	0.999*

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Table 4. Validity statistics for key SJ, CMJ and CMJH variables obtained from AMTI and PlateMate

		CMJ			
Phase	Variable (Unit)	ICC (95% CI)	CV%	SEM	r
Propulsion Phase	dt_PP (s)	0.997 (0.996 ÷ 0.998)	0.60	0.00	0.995*
	Fmax_PP (N)	0.999 (0.999 ÷ 0.999)	0.36	6.62	0.999*
Flight Phase	hmax_FP (m)	0.999 (0.999 ÷ 0.999)	0.68	0.00	0.999*
Performance Metrics	RSImod (m/s)	0.993 (0.989 ÷ 0.995)	3.01	0.01	0.986*
		CMJH			
Weighing Phase	BW (N)	0.999 (0.999 ÷ 0.999)	0.82	6.15	0.998*
	BM (kg)	0.999 (0.999 ÷ 0.999)	0.82	0.63	0.998*
Unweighting Phase	dt_UP (s)	0.996 (0.995 ÷ 0.997)	1.54	0.01	0.993*
Braking Phase	dt_BP (s)	0.999 (0.999 ÷ 0.999)	0.57	0.00	0.999*
	Fmax_BP (N)	0.999 (0.999 ÷ 0.999)	0.56	9.00	0.999*
Propulsion Phase	dt_PP (s)	0.999 (0.999 ÷ 0.999)	0.56	0.00	0.998*
	Fmax_PP (N)	0.999 (0.999 ÷ 0.999)	0.62	11.46	0.999*
Flight Phase	hmax_FP (m)	0.999 (0.999 ÷ 0.999)	0.42	0.00	0.999*
Performance Metrics	RSImod (m/s)	0.988 (0.982 ÷ 0.991)	3.91	0.02	0.976*

Note: ICC- Intraclass Correlation Coefficient; 95% CI- 95% Confidence Interval; CV%- Coefficient of Variation (%); SEM-Standard Error of Measurement; r- Pearson's r; * p<.001.

Discussion

This study set out to validate the feasibility of PlateMate portable force plates compared to a laboratory-grade AMTI system across SJ, CMJ and CMJH. Overall, the results demonstrated an excellent agreement between the systems, both in terms of the raw force-time signal comparisons and the subsequently derived variables. These findings suggest that PlateMate represents a viable, field-ready alternative to traditional laboratory-based force plates. Below, we discuss the findings in detail.

For all the observed variables, the descriptive results produced mean values that fall within expected ranges reported in the literature for similar populations (Claudino et al., 2017; Collings et al., 2024; Ferná Ortega et al., 2022; Mandic et al., 2016), with minimal differences between the systems. For instance, in CMJ, mean jump height was approximately 0.30–0.33 m in both the PlateMate and AMTI. The CMJH condition naturally improved performance (~0.35–0.40 m), reflecting the well-known contribution of arm momentum to jump height gain (Hara et al., 2006). The squat jump, which involves no preparatory countermovement, yielded slightly lower mean heights (~0.25–0.28 m) in both systems.

Other basic outcome measures showed a similar pattern, such as the Fmax which was around 1.5–2.0 times body weight in both systems, a typical value reported for maximal effort jumps in non-elite athletes (Collings et al., 2024; Donahue et al., 2021). These descriptive comparisons indicate that PlateMate not only measures similar magnitudes of performance as the laboratory-grade force plates, but also that the sample's performance was expected for their level.

Validity: raw force-time signal comparisons

Beyond descriptive statistics, the PlateMate demonstrated a near-perfect agreement to the "gold standard" when comparing raw force-time signals across all jump types, both for each plate individually (i.e., left and right) and combined. Specifically, the Bland–Altman analysis yielded trivial systematic bias between the systems across all jump conditions, with the mean difference in the recorded force at any given time point on the order of 9-11 N for the combined signal of both plates, and 6-22 N for individual plates (<2% bias when compared to the typical peak vGRF values). The 95% LoA were also narrow, spanning between -54 and 105 N for all jumps (less than 10% deviation relative to peak vGRF values). When analyzing the plates individually, the limits of agreement were slightly wider (-28 – 166 N), likely due to natural asymmetries in bilateral force production and greater sensitivity to small variations in signal timing or magnitude (Bell et al., 2014; Impellizzeri et al., 2007). Regardless, this level of agreement meets acceptable criteria for variability in biomechanical measurements (Lake et al., 2018) and indicates that PlateMate accurately captures not only the peak force, but the entire profile of the force-time curve. The reported RMSE values further confirm an exceptional accuracy of PlateMate, with average errors < 50 N for combined plates, and < 89 N for individual plates. Moreover, when each force-time record was treated as a series and correlated with its counterpart, correlations were extremely high and consistently exceeded 0.95 for all jump types.

These results confirm that the PlateMate system is feasible for both single-plate and dual-plate applications. Furthermore, it is worth noting that portable force-plates typically do not offer the option to export raw force-time data, which is a distinguished strength of the PlateMate system. The ability to access and export raw data allows for more detailed, customized analysis and facilitates transparency in data handling, enabling researchers and practitioners to independently verify results or apply their own specific analysis methods.

Validity: SJ-derived metrics

Building on these results, 13 out of 15 variables analyzed in SJ demonstrated excellent agreement between the systems (ICC > 0.974, CV% < 10%) and minimal measurement

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errors (e.g., 0.00 - 0.06 m for jump height and 0.00 - 0.05 s for time-derived variables). Correlations were also very high ($r > 0.950$) for the vast majority of variables, further confirming the strength of agreement between devices. The only exceptions were BM and hmax_vto, which showed moderate correlation ($r = 0.699$ and 0.585, respectively), though the mean difference between devices was negligible in practical terms (0.02 kg and 0.04 m, respectively). The hmax_vto also exhibited higher variability (CV% = 14.57), which is expected in the SJ condition where take-off velocity is lower than in CMJ. In such cases, even a small absolute difference between devices translates into a proportionally larger percentage error, thereby inflating the CV%. Additionally, any minor residual countermovement at take-off can further influence the velocity calculation and contribute to this variability.

Some exceptions were also observed in the RSImod which demonstrated slightly lower agreement (ICC = 0.821) and greater variability (CV% = 13.80). This, again, likely stems from the nature of the SJ test, where athletes start from a static squat position and initiate the concentric phase directly. Additionally, the SJ typically features shorter propulsion times and lower jump heights due to the absence of stored elastic energy from a countermovement. These factors may amplify the relative impact of small timing inconsistencies or measurement noise, especially when calculating ratios like RSImod, which are sensitive to small absolute changes in both jump height and time to take-off. Moreover, Bishop et al. (2018) and Gathercole et al. (2015b) both emphasized that RSImod is task-dependent and is most valid in movements with a clear eccentric-concentric transition (e.g., CMJ or drop jump) (Bishop et al., 2018; Gathercole et al., 2015b). Consequently, computing RSImod in the context of a squat jump is more prone to variability and less reliable.

Validity: CMJ and CMJH-derived metrics

Out of the 24 variables analyzed for the CMJ task, 22 variables demonstrated a near-perfect agreement (ICC ≥ 0.990), while the rest of the variables still showed an excellent agreement (ICC > 0.973). For the CMJH, 20 variables showed a near-perfect agreement (ICC ≥ 0.991) and 4 demonstrated an excellent agreement (ICC > 0.950).

Furthermore, the coefficients of variation between the systems were generally very low, falling below 5% for robust measures like jump height, peak force, and time-derived metrics, and below 10% for the rest of the variables examined. Such low CV% values suggest that the typical error or noise between the devices was small relative to the mean values. For example, the standard error of measurement (SEM) was as low as 0.00-0.01 m for jump height and 0.00-0.06 s for time-derived variables, which is practically negligible when evaluating athlete performance. It is particularly important to note that the SEM for push-off phase duration was 2 ms (0.002 s), which aligns with recommendations from previous studies who suggest that a deviation of less than 3 ms is critical to avoid inaccuracies in subsequent calculations of vertical velocity, displacement, or jump height (Hori et al., 2009; McMahon et al., 2018; Kibele, 1998).

The only exception was F2_LP where CV% was slightly over the 10% mark. This aligns with findings from Impellizzeri et al. (2007), who noted that eccentric braking measures tend to show higher variability and are more affected by asymmetries and coordination differences (Impellizzeri et al., 2007). Similarly, correlations were very high ($r \geq 0.905$) for all variables, indicating very high to near-perfect agreement between PlateMate and the AMTI system.

Study limitations

Overall, this study confirms that PlateMate delivers measurements that are virtually interchangeable with those of a laboratory-grade force plate for vertical jump assessment. From an applied perspective, PlateMate offers measurement accuracy while also providing key advantages in portability and cost-effectiveness. Despite strong validation results, several limitations must be acknowledged. First, the study included a modest sample size (n=17) which consisted solely of recreational athletes. While the statistical power analysis indicated that this number was sufficient for detecting large correlations, a larger sample might have allowed for more nuanced analyses (e.g., subgroup analyses by sex) and further increased the generalizability of findings.

Second, our testing protocol focused on the SJ, CMJ, and CMJH jump variations. The validity of PlateMate for measuring other tasks, or generally for capturing asymmetrical force outputs, remains to be verified. In our setup, participants jumped with both feet on separate force plates, and we analyzed the individual and combined force-time signal outputs. However, we did not explore asymmetries or unilateral metrics. For practitioners interested in using force plates to detect imbalances, further research should confirm that PlateMate can reliably quantify asymmetry to the same degree as laboratory-grade systems.

Finally, this study did not include a formal test-retest reliability analysis of the PlateMate system, as the primary objective was to evaluate its concurrent validity against the AMTI force plate. However, the exceptionally high ICCs and low between-device variability (CV% < 10%) suggest minimal inherent measurement noise. It is therefore reasonable to expect that PlateMate would demonstrate similarly strong reliability across repeated sessions. Nevertheless, future research should directly assess its test-retest reliability to support its use in longitudinal monitoring.

Conclusion

In conclusion, this study provides strong evidence that PlateMate is a viable solution for vertical jump assessment, delivering accuracy that is comparable to laboratory-grade force plates. Specifically, PlateMate demonstrated a near-perfect agreement with the "gold standard" (i.e., AMTI) when comparing both the raw force-time signals, and the subsequently derived variables of SJ, CMJ, and CMJH. These findings are significant for sports and rehabilitation experts as they verify that a portable and cost-effective force plate system can deliver high-quality data without the typical constraints of a laboratory-bound equipment.

Furthermore, the option to export raw force-time signals gives practitioners greater analytical flexibility compared to many subscription-based portable platforms. This makes PlateMate especially valuable for conducting detailed neuromuscular assessments in a wide range of training and rehabilitation environments. By doing so, PlateMate holds great promise for enhancing athlete monitoring, training optimization, and rehabilitation tracking.

Validating PlateMate against an industry benchmark expands the toolkit available for applied sport science, helping bring lab-level measurement quality closer to everyday practice. With its combination of accuracy, portability, and user-friendly access to raw data, PlateMate is poised to make advanced jump monitoring more accessible than ever, thereby contributing to better-informed training decisions and improved athlete development in both sports and rehabilitation settings.

Author Contributions

Conceptualization, D.M.M.; Methodology, D.M.M., J.A., and Z.A.; Formal analysis, J.A., and D.M.M..; Data curation, Z.A., M.S., and D.N.; Writing—original draft preparation, J.A., D.M.M.; Writing—review and editing, J.A., Z.A., M.S., D.N, O.M.K, and D.M.M. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board of the University of Belgrade, Faculty of Sport and Physical Education—#02-848/23-2 (Approved on: 5 May 2023).

Informed Consent Statement

Written informed consent was obtained from all subjects involved in the study.

Data Availability Statement

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

Conflicts of Interest

The authors declare no conflicts of interest.

References

Claudino, J. G., Cronin, J., Mezêncio, B., McMaster, D. T., McGuigan, M., Tricoli, V., Amadio, A. C., & Serrão, J. C. (2017). The countermovement jump to monitor neuromuscular status: A meta-analysis. *Journal of Science and Medicine in Sport, 20*, 397–402.

Anicic, Z., Janicijevic, D., Knezevic, O. M., Garcia-Ramos, A., Petrovic, M. R., Cabarkapa, D., & Mirkov, D. M. (2023). Assessment of countermovement jump: What should we report? *Life (Basel)*, *13*(1), 190.

Hubley, C. L., & Wells, R. P. (1983). A work-energy approach to determine individual joint contributions to vertical jump performance. *European Journal of Applied Physiology and Occupational Physiology, 50*, 247–254.

Lichtwark, G. A., Schuster, R. W., Kelly, L. A., Trost, S. G., & Bialkowski, A. (2024). Markerless motion capture provides accurate predictions of ground reaction forces across a range of movement tasks. *Journal of Biomechanics, 166*, 112051.

Mandic, R., Knezevic, O. M., Mirkov, D. M., & Jaric, S. (2016). Control strategy of maximum vertical jumps: The preferred countermovement depth may not be fully optimized for jump height. *Journal of Human Kinetics, 52*, 85–94. https://doi.org/10.1515/hukin-2015-0196

Hori, N., Newton, R. U., Kawamori, N., McGuigan, M. R., Kraemer, W. J., & Nosaka, K. (2009). Reliability of performance measurements derived from ground reaction force data during countermovement jump and the influence of sampling frequency. *Journal of Strength and Conditioning Research, 23*, 874–882.

McMahon, J. J., Suchomel, T. J., Lake, J. P., & Comfort, P. (2018). Understanding the key phases of the countermovement jump force-time curve. *Strength and Conditioning Journal, 40*(4), 96–106. https://doi.org/10.1519/SSC.0000000000000375

Kibele, A. (1998). Possibilities and limitations in the biomechanical analysis of countermovement jumps: A methodological study. *Journal of Applied Biomechanics, 14*, 105–117

Cormie, P., McBride, J. M., & McCaulley, G. O. (2009). Power-time, force-time, and velocity-time curve analysis of the countermovement jump: Impact of training. *Journal of Strength and Conditioning Research, 23*, 177–186.

Chavda, S., Bromley, T., Jarvis, P., Williams, S., Bishop, C., Turner, A., Lake, J., & Mundy, P. (2017). Force-time characteristics of the countermovement jump: Analyzing the curve in Excel. *Strength and Conditioning Journal, 40*(1), 1. https://doi.org/10.1519/SSC.0000000000000353

Pontillo, M., Hines, S. M., & Sennett, B. J. (2021). Prediction of ACL injuries from vertical jump kinetics in Division 1 collegiate athletes. *International Journal of Sports Physical Therapy, 16*(1), 156–161.

Aleksic, J., Mesaroš, D., Kanevsky, D., Knežević, O. M., Cabarkapa, D., Faj, L., & Mirkov, D. M. (2024). Advancing field-based vertical jump analysis: Markerless pose estimation vs. force plates. *Life (Basel, Switzerland)*, *14*(12), 1641. https://doi.org/10.3390/life14121641

Collings, T. J., Lima, Y. L., Dutaillis, B., & Bourne, M. N. (2024). Concurrent validity and test–retest reliability of VALD ForceDecks' strength, balance, and movement assessment tests. *Journal of Science and Medicine in Sport, 27*(8), 572–580. https://doi.org/10.1016/j.jsams.2024.04.014

Leard, J. S., Cirillo, M. A., Katsnelson, E., Kimiatek, D. A., Miller, T., Trebinčević, K., & Garbalosa, J. (2007). Validity of two alternative systems for measuring vertical jump height. *Journal of Strength and Conditioning Research, 21*(4), 1296–1299. https://doi.org/10.1519/R-21536.1

Balsalobre-Fernández, C. (2015). My Jump: A new method to measure vertical jump height on iPhone. *Journal of Sports Sciences*, *33*(16), 1574–1579.

Gathercole, R. J., Stellingwerff, T., & Sporer, B. C. (2015a). Effect of acute fatigue and training adaptation on countermovement jump performance in elite snowboard cross athletes. *The Journal of Strength & Conditioning Research, 29*(1), 37–46.

Petronijevic, M. S., Garcia Ramos, A., Mirkov, D. M., Jaric, S., Valdevit, Z., & Knezevic, O. M. (2018). Self-preferred initial position could be a viable alternative to the standard squat jump testing procedure. *Journal of Strength and Conditioning Research, 32*(11), 3267–3275. https://doi.org/10.1519/JSC.0000000000002385

Winter, D. A. (2009). *Biomechanics and motor control of human*

DOI 10.26773/mjssm.260904

movement (4th ed.). John Wiley & Sons.

Bishop, C., Jordan, M., Torres-Ronda, L., Loturco, I., Harry, J., Virgile, A., Mundy, P., Turner, A., & Comfort, P. (2022). Selecting metrics that matter: Comparing the use of the countermovement jump for performance profiling, neuromuscular fatigue monitoring, and injury rehabilitation testing. *Strength and Conditioning Journal.* Advance online publication. https://doi.org/10.1519/SSC.0000000000000772

Bland, J. M., & Altman, D. G. (1986). Statistical methods for assessing agreement between two methods of clinical measurement. *The Lancet, 1*, 307–310. https://doi.org/10.1016/S0140-6736(86)90837-8

Hinkle, D. E., Wiersma, W., & Jurs, S. G. (2003). *Applied statistics for the behavioral sciences* (5th ed.). Houghton Mifflin.

Klein, R. (2023). *Bland-Altman and correlation plot* [MATLAB Central File Exchange]. MathWorks. https://www.mathworks.com/matlabcentral/fileexchange/45049-bland-altman-and-correlation-plot

Ferná Ortega, J. A., Mendoza Romero, D., Sarmento, H., Prieto Mondragón, L., & Rodríguez Buitrago, J. A. (2022). Relationship between dynamic and isometric strength, power, speed, and average propulsive speed of recreational athletes. *Journal of Functional Morphology and Kinesiology, 7*, 79. https://doi.org/10.3390/jfmk7040079

Hara, M., Shibayama, A., Takeshita, D., & Fukashiro, S. (2006). The effect of arm swing on lower extremities in vertical jumping. *Journal of Biomechanics, 39*(13), 2503–2511. https://doi.org/10.1016/j.jbiomech.2005.07.030

Donahue, P. T., Wilson, S. J., Williams, C. C., Hill, C. M., & Garner, J. C. (2021). Comparison of countermovement and squat jumps performance in recreationally trained males. *International Journal of Exercise Science, 14*(1), 462–472. https://doi.org/10.70252/FXQB8485

Bell, D. R., Sanfilippo, J. L., Binkley, N., & Heiderscheit, B. C. (2014). Lean mass asymmetry influences force and power asymmetry during jumping in collegiate athletes. *Journal of Strength and Conditioning Research*, *28*(4), 884–891. https://doi.org/10.1519/JSC.0000000000000320

Impellizzeri, F. M., Rampinini, E., Maffiuletti, N., & Marcora, S. M. (2007). A vertical jump force test for assessing bilateral strength asymmetry in athletes. *Medicine & Science in Sports & Exercise, 39*(11), 2044–2050. https://doi.org/10.1249/mss.0b013e31814fb55c

Lake, J., Mundy, P., Comfort, P., McMahon, J. J., Suchomel, T. J., & Carden, P. (2018). Concurrent validity of a portable force plate using vertical jump force-time characteristics. *Journal of Applied Biomechanics, 34*(5), 410–413. https://doi.org/10.1123/jab.2017-0371'

Bishop, C., Read, P., Lake, J., Chavda, S., & Turner, A. (2018). Inter-limb asymmetries: Understanding how to calculate differences from bilateral and unilateral tests. *Strength and Conditioning Journal, 40*. https://doi.org/10.1519/SSC.0000000000000371

Gathercole, R. J., Sporer, B. C., Stellingwerff, T., & Sleivert, G. G. (2015b). Alternative countermovement-jump analysis to quantify acute neuromuscular fatigue. *International Journal of Sports Physiology and Performance, 10*(1), 84–92.

ORIGINAL SCIENTIFIC PAPER

Internal load of a repeated sprint protocol in pubertal soccer players exposed to moderate altitude

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Abstract

This study aimed to describe the performance on a repeated sprint test and assess internal load in youth soccer players at an altitude of 2650 meters. Sixty regional-level soccer players (age 14.1±1.7 years) participated in an RSA 7x30m-20" test. The study assessed height, body mass, fat mass, and Peak Height Velocity (PHV). Heart rate (HR) and blood lactate (LA) levels were monitored, and theoretical fatigue was estimated using the Fatigue Index (FI) and percentage decrement score (Sdec%). Descriptive and correlational statistics were employed for data analysis of anthropometry, performance, and internal load. ANOVA was used to compare different indicators across age groups. Across the sample, HR increased from 109±1 to 181±9 bpm during the protocol. LA mmol/L levels rose significantly at various points: pre-test vs. fourth repetition ($t=18.706$, $p<0.001$), fourth repetition vs. post-test ($t=9.115$, $p<0.001$), and pre-test vs. post-test ($t=33.919$, $p<0.001$). Performance results indicated that the 12-year-old group performed lower than other groups ($F=12.261$, $p<0.001$). The study concludes that RSA performance in the 7x30m-20" at 2650 improves with increasing age. LA and estimated fatigue were slightly higher in older participants; however, substantial inter-individual variability was observed in internal load.

Keywords: *youth soccer; heart rate, lactate, repeated sprints, sports performance*

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Introduction

The external load has been extensively studied in soccer (Maughan et al., 2021), showing that the volume of high-intensity running (19.8–25.1 km/h) varies between 335–596 meters (Gualtieri et al., 2023) and maximum speed (> 25.1 km/h) between 96–295 meters in professional competitions (Pons et al., 2021). This fact increases the importance of evaluating and developing the ability to perform repeated sprints

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RSA in players (Gualtieri et al., 2023). RSA tests are performed in the field, executing various sprints interspersed with brief recovery periods (Girard et al., 2011). Currently, various RSA protocols are implemented with differing numbers of repetitions (e.g., 6, 7, or 8), distances (e.g., 10m, 20m, or 30m), and recovery times (e.g., 15s, 20s, or 25s). However, there is no established "Gold Standard" RSA protocol that includes linear or change-of-direction movements, nor one that specifies whether to use a ball (Thurlow et al., 2024; Kyles et al., 2023).

The RSA test is consistently regarded as a specific assessment for soccer players (Castagna et al., 2018). It is dependent on the glycolytic power of the muscles and the phosphagen reserves, which ensure physiological responses (internal load) similar to those experienced during intense game periods. For instance, maximum heart rates (HR) can reach around 187 ± 9 bpm, and mean blood lactate (LA) levels 7.9 ± 0.7 mmol/L (Krustrup et al., 2006), therefore, RSA is also often recognized as a test with ecological validity (Fernández-Da-Silva et al., 2019; Castagna et al., 2018). Also, RSA best sprint and RSA mean are the most used indicators to express the RSA performance (Kyles et al., 2023; Castagna, 2018; Gibson et al., 2017; Padulo et al., 2015), and they are also necessary to estimate theoretical fatigue indicators in RSA protocols such as the fatigue index FI and the percentage decrement score Sdec% (Girard et al., 2011; Bishop et al., 2001).

On the other hand, the altitude at which soccer players compete affects the performance of teams and players (Levine et al., 2008), being a factor that benefits the locals; for this reason, FIFA categorized the altitudes as follows: near to sea level 0-500m, low altitude >500m-2000m, moderate altitude >2000m-3000m, high altitude >3000m-5,500m and extreme altitude +5,500m (Bärtsch et al., 2008). Several studies have analyzed training methods under altitude conditions controlled by hypobaric chambers (Girard et al., 2017; Brocherie et al., 2017). As altitude increases, air pressure changes, leading to what is known as hypoxic work. Under these conditions, the internal load rises during maximum efforts at moderate and high altitudes compared to sea level (Girard et al., 2017; Gore et al., 2008). While indicators such as HR and LA tend to show higher values, sprint performance may improve at high altitudes. However, repeated sprint ability (RSA) generally decreases performance (Girard et al., 2017; Brocherie et al., 2017; Salazar-Martínez et al., 2025).

Studies examining RSA in pre-pubertal and pubertal soccer players typically include participants from the same squad and present the RSA results by a large range of age (Rey et al., 2019; Buchheit and Mendez-Villanueva, 2014). The most frequently explored topic is the effectiveness of training programs in improving performance (Thurlow et al., 2024; Kyles et al., 2023). Examining results by age groups could better explain the performance and internal load of players observed within growth stages. Research on RSA during adolescence at moderate altitude is limited. Therefore, the present study aims to describe the performance in the RSA 7x30m-20" test, as well as the physiological responses of HR and LA in youth soccer players from Bogotá, DC.

Methods

Participants

Sixty soccer players from three clubs in Bogotá, Colombia, participated in this study. All players were acclimatized to altitude, as they reside in the city at an elevation of approximately 2,650 meters above sea level. The assessments were conducted on separate days at each club during regular training sessions. Eligibility criteria included being between 12 and 16 years old, training four days per week, and having authorization from the coach and the club's medical team, with only injury-free players included. All participants regularly competed in official tournaments, trained for 10 to 12 hours per week, and were affiliated with the Bogotá Soccer League. Parents and guardians provided written authorization through an informed consent form, which detailed the study's general aspects, the tests to be conducted, and the data processing in accordance with the ethical principles established in the Declaration of Helsinki. This research was authorized by the clubs involved and approved by the Santo Tomas University Ethics Committee No. 006 of 2024.

Procedures and materials

Chronological age was calculated according to the difference between the assessment date and the date of birth. Basic anthropometry measurements were performed, including height, body mass, and skinfold thickness (triceps-subscapularis). Fat mass was estimated according to the protocol for youth ages proposed by (Slaughter et al., 1988), corresponding to % fat = 1.21*(triceps skinfold + subscapularis skinfold) - 0.008*(triceps skinfold + subscapularis skinfold) ^{2} - 3.4. The peak Height Velocity PHV was calculated (Mirwald et al., 2002), where PHV = -9.236 + 0.0002708 (Lower limb length * Trunk length) - 0.001663 (Age * Lower limb length) + 0.007216 (Age * Trunk length) + 0.02292 (Body mass/height * 100).

A standardized warm-up protocol was implemented, consisting of slow jogging, dynamic stretching, and 20-meter runs at varying speeds to adequately prepare participants for subsequent testing. Following the warm-up, participants completed the RSA protocol, which involved seven 30-meter sprints with 20 seconds of active recovery between each repetition. HR bpm was continuously monitored using Polar M400 devices equipped with H-9 Bluetooth Smart sensors before the test began and after each sprint repetition. Additionally, LA, (mmol/L) was measured via finger stick at three specific time moments: prior to the test, after the fourth sprint, and immediately following completion of the RSA. The assessment utilized a range of specialized equipment, including Polifemo-radio version 2.0 infrared photocells for sprint timing, a SECA 213 portable stadiometer for height measurement, a SECA 874 floor scale for body mass assessment, Harpenden Calipers model SFC-1000 for skinfold thickness evaluation, a CASIO HS70 stopwatch for timekeeping, and a Lactate Scout 4Start analyzer for lactate measurements.

Variables obtained from the 7x30m-20" RSA test

The RSA mean time of all repetitions was considered the primary RSA performance variable. The best sprint was also considered, and the maximum speed attained was calculated using the formula: Max Speed (km/h) = distance / best time. Finally, theoretical fatigue was estimated using the fatigue index FI, presented below as equation 1 (Bishop et al., 2001), and percentage decrement score (Sdec%), presented as equation 2 (Spencer et al., 2005).

Equation 1.

$$\boldsymbol{FI} = 100 * \frac{(best\ sprint - worst\ sprint)}{Best\ sprint}$$

Equation 2.

$$\boldsymbol{Sdec}\,\% = 1 - \frac{(S1 + S2 + S3 + S\ Final)}{Best\ sprint * \#\ sprints} * 100$$

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Analysis

A priori sample size was calculated from G * Power software (V3.1.9.2, University of Kiel, Germany). The α and power (1-β) were defined as 0.05 and 0.80, respectively, by inference, sample size of the current study is considered satisfactory. Data analysis comprised descriptive statistics for anthropometric measurements and RSA 7x30m-20" performance across the total sample. In addition, simple correlation analyses were conducted to examine relationships between test performance, HR, LA and fatigue. Finally, comparisons between age groups (12, 13, 14, and 15 years) were performed using analysis of variance (ANOVA).

The significance level was set at 5% for inferential statistics, and correlation coefficients were interpreted as follows: likely ($r < 0.1$), small ($0.1 < r < 0.3$), moderate ($0.3 < r < 0.5$), large ($0.5 < r < 0.7$), very large ($0.7 < r < 0.9$) and near-perfect ($r > 0.9$). The statistical packages IBM SPSS version 27 (IBM Corp., Armonk, NY, USA) and GraphPad Prism version 8 (GraphPad Software, San Diego, California, USA, www.graphpad.com) were used.

Results

The anthropometric characteristics of the participants are summarized in Table 1, height and body mass increased with chronological age, while fat mass decreased. Considering the total sample, simple Pearson correlations showed that RSA performance associated with age $p<0.01$, height $p<0.05$, body mass $p<0.05$, and PHV $p<0.01$; that is, as these values increased, test performance improved.

Table 1. Characterization of participants and correlations according to the performance of the RSA 7x30m-20", heart rate, and blood lactate at the end of the test.

variable	age group	X	±	SD	correlation		
					RSA	HR post	LA post
Age (yrs)	Total	14.1	±	1.07	-0.51†	0.20	0.19
	12	12.4	±	0.27	0.66	0.18	0.30
	13	13.4	±	0.26	-0.18	-0.07	-0.59†
	14	14.5	±	0.26	-0.13	0.23	0.05
	15	15.5	±	0.62	-0.28	0.31	0.34
Height (cm)	Total	161.8	±	8.51	-0.31*	0.16	0.07
	12	148.8	±	4.40	-0.35	0.29	-0.64
	13	160.9	±	5.69	0.15	-0.11	-0.07
	14	163.4	±	7.85	0.30	0.09	-0.26
	15	167.8	±	7.56	-0.14	-0.12	0.27
Body mass (kg)	Total	50.2	±	9.42	-0.30*	0.23	0.04
	12	37.2	±	4.93	-0.21	0.78*	-0.10
	13	50.5	±	9.01	0.07	0.23	-0.27
	14	51.5	±	8.51	0.20	0.69	0.28
	15	55.1	±	7.28	-0.37	-0.04	0.18
Fat mass (%)	Total	15.2	±	4.75	0.26*	-0.11	-0.04
	12	17.5	±	6.59	0.32	-0.33	-0.14
	13	15.6	±	5.35	0.11	0.21	-0.01
	14	14.3	±	4.47	-0.25	-0.29	-0.14
	15	14.8	±	2.63	0.29	0.34	0.25
PHV (yrs)	Total	-0.37	±	1.02	-0.43†	0.23	0.12
	12	-2.00	±	0.28	0.50	0.44	0.07
	13	-0.76	±	0.60	0.13	0.11	-0.53*
	14	-0.12	±	0.66	0.21	-0.03	-0.06
	15	0.76	±	0.73	-0.21	0.11	0.22

Total= (n=60); 12= (n=7);13= (n=21);14= (n=19);15= (n=13); *= p<0.05; †= p<0.01

The associations mentioned before disappeared when the anthropometric is correlated by age group. Finally, regarding the internal load generated after completing the test, only body mass was associated with final HR in the 12-year-old group $p<0.05$, age with LA post-test $p<0.01$, and PHV with LA post-test in the 13-year-old group $p<0.05$.

Regarding the RSA performance, Figure 1 illustrates the values for each sprint repetition, indicating a trend of higher performance in the initial sprints, followed by a progressive decline over the course of the test. Table 2 shows that RSA was not associated with the estimated theoretical fatigue indicators (FI and Sdec%). In contrast, HR was significantly correlated with RSA mean, RSA best time, and max speed (km/h) $p<0.05$, whereas no significant correlations were observed for lactate. Finally, FI and Sdec% were not associated with HR and LA post-tests.

Figure 2 shows the HR before and throughout the RSA 7x30m-20" for the whole sample. HR pre: 109±16 bpm; HR 1s: 154±13 bpm; HR 2s: 169±13 bpm; HR 3s: 175±10 bpm; HR 4s: 177±10 bpm; HR 5s: 176±11 bpm; HR 6s: 180±11 bpm; HR

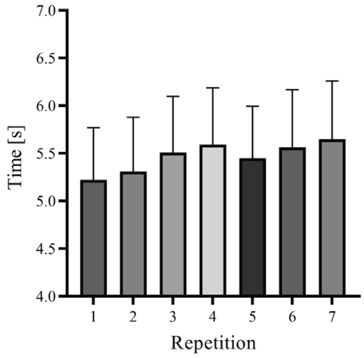

Figure 1. Performance of the RSA 7x30m-20" for each repetition expressed in RSA mean for the total sample (n=60).

Table 2. Performance of the RSA 7x30m-20", relationship with physiological indicators, and correlations between estimated theoretical fatigue and internal load of the test in the total of participants (n=60)

variable	X	±	D.E	correlation		
				RSA	HR Post	LA Post
RSA Mean (s)	5.46	±	0.54	-	-0.27*	-0.09
RSA Min (s)	5.13	±	0.51	0.95†	-0.28*	-0.13
Max. Speed (km/h)	21.23	±	2.16	-0.93†	0.28*	0.14
RSA Fatigue Index	-13.54	±	6.43	-0.07	0.01	-0.09
RSA ($S_{dec\%}$).	-6.55	±	3.60	-0.01	-0.04	-0.01

$S_{dec\%}$ = Percentage decrement score; *= p<0.05; †= p<0.01

post: 181±9 bpm. The most accelerated increase is between the pre-test and the first sprint. It gradually increases until reaching a small plateau between the 4th and 5th sprint but continues to increase until the end of the protocol. In parallel, the lactate values are represented in Figure 3, where LA increases as the test progresses: LA pre: 2.3±0.8 mmol/L; LA 4s: 8.3±2.1 mmol/L; LA post:11.2±2.1. Comparisons pre vs 4s t= 18.706; pre vs post t= 33.919 and 4s vs post t= 9.115 in all cases p<0.001.

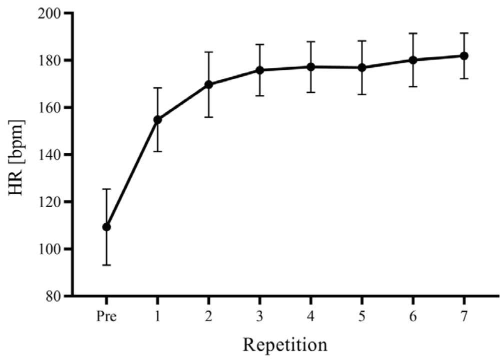

Figure 2. Heart Rate before and throughout for the RSA 7x30m-20" for the total sample (n=60).

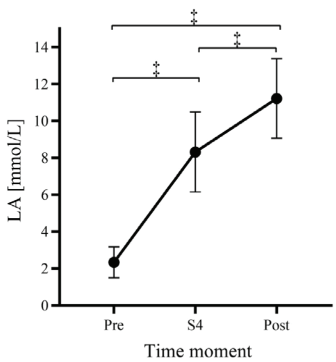

Figure 3. Comparison of blood lactate at three different times during the RSA 7x30m-20" for the total sample (n=60). ‡ = p<0.001.

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Finally, Figure 4 presents ANOVA comparisons according to age group. 4a, the RSA performance, where the 12-year-old group presented differences with the other age groups, F = 12.261, p<0.001, η^2 = 0.396; 4b, HR F = 1.135, η^2 = 0.057; 4c, LA F = 1.036, η^2 = 0.053; 4d, (Sdec%). F = 1.306, η^2 =0.065; and 4e, FI F = 0.977, η^2 =0.050.

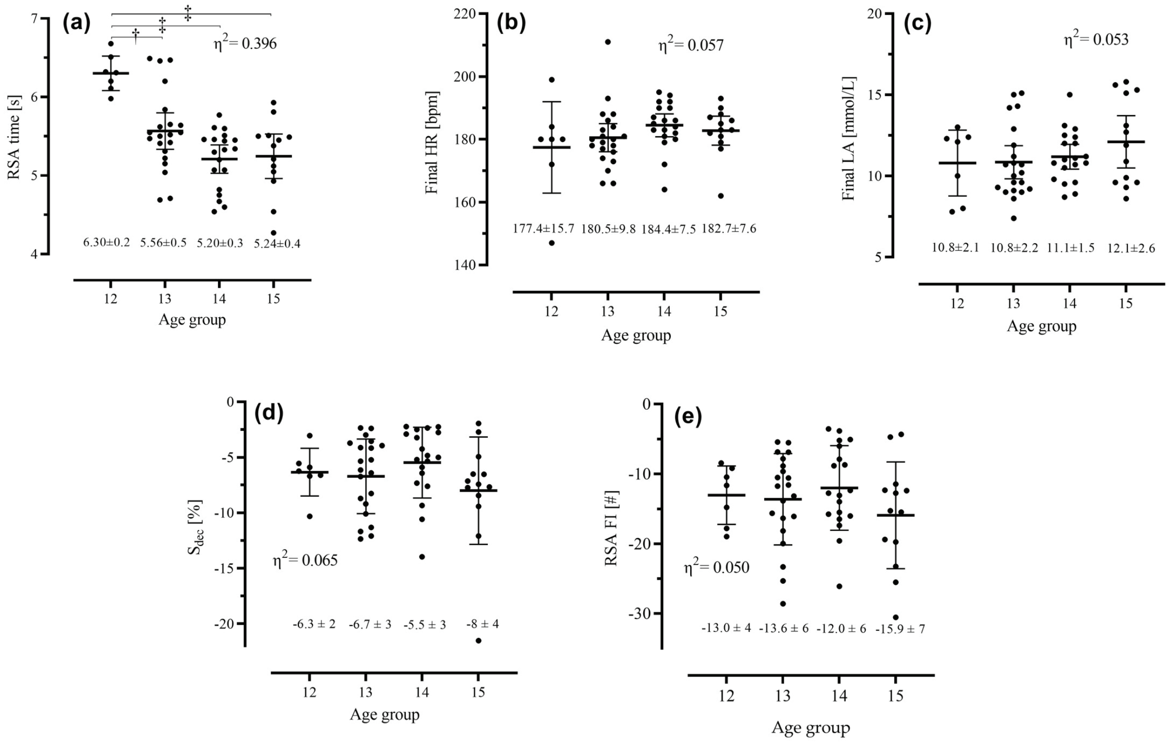

Figure 4. Comparisons by age group. 4a, RSA performance; 4b, Heart rate; 4c, Blood lactate; 4d, Fatigue index; 4e, % percentage decrement score. †= p<0.01; ‡= p<0.001.

Discussion

This study described the results of the 7x30m-20″ RSA protocol and the associated internal load in youth soccer players. First, performance tended to be better in the initial sprints and worse in the final sprints; HR and LA increased throughout the test, reaching values of 181.9 ± 9.6 ppm and 11.2 ± 2.1 mmol/L, respectively. Second, regarding the internal load, the estimated theoretical fatigue indicators were not related to HR and LA. Third, RSA was associated with anthropometric measurements; however, these findings may have been influenced by the broad age range of the participants (12-15 years). When analyzed by age groups, these associations were no longer observed, with the 12-years group demonstrating lower performance compared to de older groups. Finally, RSA performance indicators were associated with an increase in HR, but not with LA. Inter-individual variability was observed in HR, LA, and fatigue according age groups.

The results were consistent with the characteristics of the RSA test, in which performance progressively declines across repetitions as fatigue develops (Girard et al., 2017; 2011; Salazar-Martínez et al., 2025); The mean of the minimum times achieved across the total sample was 5.13 ± 0.51 s, corresponding to speeds of 21.23 ± 2.16 km/h. An age-related improvement in performance was also observed; however, the 14-year-old group demonstrated the best results, slightly outperforming the 15-year-old group. Notably, the performance of the 14-year-old group was comparable to that reported by Akdogan et al. (2019), who implemented a 7x35m-30" RSA protocol and reported a mean time of 5.35 ± 0.30s in competitive soccer players aged 14.6 ± 0.5 years. Interestingly, that study concluded that six weeks of training with small-sided games of varying formats did not results in improvements in RSA, 10m, and 30m sprint performance.

RSA performance has typically been reported in players older than 14 years; however, previous studies have employed protocols with different distances and recovery intervals, limiting direct comparisons with the present findings. For instance, Rey et al. (2019), evaluated 27 players using a 6x25m-25" RSA protocol, reporting a mean time of 4.20 ± 0.19s, concluding that training twice per week (4-6 sets of 15 repetitions over 30m) positively influenced RSA performance. Similarly, Buchheit and Méndez-Villanueva (2014), in a large sample of 270 players aged 14.5 ± 1.6 years, reported mean times of 4.71 ± 0.32s in a 10x30m-30" RSA protocol. They further suggested that 55-70% of RSA is explained by locomotor parameters of maximum aerobic speed MAS, maximum sprint speed MSS and anaerobic sprint reserve ASR, with the remaining variance likely influenced by growth, maturation and glycolytic capacity.

Consequently, evidence on RSA protocol outcomes in children under 14 years of age remains limited. This research found that the 12-year-old group exhibited lower performance compared to the other age groups, with significant differences in RSA times, possibly because adolescents tend to have more glycolytic power than children. In fact, it is important to highlight that in pre-pubertal stages, there is a predisposition for long-duration work and low-moderate intensities (Armstrong and Welsman, 2020). These findings differ from a study that included a sample of 135 Portuguese soccer players where the performance of a 7x34.2 -25" RSA with slalom was reported for 11 years old (n=40) 8.87± 0.49s, for 12 years old (n=57) 8.45± 0.45s, for 13 years old (n=83) 8.23± 0.45s, for 14 years old (n=80) 7.87± 0.33s and for 15 years old (n=66) 7.68± 0.31s, since the results they represent have an improvement of less than 5% between each age group. The study indicated that players advanced in maturation (evaluated by skeletal age) performed better than their contemporaries (Valente dos Santos et al., 2012).

Naturally peak HR values in players under 15 years of age exposed to RSA protocol loads of at least 30m are ~181 bpm (Charron et al., 2020; Gibson et al., 2017), which is consistent with the results found in this research. HR values in children and young people differ from those of adults during high-intensity exercise, mainly due to their smaller body size, incomplete maturation, and mechanical efficiencies (Mascherini et al., 2023; Dupuy et al., 2022; Armstrong and Welsman, 2020). Regarding blood lactate, values are usually around ~7.8 mmol/L in 6x30m-30" protocols in children under 15 (Charron et al., 2020; Gibson et al., 2017), increasing slightly with age. However, this work presented values higher than 10.8 mmol/L since the protocol executed had a recovery time reduced to 20 seconds, which usually affects the internal load on the RSA (Gibson et al., 2017; Padulo et al., 2015). However, lactate in children and adolescents is usually lower compared to adults in high-intensity exercises under the same conditions (Dupuy et al., 2022).

On the other hand, altitude has traditionally been used to train aerobic endurance athletes who intend to compete at lower altitudes "live low-train high" (Brocherie et al., 2017). In the case of RSA, performance is negatively affected at altitudes of 3000m since fatigue sets in more quickly (Girard et al., 2017). However, multiple sprint training at that altitude can increase the performance of a 6x40-20" RSA and decrease the estimated theoretical fatigue in soccer players of 15.3 ± 0.5 when they return to lower altitudes (Gatterer et al., 2014). It should be noted that the present research was conducted in Bogotá DC, Colombia at 2625m (a moderate altitude according to FIFA), the same place where the observed participants they live, who possibly have chronic hypoxia (Gore et al., 2008); therefore, the results found for HR and LA could be higher when comparing the same external load executed at an altitude close to sea level (Girard et al., 2017; Gore et al., 2008; Bowtell et al., 2014).

According to Bowtell et al. (2014), fatigue can worsen by up to 4.9% at altitudes of 2000–3000 m in RSA tests with 10 repetitions of 6 seconds running at maximum intensity with 30 seconds of recovery for individuals not adapted to altitude. In this study, the fatigue index and the percentage decrement score (Sdec%) increments with small proportion of total variance explained by age groups. Finally, LA values were 10.8±2.1 mmol/L for 12 years, 10.8±2.2 mmol/L for 13 years, 11.1±1.5 mmol/L for 14 years, and 12.1±2.6 mmol/L for 15 years, higher results than studies in these ages at an altitude close to sea level, which are usually ~8.0 mmol/L (Charron et al., 2020; Gibson et al., 2017).

The limitations of this study include the lack of control of rate perceived exertion (RPE) and the sample size, which limits the exploration of the pre-pubertal stage, making it necessary to extend the analysis beyond the age of 11. However, given the scarcity of studies controlling the external and internal load in RSA protocols for child and youth soccer players exposed to moderate altitude, the reason why this study is novel and of general interest to sports science. Future studies may compare internal load across different altitude levels, as well as the time required to acclimatize to varying altitudes, given that players begin competing in diverse environments from a very young age.

Conclusions

The study concludes that RSA performance in the 7×30m–20" test at an altitude of 2650m in pubertal players improves with increasing age. Test performance is similar to that of adult competitive players, with better results in the initial sprints. LA and fatigue were slightly higher in older participants and compared to other studies in this age groups; however, substantial inter-individual variability was observed in internal load across age groups.

Conflicts of Interest

The authors declare no conflict of interest.

References

Akdoğan, E., Yılmaz, İlker., Köklü, Y., Alemdaroğlu, U., & Cerrah, A. O. (2021). The effect of isolated or combined small-sided games and speed endurance training on physical performance parameters in young soccer players. *Kinesiology*, *53*(1), 78–85. https://doi.org/10.26582/k.53.1.10

Armstrong, N., & Welsman, J. (2020). Multilevel allometric modelling of maximum cardiac output, maximum arteriovenous oxygen difference, and peak oxygen uptake in 11-13-year-olds. *European Journal of Applied Physiology, 120*(2), 527–537. https://doi.org/10.1007/s00421-020-04300-0

Bärtsch, P., Dvorak, J., & Saltin, B. (2008). Football at high altitude. *Scandinavian Journal of Medicine & Science in Sports, 18 Suppl 1*, iii–iv. https://doi.org/10.1111/j.1600-0838.2008.00826.x

Bishop, D., Spencer, M., Duffield, R., & Lawrence, S. (2001). The validity of a repeated sprint ability test. *Journal of Science and Medicine in Sport*, 4(1), 19–29. https://doi.org/10.1016/s1440-2440(01)80004-9

Bowtell, J. L., Cooke, K., Turner, R., Mileva, K. N., & Sumners, D. P. (2014). Acute physiological and performance responses to repeated sprints in varying degrees of hypoxia. *Journal of Science and Medicine in Sport*, *17*(4), 399–403. https://doi.org/10.1016/j.jsams.2013.05.016

Brocherie, F., Girard, O., Faiss, R., & Millet, G. P. (2017). Effects of Repeated-Sprint Training in Hypoxia on Sea-Level Performance: A Meta-Analysis. *Sports Medicine*, *47*(8), 1651–1660. https://doi.org/10.1007/s40279-017-0685-3

Buchheit, M., & Mendez-Villanueva, A. (2014). Changes in repeated-sprint performance in relation to change in locomotor profile in highly-trained young soccer players. *Journal of Sports Sciences*, *32*(13), 1309–1317. https://doi.org/10.1080/02640414.2014.918272

Castagna, C., Lorenzo, F., Krustrup, P., Fernandes-da-Silva, J., Póvoas, S. C. A., Bernardini, A., & D'Ottavio, S. (2018). Reliability Characteristics and Applicability of a Repeated Sprint Ability Test in Young Male Soccer Players. *Journal of Strength and Conditioning Research*, *32*(6), 1538–1544. https://doi.org/10.1519/JSC.0000000000002031

Charron, J., Garcia, J. E. V., Roy, P., Ferland, P. M., & Comtois, A. S. (2020). Physiological Responses to Repeated Running

DOI 10.26773/mjssm.260905

Sprint Ability Tests: A Systematic Review. *International Journal of Exercise Science*, *13*(4), 1190–1205.

Dupuy, A., Birat, A., Maurelli, O., Garnier, Y. M., Blazevich, A. J., Rance, M., & Ratel, S. (2022). Post-exercise heart rate recovery and parasympathetic reactivation are comparable between prepubertal boys and well-trained adult male endurance athletes. *European Journal of Applied Physiology, 122*(2), 345–355. https://doi.org/10.1007/s00421-021-04823-0

Fernandes-Da-Silva, J., Castagna, C., Teixeira, A. S., Carminatti, L. J., Francini, L., Póvoas, S. C. A., & Antonacci Guglielmo, L. G. (2021). Ecological and Construct Validity of a Repeated Sprint Test in Male Youth Soccer Players. *Journal of Strength and Conditioning Research*, *35*(7), 2000–2009. https://doi.org/10.1519/JSC.0000000000003047

Gatterer, H., Philippe, M., Menz, V., Mosbach, F., Faulhaber, M., & Burtscher, M. (2014). Shuttle-run sprint training in hypoxia for youth elite soccer players: a pilot study. *Journal of sports science & medicine, 13*(4), 731–735.

Gibson, N., Brownstein, C., Ball, D., & Twist, C. (2017). Physiological, Perceptual and Performance Responses Associated With Self-Selected Versus Standardized Recovery Periods During a Repeated Sprint Protocol in Elite Youth Football Players: A Preliminary Study. *Pediatric Exercise Science*, *29*(2), 186–193. https://doi.org/10.1123/pes.2016-0130

Girard, O., Brocherie, F., & Millet, G. P. (2017). Effects of Altitude/Hypoxia on Single- and Multiple-Sprint Performance: A Comprehensive Review. *Sports Medicine*, *47*(10), 1931–1949. https://doi.org/10.1007/s40279-017-0733-z

Girard, O., Mendez-Villanueva, A., & Bishop, D. (2011). Repeated-sprint ability—Part I. *Sports Medicine*, 41(8), 673–694. http://dx.doi.org/10.2165/11590550-000000000-00000

Gore, C. J., McSharry, P. E., Hewitt, A. J., & Saunders, P. U. (2008). Preparation for football competition at moderate to high altitude. *Scandinavian Journal of Medicine & Science in Sports, 18 Suppl 1*, 85–95. https://doi.org/10.1111/j.1600-0838.2008.00836.x

Gualtieri, A., Rampinini, E., Dello Iacono, A., & Beato, M. (2023). High-speed running and sprinting in professional adult soccer: Current thresholds definition, match demands and training strategies. A systematic review. *Frontiers in Sports and Active Living*, 5, 1116293. https://doi.org/10.3389/fspor.2023.1116293

Krustrup, P., Mohr, M., Steensberg, A., Bencke, J., Kjaer, M., & Bangsbo, J. (2006). Muscle and blood metabolites during a soccer game: implications for sprint performance. *Medicine & Science in Sports & Exercise*, *38*(6), 1165–1174. https://doi.org/10.1249/01.mss.0000222845.89262.cd

Kyles, A., Oliver, J. L., Cahill, M. J., Lloyd, R. S., & Pedley, J. (2023). Linear and Change of Direction Repeated Sprint Ability Tests: A Systematic Review. *Journal of Strength and Conditioning Research*, *37*(8), 1703–1717. https://doi.org/10.1519/JSC.0000000000004447

Levine, B. D., Stray-Gundersen, J., & Mehta, R. D. (2008). Effect of altitude on football performance. *Scandinavian Journal of Medicine & Science in Sports, 18 Suppl 1*, 76–84. https://doi.org/10.1111/j.1600-0838.2008.00835.x

Mascherini, G., Galanti, G., Stefani, L., & Izzicupo, P. (2023). Normative values for heart rate response to exercise in young athletes at 10-18 years old. *European Journal of Sport Science*, *23*(7), 1186–1193. https://doi.org/10.1080/17461391.2022.2086490

Maughan, P. C., MacFarlane, N. G., & Swinton, P. A. (2021). Relationship Between Subjective and External Training Load Variables in Youth Soccer Players. *International Journal of Sports Physiology and Performance*, *16*(8), 1127–1133. https://doi.org/10.1123/ijspp.2019-0956

Mirwald, R. L., Baxter-Jones, A. D., Bailey, D. A., & Beunen, G. P. (2002). An assessment of maturity from anthropometric measurements. *Medicine & Science in Sports & Exercise*, *34*(4), 689–694. https://doi.org/10.1097/00005768-200204000-00020

Padulo, J., Tabben, M., Ardigò, L. P., Ionel, M., Popa, C., Gevat, C., Zagatto, A. M., & Dello Iacono, A. (2015). Repeated sprint ability related to recovery time in young soccer players. *Research in Sports Medicine*, *23*(4), 412–423. https://doi.org/10.1080/15438627.2015.1076419

Pons, E., Ponce-Bordón, J. C., Díaz-García, J., López del Campo, R., Resta, R., Peirau, X., & García-Calvo, T. (2021). A longitudinal exploration of match running performance during a football match in the Spanish La Liga: A four-season study. *International Journal of Environmental Research and Public Health,* 18(3), 1133. https://doi.org/10.3390/ijerph18031133

Rey, E., Padrón-Cabo, A., Costa, P. B., & Lago-Fuentes, C. (2019). Effects of different repeated sprint-training frequencies in youth soccer players. *Biology of Sport*, *36*(3), 257–264. https://doi.org/10.5114/biolsport.2019.87047

Salazar-Martínez, J. L., Valencia-S??nchez, W. G., & Celis-Moreno, J. M. (2025). Relationship between repeated sprint ability and maximal oxygen uptake in youth football players. *Montenegrin Journal of Sports Science and Medicine, 14*(2), 39-45. https://doi.org/10.26773/mjssm.250905

Slaughter, M., Lohman T., Boileao, R., Horswill, C., Stillman, R., Van Loan, M., & Bemben, D. (1988). Skinfold equation for estimation of body fatness in children and youth. *Hum Biol*, 60, 709-23.

Spencer, M., Bishop, D., Dawson, B., & Goodman, C. (2005). Physiological and metabolic responses of repeated-sprint activities: *Specific to field-based team sports. Sports Medicine*, 35, 1025–1044. https://doi.org/10.2165/00007256-200535120-00003

Thurlow, F., Huynh, M., Townshend, A., McLaren, S. J., James, L. P., Taylor, J. M., Weston, M., & Weakley, J. (2024). The Effects of Repeated-Sprint Training on Physical Fitness and Physiological Adaptation in Athletes: A Systematic Review and Meta-Analysis. *Sports Medicine*, *54*(4), 953–974. https://doi.org/10.1007/s40279-023-01959-1

Valente-dos-Santos, J., Coelho-e-Silva, M. J., Martins, R. A., Figueiredo, A. J., Cyrino, E. S., Sherar, L. B., Vaeyens, R., Huijgen, B. C., Elferink-Gemser, M. T., & Malina, R. M. (2012). Modelling developmental changes in repeated-sprint ability by chronological and skeletal ages in young soccer players. *International Journal of Sports Medicine*, *33*(10), 773–780. https://doi.org/10.1055/s-0032-1308996.

ORIGINAL SCIENTIFIC PAPER

The relevance of the school setting for the development of physical fitness in male adolescents in Chile

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Abstract

The school setting offers adolescents opportunities to engage in physical activity, potentially promoting the normal development of physical fitness. If so, school closure should impair fitness development. We leveraged data from the COVID-19 pandemic to test this idea. We aimed to examine the effects of school closure during the COVID-19 pandemic on the physical fitness of male adolescents from a private school in Chile. Longitudinal records from Physical Education classes were analyzed. The remote-schooling group included 92 boys (median [25th percentile, 75th percentile] age 12.8 [12.5, 13.1] years) measured before school closure due to the pandemic (March 2019) and after reopening (March 2021). The in-person-schooling group included 94 boys (12.7 [12.5, 13.0] years) who were measured in March 2017 and March 2019 and were normally exposed to the school setting. Outcomes included body mass index, maximum oxygen uptake, running speed, sit-ups, standing long jump, and pull-ups. ANOVA was used to test whether changes in the remote-schooling group were different from those in the in-person-schooling group, i.e., group-by-time interactions. Changes in body mass index and pull-ups did not differ between the remote-schooling group and the in-person-schooling group. Nevertheless, compared with the in-person-schooling group, the remote-schooling group showed attenuated increases in maximum oxygen uptake (by 2.5 mL/kg/min), 50-m and 800-m running speed (by 0.4 and 0.8 m/s, respectively), sit-ups (by 4 repetitions), and standing long jump (by 20 cm) (P-interaction < 0.001). School closure thus impaired the normal development of physical fitness in boys from a high socioeconomic background. This highlights the role of schools as health-promoting settings.

Keywords: *Physical Activity; Cardiorespiratory Fitness; Obesity; Exercise Test*

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Introduction

The Ottawa Charter claims that health is built where people live, play, and love (WHO, 1987). Adolescents spend a large proportion of their days in school. Schools should not only convey disciplinary knowledge but also promote healthy habits to foster normal development (UNICEF, 2021). The school setting is thus expected to have a significant influence on adolescents' health by shaping daily routines and offering opportunities for active lifestyles and peer interactions (UNICEF, 2021; WHO & UNESCO, 2021). Testing this idea requires studying adolescents who stopped attending school in person, and therefore partially lost the influence of the setting. School closures during the COVID-19 pandemic offered a natural quasi-experimental design to contrast the effects of exposure versus non-exposure to the school environment on adolescents' health.

Shortly after COVID-19 was declared a global pandemic in March 2020, Chile implemented measures to slow the virus's spread. Schools were closed and remained so throughout 2020, with classes held remotely (Kuzmanic et al., 2023). Sports facilities and public recreational spaces were also closed, and outdoor activities were restricted to specific daytimes. These measures disrupted the routines of children and adolescents, making it hard to maintain regular physical activity, balanced eating, and consistent sleep patterns. Consequently, concerns arose about their overall health, weight status, and physical fitness. Importantly, most studies have examined these effects on disadvantaged populations. There is therefore a gap in understanding how school closure and remote schooling affected adolescents from other socioeconomic backgrounds.

Physical fitness represents a set of attributes that determine the ability to perform physical activities (Ortega et al., 2008). These include cardiorespiratory fitness, muscular fitness, speed, agility, flexibility, and anthropometry (American College of Sports Medicine et al., 2018). Physical activity levels play a key role in maintaining adequate fitness (Zaqout et al., 2016). In this context, schools act as a key environment where adolescents engage in organized sports, develop active habits, and sustain fitness through structured opportunities. Thus, limited access to physical education classes and other school-related recreational activities likely impaired the physical fitness of youngsters during the pandemic. This is particularly concerning in adolescence, a critical period for physical development.

The evidence on the pandemic's impact on physical fitness is mixed. Studies in Spain and Croatia found no changes in cardiorespiratory fitness or body mass index (BMI) shortly after the school closures. Subgroup analyses, however, revealed declines in cardiorespiratory fitness among economically disadvantaged Spanish youth and in muscular fitness among Croatian boys (Medrano et al., 2021; Sunda et al., 2021). A meta-analysis across countries reported average increases in body weight of 2.6 kg and in BMI of 0.77 kg/m^2 during the first five months of the pandemic (Chang et al., 2021). In contrast, a Spanish study found no changes in cardiorespiratory fitness or BMI in adolescents eight months into the pandemic (November 2020) (López-Bueno et al., 2021). Data from the UK showed declines in cardiorespiratory fitness and increases in BMI from November 2019 (pre-pandemic) to November 2020, which were maintained in November 2021 (Basterfield et al., 2024).

These studies highlight the complex effects of school closures on physical fitness in children and adolescents. Importantly, most studies have focused on disadvantaged groups, as they seem to be the most affected by the school closures (Armitage & Nellums, 2020). The impact on adolescents from more favorable socioeconomic backgrounds is less known. Building on this gap, we aimed to examine the effects of school closures on the physical fitness of male adolescents from a private school in Chile.

Methods

Design and setting

This report followed the STROBE guidelines for reporting observational studies (see Supplementary Table 1 for the checklist). This was an observational, analytical, cohort study with a time-matched control group. We analyzed the dataset of physical fitness assessments conducted at a private school in Santiago, Chile. The school is an all-male institution that provides education across twelve grades (ages 6-17 years), with a total enrollment of approximately 1,200 students. The annual tuition fee is approximately 7,500 USD, fully paid by the families. The school is in one of the most affluent communities in the country. In Chile, the academic year starts in March. For this study, we analyzed physical fitness assessments conducted at the beginning of the academic year as part of Physical Education classes. The assessment included cardiorespiratory fitness, speed, muscular strength, and anthropometric measurements.

Participants

We analyzed data from a group of adolescents assessed before the school closure (March 2019; "Before" time point) and after school reopening two years later (March 2021; "After" time point). This group was referred to as the "remote-schooling" group (Figure 1A). Notably, physical fitness is expected to change due to normal growth and development. We therefore included a time-matched control group ("in-person-schooling") for comparison, as has been previously done (Suárez-Reyes et al., 2024). The in-person-schooling group included adolescents assessed in March 2017 ("Before" time point) and again in March 2019 ("After" time point). The in-person-schooling group was matched in time (two years between assessments) and age to the remote-schooling group but was unexposed to the school closure (Figure 1A).

We included the data of male adolescents who had: [a] physical fitness outcomes measured at both time points ("Before" and "After" time points); [b] height and body weight measured at both time points; [c] a signed informed consent form from their parents or guardians; and [d] a signed assent form. The study was approved by the Scientific Ethics Committee of Universidad Finis Terrae, Chile (ID 23-048).

Physical fitness outcomes

Anthropometric measurements included body weight and height. Weight was measured with an electronic scale (Medisana® PSM 40446, China), and height with a stadiometer (Seca® 213, Hamburg, Germany). BMI was calculated as the ratio of body weight to height squared (kg/m^2). BMI z-scores for children aged 5 to 19 were calculated in

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R using the anthroplus package (Schumacher et al., 2011). Weight status was categorized as underweight (BMI z-score < –1.00), healthy weight (BMI z-score from –1.00 to 1.00), overweight (BMI z-score from >1.00 to 2.00), or obesity (BMI z-score > 2.00) (WHO, 2019).

Cardiorespiratory fitness (i.e., maximum oxygen consumption [VO_2max]) was assessed with the Cooper test on a 300-m track. Participants ran or walked for 12 minutes, and the covered distance was recorded. The following equation was used to estimate the VO_2max (mLO_2/kg/min): 22.351 × distance (km) – 11.288 (Cooper, 1968).

Speed was assessed using 50-m and 800-m run tests. Participants were instructed to run as fast as possible over these distances on a track. Time to complete each distance was measured with a stopwatch (Casio® HS 80 TW, China), and average speed (m/s) was calculated as distance divided by time.

Muscle strength was assessed using sit-ups in one minute, standing long jump, and pull-ups. For the sit-up test, participants laid on their backs with their legs bent and arms crossed over their chests. A classmate held their feet on the floor while the participant performed as many sit-up repetitions as possible in one minute. For the standing long jump, participants jumped as far as possible with their feet together, and the distance from toes at take-off to heels at landing was recorded in centimeters. For the pull-up test, participants hung from a horizontal bar with arms fully extended, pulling their bodies upward until the chin surpassed the bar and descending to full elbow extension. Leg swing was not allowed, and the total number of pull-up repetitions was recorded.

Statistics

Analyses were conducted with R (version 4.4.0) in RStudio (version 2024.12.0+467). Lilliefors Kolmogorov-Smirnov was used to test the distribution of numerical variables at the before and after time points (lillie.test function, nortest package (Gross & Ligges, 2015)). Most variables were non-normally distributed. Thus, for consistency, data for all numerical variables are shown as medians with 25th and 75th percentiles. All the values in the Tables and Figures are reported on their original scale. Nevertheless, physical fitness outcomes were log10-transformed for inferential analyses, except for BMI Z-score. ANOVA models were used to test the main effects of group (in-person-schooling versus remote-schooling), time (before versus after, as repeated measures), and their interaction on each physical fitness outcome (aov function, base R). In the case of significant interactions, post-hoc comparisons were conducted between groups at each time point. The Bonferroni method was used to adjust P-values for multiple comparisons (two comparisons: groups at the before and after time points). Of note, changes in the in-person-schooling group are considered the expected response. A significant group-by-time interaction thus indicates that the changes in the remote-schooling group were different from expected. Such a result indicates that the school closure influenced the response of the outcome over the two years. For example, in the case of a significant group-by-time interaction, a smaller increase in the remote-schooling group than in the in-person-schooling group (the expected increase) would indicate that the school closure attenuated the expected increase. Weight status is shown as percentages in each category. Fisher's exact test was used to determine the association between group and weight status at each time point separately. $P < 0.05$ was considered statistically significant.

Results

Figure 1B shows the flowchart for participant selection. In total, 94 male adolescents were included in the in-person-schooling group and 92 in the remote-schooling group. Table 1 summarizes all variables by group and time point.

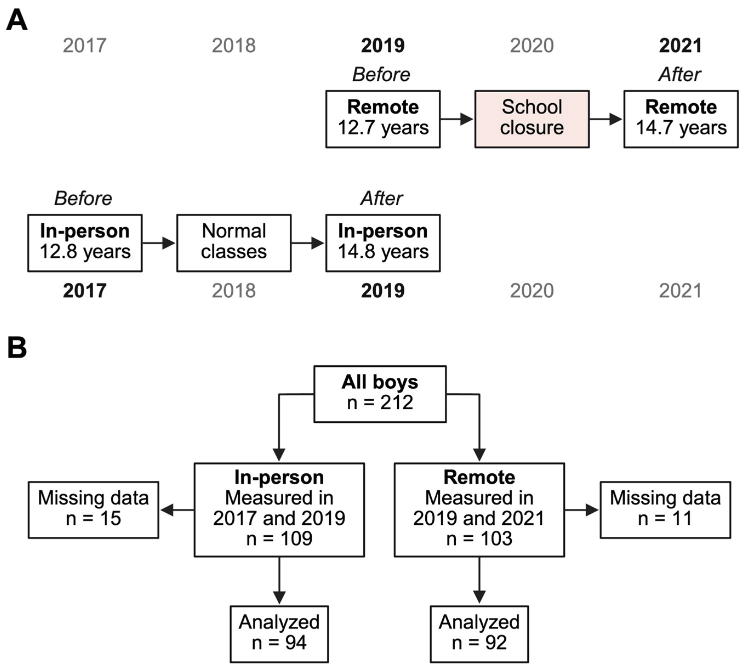

Figure 1. Study design and selection of participants. (A) Time points of the assessments in the remote-schooling group and its time-matched in-person-schooling group. (B) Flowchart for the selection of participants. Created in BioRender. Fernandez verdejo, R. E. (2026) https://BioRender.com/58ykxym.

Table 1. Characteristics of the participants by group and time point.

	In-person-schooling (n = 94)						Remote-schooling (n = 92)					
	Before			After			Before			After		
	Mdn or %	p25	p75	Mdn or %	p25	p75	Mdn or %	p25	p75	Mdn or %	p25	p75
Age, years	12.8	12.5	13.1	14.8	14.5	15.1	12.7	12.5	13.0	14.7	14.5	15.0
Weight, kg	52.1	47.6	56.3	61.4	56.3	65.4	50.5	46.0	55.6	61.3	56.3	65.2
Height, cm	159	154	166	173	169	177	162	156	167	176	172	180
BMI, kg/m^2	20.2	19.0	21.7	20.5	19.1	21.6	19.5	18.2	20.6	20.0	18.7	20.7
BMI, Z-score	0.89	0.43	1.31	0.36	-0.25	0.72	0.61	0.13	0.98	0.17	-0.42	0.46
Weight status												
Underweight, %	1.1	-	-	1.1	-	-	4.3	-	-	9.8	-	-
Healthy weight, %	56.4	-	-	83.0	-	-	72.8	-	-	83.7	-	-
Overweight, %	40.4	-	-	13.8	-	-	22.8	-	-	6.5	-	-
Obesity, %	2.1	-	-	2.1	-	-	0.0	-	-	0.0	-	-
VO_2max, mLO_2/kg/min	44.6	40.0	47.8	49.1	45.2	53.2	45.5	41.0	48.6	46.4	43.5	50.4
50-m speed, m/s	6.1	5.8	6.4	6.9	6.8	7.2	6.0	5.8	6.3	6.7	6.3	7.0
800-m speed, m/s	4.2	4.1	4.4	5.4	4.4	5.6	4.2	4.0	4.4	4.4	4.2	5.2
Sit-ups, repetitions	45	40	49	56	50	61	44	39	49	53	47	58
Standing long jump, cm	167	156	182	221	206	235	180	170	193	224	203	233
Pull-ups, repetitions	4	2	7	8	5	11	3	1	5	6	3	9

All participants are males. BMI, body mass index; Mdn, median; p25, 25th percentile; p75, 75th percentile; VO_2max, maximum oxygen uptake.

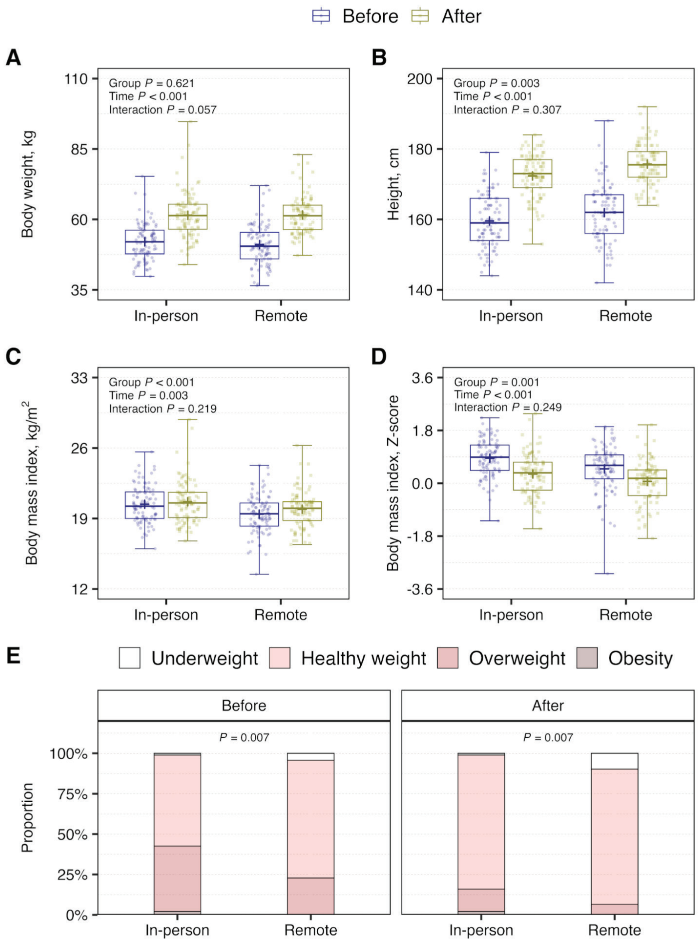

Figure 2. Comparison of anthropometric outcomes before and after two years in male adolescents exposed (remote-schooling) or not (in-person-schooling) to the school closure due to the COVID-19 pandemic. In A-D, ANOVA models were fitted including group, time (repeated measures), and their interaction. In A-C, the analyses were conducted using log10-transformed values, but the variables were plotted on their original scale. In E, Fischer's exact test was used at each time point separately. In-person-schooling n = 94; Remote-schooling n = 92.

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The remote-schooling group had higher height and lower BMI compared with the in-person-schooling group (main effect of group; Figure 2B-D). As expected, body weight, height, and BMI changed after two years of growth and development (main effect of time; Figure 2A-D). There were no group-by-time interactions in these outcomes, indicating that the magnitude of the change was not different between groups (Supplementary Table 2). In agreement, the remote-schooling group (versus the in-person-schooling group) had a lower proportion of overweight and obesity at the before time point (22.8% versus 42.6%), and the difference was maintained after two years (6.5% versus 16.0%; Figure 2E).

A statistically significant group-by-time interaction was observed in VO_2max, indicating that the change in VO_2max over two years differed between groups (Figure 3A). Indeed, VO_2max increased only by 2.0 mL/kg/min in the remote-schooling group, compared with 4.5 mL/kg/min in the in-person schooling group (Supplementary Table 2). This indicates that the expected increase in VO_2max in the remote-schooling group was attenuated by 2.5 mL/kg/min (Supplementary Table 2). Post-hoc analyses revealed no difference between groups before, but lower VO_2max in the remote-schooling group after two years (Figure 3A). Statistically significant group-by-time interactions were also observed in 50-m speed, 800-m speed, and sit-ups (Figure 3B-D). Compared with the in-person-schooling group, the increases in the remote-schooling group were attenuated by 0.4 m/s in 50-m speed, 0.8 m/s in 800-m speed, and 4 repetitions in sit-ups (Supplementary Table 2). Again, post-hoc analyses revealed that the difference between groups was manifested only after two years (Figure 3B-D). A statistically significant group-by-time interaction was also observed in the standing long jump, with attenuated increases in the remote-schooling group by 20 cm (Figure 3E and Supplementary Table 2). In this case, however, post-hoc analyses showed differences between groups before, not after, the two years (Figure 3E). Finally, the remote-schooling group performed fewer pull-up repetitions compared with the in-person-schooling group (main effect of group; Figure 3F). Yet both groups showed similar increases after two years (main effect of time; Figure 3F and Supplementary Table 2).

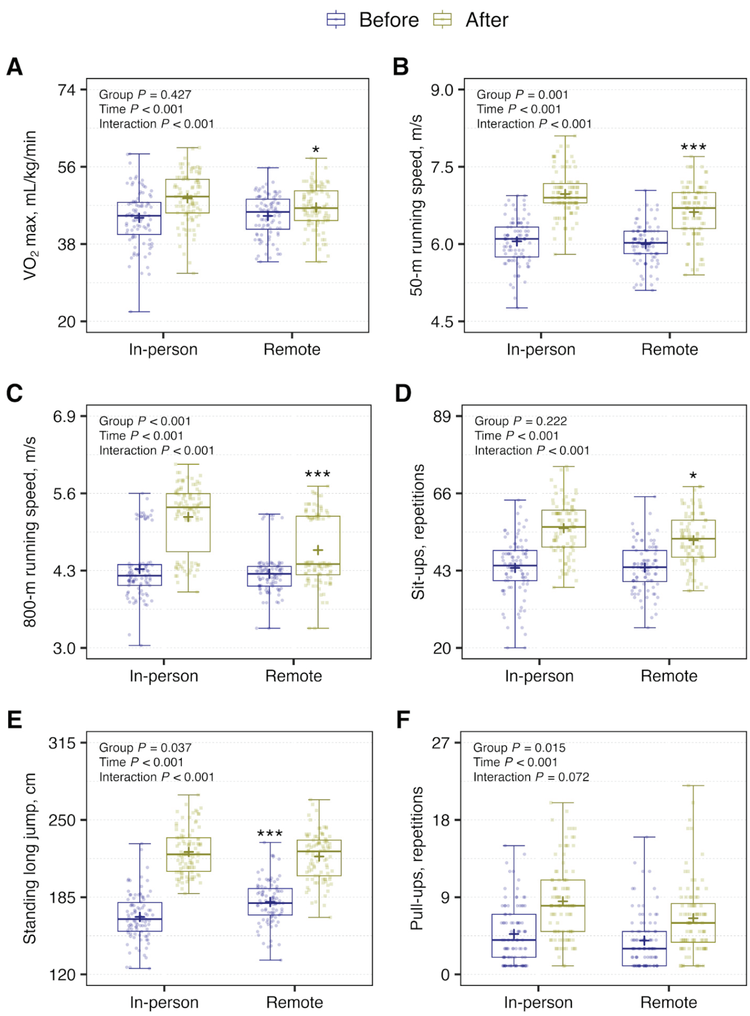

Figure 3. Comparison of cardiorespiratory and muscular fitness outcomes before and after two years in male adolescents exposed (remote-schooling) or not (in-person-schooling) to the school closure due to the COVID-19 pandemic. ANOVA models were fitted including group, time (repeated measures), and their interaction. The analyses were conducted using log10-transformed values, but the variables were plotted on their original scale. *P < 0.05, ***P < 0.001 versus the In-person-schooling group at the same time point for the post-hoc comparison with Bonferroni adjustment. In-person-schooling n = 94; Remote-schooling n = 92.

Discussion

This study aimed to determine the effects of the school closure on the physical fitness of male adolescents attending a private school in Chile. We leveraged data from the COVID-19 pandemic to compare a group of students who were exposed to school closures (remote-schooling) with a control group that attended school normally (in-person-schooling). Both groups were comparable in age and sex and belonged to the same school. Anthropometric outcomes changed similarly in both groups over two years. Nevertheless, the normal gains in cardiorespiratory fitness, speed, and strength were consistently attenuated in the remote-schooling group, suggesting a negative impact of school closures on physical fitness.

The anthropometric changes observed in our participants agree with the expected growth during adolescence. Peak growth in males occurs between 12 and 14 years of age (Chulani & Gordon, 2014), which matches the age of our participants. Both the remote-schooling and in-person-schooling groups showed similar increases in height and weight, indicating that school closure did not affect normal growth.

School closures during the COVID-19 pandemic most likely disrupted children's routines and habits, raising concerns about their health. Similar concerns have been observed during other periods away from school, such as summer holidays, when lower physical activity, reduced cardiorespiratory fitness, and increased adiposity are common (Eglitis et al., 2024). Nevertheless, previous findings during the COVID-19 pandemic have been mixed. Some studies reported increases in the prevalence of overweight and obesity, whereas others did not (Chang et al., 2021; Medrano et al., 2021). Pierce et al. (2023) documented an accelerated rate of BMI increase in early 2020, and a stabilization in 2021, resulting in BMIs above pre-pandemic levels. Basterfield et al. (2024) also reported an initial increase in BMI post-lockdown, followed by stabilization that did not return to pre-pandemic levels. In a previous study with a similar time-matched control design, increases in adiposity were also observed in students from public schools during 2019-2021 (Suárez-Reyes et al., 2024). In contrast, here we did not detect an increase in the prevalence of overweight or obesity in either group. The prevalence remained below 20% in both groups, which is lower than national estimates showing >30% overweight and 16% obesity prevalence in 14-year-old boys in Chile (Junta Nacional de Auxilio Escolar y Becas JUNAEB, 2021, 2022). Notably, those national estimates consider only students attending public schools, whereas our current sample included only students attending a private school. Higher socioeconomic status, often reflected in parental education, has been associated with lower weight gain in children during the school closures. This pattern likely results from better dietary routines, encouragement of physical activity, and limited screen time (Pedersen et al., 2022). Such an advantage may have protected our participants.

Regarding other physical fitness outcomes, both groups showed improvements over the two years (Welde et al., 2020). However, the gains in the remote-schooling group were attenuated across most outcomes. Cardiorespiratory fitness (VO_2max) increased in both groups, but the increase was 2.5 mL/kg/min lower in the remote-schooling than the in-person-schooling group. Cardiorespiratory fitness is a strong predictor of current and future health in youth, and therefore, attenuated increases may indicate less favorable health outcomes. The attenuated increase in the remote-schooling group potentially resulted from reduced opportunities for physical activity due to school closure (Raghuveer et al., 2020). Despite this, note that the median values of both groups remained within healthy fitness ranges for boys aged 12 to 14 years (Lang et al., 2019). Our findings partially contrast with those of Basterfield et al (2024), who reported a decline in cardiorespiratory fitness immediately after lockdown, followed by a recovery and subsequent increase. Whether our remote-schooling group attained the expected cardiorespiratory fitness later after school reopening is unknown.

The remote-schooling group also showed smaller improvements in speed compared with the in-person-schooling group. Speed is related to musculoskeletal and bone health, as well as athletic performance. Our results thus imply that the attenuated gains in speed could impact physical development (Mello et al., 2023).

Muscular strength also showed attenuated increases in the remote-schooling group compared with the in-person-schooling group. Notably, the difference in standing long jump gains may partially reflect differences in performance at the before time point, with the in-person-schooling group starting with a lower performance and thus showing greater improvement. In agreement, Basterfield et al. (2024) reported increases in standing long jump and other strength measures from pre to post pandemic. Nevertheless, they interpreted these gains as evidence that strength was unaffected by the pandemic. Using a time-matched control group, we showed here that the gains were smaller than expected due to normal growth and maturation. Our time-matched design thus allowed us to distinguish the effects of school closure from the normal, expected changes. As muscular strength is linked to multiple health outcomes, the reduced gains in the remote-schooling group could have long-term health implications (Mello et al., 2023). Finally, although the increase in pull-ups was not different between groups, there was a borderline significant interaction consistent with the other muscular strength outcomes.

While this study provides valuable insights, some limitations should be noted. First, although school closure represents a major change in the routine of adolescents, the effects in the remote-schooling group cannot be attributed solely to school closure. Other factors, such as COVID-19 infections and their lingering effects, may have influenced the physical fitness in the remote-schooling group. Second, we did not have measurements of physical activity in any group. Thus, the idea that reduced physical activity levels due to school closure are major determinants of the attenuated fitness gains cannot be confirmed. Note that some studies reported declines in the physical activity levels during the pandemic, whereas others suggested sustained low levels or a partial recovery (Jago et al., 2023; Suárez-Reyes et al., 2024). In any case, reduced opportunities for physical activity due to school closures remain a likely contributor to the attenuated increase in physical fitness. Third, fitness tests were conducted as part of routine school assessments, which may have limited measurement accuracy. Yet school-based testing remains a practical and cost-effective method to monitor youth fitness (Joensuu et al., 2024). Fourth, as the study included a single school, caution is needed when generalizing findings. A major strength of our study was the inclusion of a time-matched control group from the same school. This group allowed us to distinguish the changes due to the school closure from those due to normal growth and development. Finally, we did not adjust for covariates such

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as maturation status, as these data are not routinely collected in school-based assessments. Yet our design, including students from the same school, age, and sex, partially mitigates this issue.

In conclusion, our study suggests that schools play a key role in supporting the development of physical fitness during adolescence. The students from a high socioeconomic background showed overall increases in physical fitness. Nevertheless, the effects were attenuated in the group that was exposed to the school closure. These results provide valuable evidence on the role of schools as environments for promoting health beyond academics, even in a socioeconomically advantaged population.

References

American College of Sports Medicine, Riebe, D., Ehrman, J. K., Liguori, G., & Magal, M. (2018). *ACSM's guidelines for exercise testing and prescription* (10th ed.). Wolters Kluwer Health. http://213.55.90.4/admin/home/Dmu%20Academic%20Resource/Postgraduate%20Studies/Health%20and%20fitness/-Exercise-Testing-and-Prescription.pdf

Armitage, R., & Nellums, L. B. (2020). Considering inequalities in the school closure response to COVID-19. *The Lancet. Global Health*, *8*(5), e644. https://doi.org/10.1016/S2214-109X(20)30116-9

Basterfield, L., Galna, B., Burn, N. L., Batten, H., Weston, M., Goffe, L., Lawn, M., & Weston, K. L. (2024). Back to 'normal'? BMI, physical fitness and health-related quality of life of children from North East England before, during and after the COVID-19 lockdowns. *Journal of Sports Sciences*, *42*(8), 688–700. https://doi.org/10.1080/02640414.2024.2359259

Chang, T.-H., Chen, Y.-C., Chen, W.-Y., Chen, C.-Y., Hsu, W.-Y., Chou, Y., & Chang, Y.-H. (2021). Weight Gain Associated with COVID-19 Lockdown in Children and Adolescents: A Systematic Review and Meta-Analysis. *Nutrients*, *13*(10), 3668. https://doi.org/10.3390/nu13103668

Chulani, V. L., & Gordon, L. P. (2014). Adolescent Growth and Development. *Primary Care: Clinics in Office Practice*, *41*(3), 465–487. https://doi.org/10.1016/j.pop.2014.05.002

Cooper, K. H. (1968). A means of assessing maximal oxygen intake. Correlation between field and treadmill testing. *JAMA*, *203*(3), 201–204. http://www.ncbi.nlm.nih.gov/pubmed/5694044

Eglitis, E., Miatke, A., Virgara, R., Machell, A., Olds, T., Richardson, M., & Maher, C. (2024). Children's Health, Wellbeing and Academic Outcomes over the Summer Holidays: A Scoping Review. *Children*, *11*(3), 287. https://doi.org/10.3390/children11030287

Gross, J., & Ligges, U. (2015). nortest: Tests for Normality. In *CRAN: Contributed Packages*. https://doi.org/10.32614/CRAN.package.nortest

Jago, R., Salway, R., House, D., Walker, R., Emm-Collison, L., Sansum, K., Breheny, K., Reid, T., Churchward, S., Williams, J. G., Foster, C., Hollingworth, W., & de Vocht, F. (2023). Short and medium-term effects of the COVID-19 lockdowns on child and parent accelerometer-measured physical activity and sedentary time: a natural experiment. *International Journal of Behavioral Nutrition and Physical Activity*, *20*(1). https://doi.org/10.1186/s12966-023-01441-1

Joensuu, L., Csányi, T., Huhtiniemi, M., Kälbi, K., Magalhães, J., Milanović, I., Morrison, S. A., Ortega, F. B., Sardinha, L. B., Starc, G., Tammelin, T. H., & Jurak, G. (2024). How to design and establish a national school-based physical fitness monitoring and surveillance system for children and adolescents: A 10-step approach recommended by the FitBack network. In *Scandinavian Journal of Medicine and Science in Sports* (Vol. 34, Number 3). John Wiley and Sons Inc. https://doi.org/10.1111/sms.14593

Junta Nacional de Auxilio Escolar y Becas JUNAEB. (2021). *Mapa Nutricional JUNAEB 2019*. https://www.junaeb.cl/wp-content/uploads/2023/03/Informe-Mapa-Nutricional-2019-1.pdf

Junta Nacional de Auxilio Escolar y Becas JUNAEB. (2022). *Mapa Nutricional JUNAEB 2021*. https://chilealimentos.com/chilecrecesano/wp-content/uploads/sites/2/2015/01/INFORME-MAPA-NUTRICIONAL-2021_FINAL.pdf

Kuzmanic, D., Valenzuela, J. P., Claro, S., Canales, A., Cerda, D., & Undurraga, E. A. (2023). Socioeconomic disparities in the reopening of schools during the pandemic in Chile. *International Journal of Educational Development*, *100*. https://doi.org/10.1016/j.ijedudev.2023.102805

Lang, J. J., Tremblay, M. S., Ortega, F. B., Ruiz, J. R., & Tomkinson, G. R. (2019). Review of criterion-referenced standards for cardiorespiratory fitness: what percentage of 1 142 026 international children and youth are apparently healthy? *British Journal of Sports Medicine*, *53*(15), 953–958. https://doi.org/10.1136/bjsports-2016-096955

López-Bueno, R., Calatayud, J., Louis Andersen, L., Casaña, J., Ezzatvar, Y., Antonio Casajús, J., Felipe López-Sánchez, G., Smith, L., & Smith LeeSmith, L. (2021). Cardiorespiratory fitness in adolescents before and after the COVID-19 confinement: a prospective cohort study. *European Journal of Pediatrics*, *180*, 2287–2293. https://doi.org/10.1007/s00431-021-04029-8/Published

Medrano, M., Cadenas-Sanchez, C., Oses, M., Arenaza, L., Amasene, M., & Labayen, I. (2021). Changes in lifestyle behaviours during the COVID-19 confinement in Spanish children: A longitudinal analysis from the MUGI project. *Pediatric Obesity*, *16*(4). https://doi.org/10.1111/ijpo.12731

Mello, J. B., Rodríguez-Rodríguez, F., Gracia-Marco, L., Teodoro, J. L., Gaya, A. R., & Gaya, A. C. A. (2023). Speed, agility, and musculoskeletal fitness are independently associated with areal bone mineral density in children. *Frontiers in Physiology*, *14*. https://doi.org/10.3389/fphys.2023.1080091

Ortega, F. B., Ruiz, J. R., Castillo, M. J., & Sjöström, M. (2008). Physical fitness in childhood and adolescence: a powerful marker of health. *International Journal of Obesity*, *32*(1), 1–11. https://doi.org/10.1038/sj.ijo.0803774

Pedersen, J., Rasmussen, M. G., Olesen, L. G., Klakk, H., Kristensen, P. L., & Grøntved, A. (2022). Recreational screen media use in Danish school-aged children and the role of parental education, family structures, and household screen media rules. *Preventive Medicine*, *155*. https://doi.org/10.1016/j.ypmed.2021.106908

Pierce, S. L., Kompaniyets, L., Freedman, D. S., Goodman, A. B., & Blanck, H. M. (2023). Children's rates of BMI change during pre-pandemic and two COVID-19 pandemic periods, IQVIA Ambulatory Electronic Medical Record, January 2018 Through November 2021. *Obesity (Silver Spring, Md.)*, *31*(3), 693–698. https://doi.org/10.1002/

oby.23643

Raghuveer, G., Hartz, J., Lubans, D. R., Takken, T., Wiltz, J. L., Mietus-Snyder, M., Perak, A. M., Baker-Smith, C., Pietris, N., & Edwards, N. M. (2020). Cardiorespiratory Fitness in Youth: An Important Marker of Health: A Scientific Statement From the American Heart Association. In *Circulation* (Vol. 142, Number 7, pp. E101–E118). Lippincott Williams and Wilkins. https://doi.org/10.1161/CIR.0000000000000866

Schumacher, D., Borghi, E., Gatica-Domínguez, G., & World Health Organization. (2011). *Computation of the WHO 2007 References for School-Age Children and Adolescents (5 to 19 Years)*. https://github.com/WorldHealthOrganization/anthroplus/issues

Suárez-Reyes, M., Fernández-Verdejo, R., Quintiliano, D., Pinheiro, A. C., & Pizarro, T. (2024). Effects of school closure on lifestyle behaviours and health outcomes in children during the COVID-19 pandemic in Chile: A time-matched analysis. *Pediatric Obesity*, *19*(12), e13182. https://doi.org/10.1111/ijpo.13182

Sunda, M., Gilic, B., Peric, I., Savicevic, A. J., & Sekulic, D. (2021). Evidencing the influence of the covid-19 pandemic and imposed lockdown measures on fitness status in adolescents: A preliminary report. *Healthcare (Switzerland)*, *9*(6). https://doi.org/10.3390/healthcare9060681

UNICEF. (2021). *El rol de la escuela en la prevención del sobrepeso y la obesidad en estudiantes de América Latina y el Caribe*. https://www.unicef.org/lac/media/30431/file/El-rol-de-la-escuela-en-la-prevencion-del-sobrepeso.pdf

Welde, B., Morseth, B., Handegård, B. H., & Lagestad, P. (2020). Effect of Sex, Body Mass Index and Physical Activity Level on Peak Oxygen Uptake Among 14–19 Years Old Adolescents. *Frontiers in Sports and Active Living*, *2*. https://doi.org/10.3389/fspor.2020.00078

WHO. (1987). Ottawa Charter for Health Promotion. *Bulletin of the Pan American Health Organization*, *21*(2), 200–204. http://www.ncbi.nlm.nih.gov/pubmed/3664056

WHO. (2019). *Growth reference data for 5-19 years*. https://www.who.int/tools/growth-reference-data-for-5to19-years/indicators/bmi-for-age

WHO, & UNESCO. (2021). *Making Every School a Health-Promoting School: Global Standards and Indicators for Health-Promoting Schools and Systems*. World Health Organization. https://www.who.int/publications/i/item/9789240025059

Zaqout, M., Vyncke, K., Moreno, L. A., De Miguel-Etayo, P., Lauria, F., Molnar, D., Lissner, L., Hunsberger, M., Veidebaum, T., Tornaritis, M., Reisch, L. A., Bammann, K., Sprengeler, O., Ahrens, W., & Michels, N. (2016). Determinant factors of physical fitness in European children. *International Journal of Public Health*, *61*(5), 573–582. https://doi.org/10.1007/s00038-016-0811-2

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ORIGINAL SCIENTIFIC PAPER

Greater Goal Difference is Associated with Lower Physical Demands in Cerebral Palsy Football Referees

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Abstract

This study examines the association between match outcome variables, total goals, goal difference, and the physical demands placed on referees in cerebral palsy (CP) football. Thirteen international referees were monitored via global positioning devices during 42 official matches at the 2022 CP Football World Cup and World Championships. Physical demands, including distances covered at various speeds and acceleration/deceleration metrics, were analyzed. Results revealed moderate to high negative correlations between goal difference and total, explosive, walking, jogging, medium-intensity running, high-intensity running and sprinting distances; maximum speed, accelerations, low intensity acceleration in zones 1 and 2, low intensity deceleration in zones 1 and 2, and player load (ρ = -0.30 to -0.54; p <0.001 to 0.04). In contrast, total goals showed only isolated, moderate correlations with medium-intensity running distance and deceleration Z1 (ρ = -0.33; p < 0.03 to 0.04). These findings indicate that match competitiveness, reflected by the goal difference, is a key factor associated with referees' physical workload in CP football, with closer matches eliciting higher physical demands on the referees. The results highlight the importance of considering match context in referees' training, recovery management, and match allocations, ensuring they are adequately prepared for the high demands of closely contested matches and can recover effectively during international-level CP football competitions.

Keywords: *soccer, contextual factors, performance, external load, officials*

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Introduction

People with cerebral palsy (CP) live with a lifelong prevalent physical disability, characterized by heterogeneous conditions that impact participation in para-sports at different competitive levels (Romeo et al., 2024). Many individuals with CP participate in CP football, a competitive format designed for para-athletes with mild motor impairments (GMFCS I–II), such as spastic hypertonia, ataxia, or dyskinesia (Hen-

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ríquez et al., 2023; Reina et al., 2020). The professionalization of para-sports has increased research interest in the performance factors of both para-athletes and referees (Bao et al., 2025). However, while much of the research has focused on para-footballers with CP or related neurological conditions, there is still limited information regarding the referees who officiate football matches for para-athletes with CP (Henríquez, Ozaeta, et al., 2024). Specifically, CP football shares the fundamental characteristics of conventional football, requiring a range of motor skills and high-intensity efforts during key moments of play (Castillo et al., 2025). However, it is contested in a seven-a-side format on a reduced-size pitch (usually 70 × 50 m), with a standard men's match consisting of two 30-min halves separated by a 10-min break. In the event of a draw at the end of regular time, two extra periods of 15 min are played, with a 5-min break before the first extra period and no resting interval between them (International Federation of Cerebral Palsy Football, 2023).

From a physical and physiological perspective, refereeing is an intermittent activity that predominantly relies on the aerobic system, with occasional actions of high-intensity effort in which the anaerobic system is interspersed (Castagna et al., 2007). Referees in CP football officiate matches that follow specific adaptations of standard football rules (i.e., smaller field size, lower number of players, no offside rule, shorter match time) that favor the participation of players categorized based on the impact of the eligible coordination impairments (Peña-González et al., 2022). Even with these match modifications, previous research shows that CP football referees face substantial physical demands, covering on average more than 5700 m per match, including over 900 m at moderate intensity and more than 150 m at high to maximal sprinting intensity (Henríquez, Ozaeta, et al., 2024). Despite the relatively short duration of these high-speed efforts, referees perform an exceptionally high number of rapid speed changes with around 1800 accelerations and 1850 decelerations per match, underscoring the intense and intermittent nature of officiating in CP Football (Henríquez, Ozaeta, et al., 2024). Since there is only one study that has examined these demands, further research is needed to provide stronger and more comprehensive evidence regarding these demands.

CP football referees officiate a sport with a higher number of goals per match compared to regular football, likely due to the specific technical and tactical characteristics of this discipline (Castagna et al., 2007; Henríquez, Reina, et al., 2024; Peña-González et al., 2022). As in regular football, the physical demands placed on players can vary according to contextual factors such as the level of opposition and final outcomes, although this remains unknown in the context of CP football referees (Henríquez, Reina, et al., 2024). Referee decisions have a substantial impact on match outcomes, highlighting the importance of understanding the physical demands they face (Castagna et al., 2007). Therefore, this study aimed to analyze the association between match outcome variables (i.e., total goals and goal difference) and the physical demands (i.e., distances covered at different intensities, accelerations and decelerations) of CP football referees, during international-level official matches. The main hypothesis is that a higher number of total goals and a greater goal difference will be associated with lower physical demands in terms of distance covered at different intensities and lower acceleration/deceleration variables in CP football referees.

Methods

Participants

This study analyzed 13 international referees (10 men and 3 women; age: 39.17 ± 8.26 yr; weight: 76.07 ± 13.39 kg; height: 174.04 ± 9.97 cm; body mass index: 24.99 ± 3.28 kg/m²) from 11 nationalities who voluntarily participated in this study. The participants officiated matches during two 2022 world competitions for men's CP football and had 18.62 ± 9.24 yr of refereeing experience in regular football and 6.54 ± 4.22 yr of refereeing in CP football. All referees were fully informed of the study protocols and provided written informed consent to participate. The study received ethical approval from a university Ethics Committee (reference no. DPS.RRV.03.17).

Procedures

A correlational study design was used to examine the associations between match outcome variables (total goals [TG] and final goal difference between teams [GD]) with the referees' match physical demands. Data was collected from 42 official CP football male international-level matches (i.e., 1 minimum and 5 maximum observations per referee) played between 09:00 to 18:00 hours in the 2022 men's CP Football world competitions (i.e., World Cup and World Championships) held at sea level in Catalonia region (Spain). Matches that went into extra time were considered, but only data from the regular two extra periods were analyzed. All referees wore vests fitted with global positioning system (GPS) devices to monitor the physical demands in matches conducted on an artificial turf field with official CP football dimensions. Prior to the matches, participants abstained from engaging in any strenuous physical activity and completed a 15-minute warm-up established by the head referee.

Measures

The match outcome variables analyzed were TG, representing the total number of goals achieved by both teams at the end of the match; and GD, defined as the absolute difference in goals between the two teams at the end of the match. These data were obtained from the official match reports of the games analyzed and publicly available (https://www.ifcpf.com/). Match running performance was assessed using WIMU PRO™ devices (RealTrack Systems SL, Almería, Spain) using GPS technology, with a sampling frequency of 10 Hz. The validity and reliability of these devices for evaluating physical demands have been previously established (Bastida-Castillo et al., 2018) and have also been used in CP football referees (Henríquez, Ozaeta, et al., 2024). Prior to each match (i.e., 15 min before the warm-up), the GPS units were activated and synchronized following the manufacturer's guidelines. Data were extracted and processed using SPRO™ software (RealTrack Systems SL, Almería, Spain) after the end of each match.

The variables analyzed in this study included the total distance covered, explosive distance (distance covered with accelerations > 1.12 m/s²), maximum speed (km/h), and distance covered at various speed thresholds: walking (0–6 km/h), jogging (6–12 km/h), medium-intensity running (MIR: 12–18 km/h), high-intensity running (HIR: 18–21 km/h), sprinting (21–24 km/h), and maximum sprinting (> 24 km/h) (Gamonales et al., 2022; Henríquez, Ozaeta, et al., 2024). Additionally, high-intensity braking distance (HIBD; distance with deceleration > 2 m/s²), high-speed running actions (HSRA; > 21 km/h) and number of sprints (n) metrics were also included (Lago-Peñas et al., 2024; Mara et al., 2017). These absolute speed thresholds were selected

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as they represent the default configuration of the WIMU PRO™ software and have been previously utilized in elite conventional football contexts, such as the Spanish LaLiga (Lago-Peñas et al., 2024). The total number of accelerations and decelerations, defined as any change in velocity crossing the zero axis, was recorded alongside the maximal acceleration (ACCmax: m/s²) and maximal deceleration (DECmax: -m/s²) (Martin-Sanchez et al., 2022). The distance covered while accelerating and decelerating was classified based on the intensity of these actions into four zones: Zone 1 (distance accelerating/decelerating: 0–1 m/s²), Zone 2 (distance accelerating/decelerating: 1–2 m/s²), Zone 3 (distance accelerating/decelerating: 2–3 m/s²), and Zone 4 (distance accelerating/decelerating: > 3 m/s²). (Oliva-Lozano et al., 2021). Finally, the player load was used and represented in arbitrary units (Reche-Soto et al., 2019).

Statistical analysis

Descriptive statistics data were presented using sample size, means, standard deviations, minima and maxima. Normality and homoscedasticity of data distribution were tested using the Shapiro–Wilk and Levene tests. The Shapiro–Wilk test indicated that the variables TG and GD did not follow a normal distribution; consequently, the associations between physical match demands and match outcome variables were calculated using Spearman's Rank Correlation Coefficient (ρ). The following scale was used to interpret the magnitudes of the correlations: less than 0.1, trivial; from 0.1 to 0.3, low; from 0.3 to 0.5, moderate; from 0.5 to 0.7, high; 0.7-0.9, very high; and greater than 0.9, almost perfect (Hopkins et al., 2009). The data analysis was carried out using JASP (JASP for Windows, version 0.17, Amsterdam, Netherlands). Statistical significance was set at $p < 0.05$.

Results

Descriptive statistics for match variables and referees' physical demands metrics across the 42 analyzed matches are presented in Table 1. The matches were characterized by a high-scoring nature, with TG averaging 5.19 ± 3.41 and a mean GD of 3.67 ± 3.84. Regarding physical demands, referees covered a Total Distance of 5026.45 ± 1265.00 m per match. The distance was predominantly covered at lower intensities, with Walking and Jogging constituting the largest portions at 2407.14 ± 283.27 m and 1709.26 ± 659.43 m, respectively. The number of accelerations and decelerations per match were 1754.81 ± 137.05 and 1764.21 ± 133.36, respectively.

Table 1. Descriptive statistics of match and physical variables of referees in cerebral palsy football (n = 42)

	Mean	SD	Minimum	Maximum
Match variables				
Total goals (n)	5.19	3.41	0.00	16.00
Goal difference (n)	3.67	3.84	0.00	16.00
Physical variables				
Total distance (m)	5026.45	1265.00	2386.70	6416.70
Explosive distance (m)	367.35	182.38	46.70	732.50
Walking distance (m)	2407.14	283.27	1823.30	3116.50
Jogging distance (m)	1709.26	659.43	498.70	2774.10
Medium-intensity running (m)	755.81	414.79	64.70	1626.30
High-intensity running (m)	99.79	81.59	0.00	263.30
Sprinting (m)	38.82	50.57	0.00	173.70
Maximum sprinting (m)	15.63	36.61	0.00	190.40
HIBD (m)	62.08	48.78	2.99	170.22
Sprints (n)	1.33	2.65	0.00	10.00
HSRA (n)	4.21	5.34	0.00	18.00
Maximum speed (km/h)	21.47	3.42	14.96	28.59
Accelerations (n)	1754.81	137.05	1457.00	1974.00
Decelerations (n)	1764.21	133.36	1481.00	1987.00
ACC_{max} (m/s²)	7.27	1.18	4.93	10.16
Accelerations Z1 (n)	1253.62	250.79	840.54	1860.63
Accelerations Z2 (n)	886.96	315.29	169.00	1294.40
Accelerations Z3 (n)	336.01	210.94	11.90	867.16
Accelerations Z4 (n)	73.64	72.57	0.00	276.19
DEC_{max} (m/s²)	-7.81	1.47	-11.45	-4.69
Decelerations Z1 (n)	1307.71	241.60	856.41	1748.61
Decelerations Z2 (n)	848.40	315.38	166.00	1269.96
Decelerations Z3 (n)	257.08	157.42	24.00	624.75
Decelerations Z4 (n)	81.42	78.97	0.00	326.43
Player Load (AU)	48.24	21.55	8.63	99.29

Note. SD: standard deviation; HIBD: high-intensity braking distance; HSRA: high-speed running actions; ACC_{max}: maximum acceleration; DEC_{max}: maximum deceleration.

The associations between TG or GD and physical variables related to distance covered at different intensities are presented in Table 2. Several significant negative correlations were observed between GD and physical demands. Specifically, greater GD was significantly associated with lower values of referees Total Distance (ρ = -0.52; $p < 0.001$; high), Explosive Distance (ρ = -0.36; p = 0.02; moderate), Walking (ρ = -0.32; p = 0.04; moderate), Jogging (ρ = -0.54; $p < 0.001$; high), MIR (ρ = -0.48; $p < 0.001$; moderate) and HIR (ρ = -0.37; p = 0.02; moderate). Additionally, sprints (ρ = -0.30; p = 0.04; moderate) and maximum speed (ρ = -0.47; $p < 0.001$; moderate) were also correlated with GD. No associations were observed between GD and Sprinting, HIBD or HSRA. No significant correlations were found between TG and any of the physical demands variables (ρ = -0.11 to -0.29; $p > 0.05$), except for MIR (ρ = -0.33; p = 0.04; moderate).

Table 2. Associations between Total Goals and/or Goal Difference and physical response variables by referees in cerebral palsy football matches related to the total distance

Variables	TG			GD		
	ρ	CI (95%)	p value	ρ	CI (95%)	p value
Total distance (m)	-0.29	(-0.54, 0.00)	0.06	-0.52†	(-0.70, -0.27)	0.00
Explosive distance (m)	-0.11	(-0.49, 0.03)	0.25	-0.36*	(-0.58, -0.09)	0.02
Walking distance (m)	-0.28	(-0.55, 0.02)	0.07	-0.32*	(-0.56, -0.02)	0.04
Jogging distance (m)	-0.26	(-0.51, 0.05)	0.10	-0.54†	(-0.74, -0.29)	0.00
MIR (m)	-0.33*	(-0.56, -0.04)	0.04	-0.48†	(-0.67, -0.22)	0.00
HIR (m)	-0.25	(-0.50, 0.06)	0.11	-0.37*	(-0.60, -0.07)	0.02
Sprinting (m)	-0.13	(-0.42, 0.18)	0.40	-0.25	(-0.52, 0.06)	0.11
Maximum sprinting (m)	-0.19	(-0.47, 0.10)	0.23	-0.31*	(-0.57, 0.00)	0.04
HIBD (m)	-0.15	(-0.41, 0.15)	0.35	-0.24	(-0.48, 0.01)	0.12
Sprints (n)	-018	(-0.46, 0.12)	0.25	-0.30*	(-0.57, 0.00)	0.04
HSRA (n)	-0.17	(-0.46, 0.12)	0.28	-0.26	(-0.52, 0.03)	0.10
Maximum speed (km/h)	-0.15	(-0.44, 0.18)	0.34	-0.47†	(-0.70, -0.19)	0.00

Note. TG: total goals; GD: goal difference; ρ: Spearman's rank correlation coefficient; CI: confidence interval; MIR: medium-intensity running; HIR: high-intensity running; HIBD: high-intensity braking distance; HSRA: high-speed running actions; * $p < 0.05$; † $p < 0.01$.

The associations between TG or GD and physical variables related to accelerations, decelerations and/or Player Load are presented in Table 3. Several significant correlations were observed between GD and physical demands variables. Specifically, greater GD was associated with lower values in accelerations (ρ = -0.32; $p < 0.04$; moderate), low-intensity accelerations in zones 1 and 2 (ρ = from -0.47 to -0.50; $p < 0.001$; moderate), low-intensity decelerations in zones 1 and 2 (ρ = from -0.49 to -0.53; $p < 0.001$; moderate to high), and Player Load (ρ = -0.50; $p < 0.001$; moderate). Other physical variables related to accelerations or decelerations, including ACCmax, accelerations in zones 3 and 4, number of decel-

Table 3. Associations between Total Goals and/or Goal Difference and accelerations, decelerations, maximal acceleration, maximal deceleration, distance covered accelerating and decelerating at different speeds, and player load

Variables	TG			GD		
	ρ	CI (95%)	p value	ρ	CI (95%)	p value
Accelerations						
n	-0.23	(-0.52, 0.09)	0.15	-0.32*	(-0.58, 0.00)	0.04
ACCmax (m/s^2)	-0.01	(-0.31, 0.29)	0.97	-0.03	(-0.31, 0.28)	0.85
Zone 1 (m)	-0.30	(-0.56, 0.00)	0.06	-0.47†	(-0.67, -0.18)	0.00
Zone 2 (m)	-0.23	(-0.54, 0.11)	0.14	-0.50†	(-0.73, -0.22)	0.00
Zone 3 (m)	-0.18	(-0.44, 0.12)	0.26	-0.30	(-0.52, -0.03)	0.05
Zone 4 (m)	-0.09	(-0.37, 0.20)	0.57	-0.19	(-0.44, 0.09)	0.23
Decelerations						
n	-0.22	(-0.51, 0.11)	0.16	-0.28	(-0.55, -0.04)	0.07
DECmax ($-m/s^2$)	0.07	(-0.23, 0.35)	0.65	-0.09	(-0.20, 0.36)	0.59
Zone 1 (m)	-0.33*	(-0.60, 0.01)	0.03	-0.53†	(-0.71, -0.27)	0.00
Zone 2 (m)	-0.22	(-0.51, 0.11)	0.16	-0.49†	(-0.73, -0.23)	0.00
Zone 3 (m)	-0.16	(-0.43, 0.12)	0.31	-0.29	(-0.52, -0.04)	0.06
Zone 4 (m)	-0.16	(-0.44, 0.12)	0.32	-0.14	(-0.39, 0.15)	0.39
Player Load (AU)	-0.13	(-0.43, 0.17)	0.41	-0.50†	(-0.71, -0.20)	0.00

Note. TG: total goals; GD: goal difference; ρ: Spearman's rank correlation coefficient; CI: confidence interval; * $p < 0.05$; † $p < 0.01$.

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erations, DECmax and decelerations in zones 3 and 4 were not correlated with GD ($p > 0.05$). No significant correlations were found between TG and any physical demands variables related to accelerations or decelerations ($\rho = -0.01$ to -0.23; $p > 0.05$) except for deceleration in zone 3 ($\rho = 0.33$; $p = 0.03$; moderate).

Discussion

The results of the present study suggest a limited association between the competitive context of the matches, specifically GD, and the physical demands of referees in CP football at international-level matches. While the total number of goals showed only isolated, moderate negative correlations with MIR and low-intensity decelerations, moderate to high negative associations were observed between GD and multiple physical demands variables, such as Total Distance, distances covered at different intensities (ranging from Walking to HIR), as well as variables related to accelerations, decelerations and Player Load. Although no studies have been found examining how match outcome may influence the physical demands of CP football referees, scientific literature has analyzed the influence of match outcome on regular football players' and referees' physical demands (Fan et al., 2025; Jerkovic et al., 2022; O'Donoghue & Tenga, 2001). Hence, this represents the first study that analyzes the association between match outcome and the physical demands of CP football refereeing.

Previous research has shown that the total number of goals scored in CP football matches tends to be higher than in regular football matches, which may have implications for the physical demands experienced by players and referees officiating the competition (Henríquez, Ozaeta, et al., 2024; Peña-González et al., 2022). According to the CIES Football Observatory 40th report, the average goal difference per match across European leagues is approximately 1.34 goals (Poli et al., 2018), in contrast, the results of the present study revealed a substantially larger value in CP football, with a mean goal difference of 3.67 goals. This markedly greater competitive imbalance may reflect structural and functional differences in team composition, dynamics, and match physical demands between CP and regular football (Peña-González et al., 2022). The competitive level of national teams can vary substantially depending on each country's resources, structures for para-athletes development, and investment in para-sport programs (Dehghansai et al., 2022). As a result, nations with more established talent identification systems, better training environments, and greater economic support tend to field higher-level players, whereas countries with fewer resources may present less experienced or less physically prepared athletes (Peña-González et al., 2025).

The results of the present study suggest that GD is meaningfully associated with the physical demands of referees in CP football. Specifically, larger GD was associated with reduced total distance covered, shorter distances at different running intensities, and lower values for explosive distance, sprinting actions, and maximum speed. These results align with findings reported by (Fan et al., 2025) in professional Chinese Super League referees, who exhibited greater total distance, high-speed running, and sprinting activity during matches that finished in a tie. In balanced matches, gameplay tends to be faster and more chaotic, with numerous counterattacks, individual duels, and possession turnovers, forcing referees to respond with constant positional adjustments, including accelerations and decelerations (Aquino et al., 2021). Matches that are more evenly contested are associated with higher physical demands (Buchheit et al., 2018; Jerkovic et al., 2022; O'Donoghue & Tenga, 2001); therefore, in matches with a larger GD, players' physical demands are likely reduced, and consequently, referees' responses, which are influenced by players' activity levels (Weston et al., 2011; Zhou et al., 2025), would also be lower.

Nevertheless, certain differences emerge between regular football and CP football. While Fan et al. (2025) observed increased running performance in matches with wide score margins (≥ 2 goals), possibly due to a more open and less structured game dynamic, the opposite trend was observed in the present study. According to the results of the present study, referees' physical demands in CP football progressively decreased as the GD increased, suggesting that once the outcome of a match becomes evident, the pace and tactical intensity decline markedly. This difference likely reflects the specific nature of CP football. The high competitive imbalance (mean goal difference = 3.67) and diverse player profiles may reduce match intensity once a team takes a clear lead. Consequently, CP football referees appear to adjust their positioning less frequently and to cover smaller areas of the pitch, resulting in a lower overall workload compared with matches that remain competitive until the final minutes.

Regarding variables related to accelerations and decelerations, negative associations were identified between GD and the total number of accelerations, as well as low-to-medium intensity accelerations and decelerations (zones 1 and 2). Once again, these patterns can be explained by a reduced need to closely follow the game when the match outcome is practically decided. Referees may perform fewer total movements but still engage in bursts of high-intensity accelerations, possibly for positioning during counterattacks or to maintain offside-line awareness. In situations where one team clearly dominates, the competitive pace tends to drop (Buchheit et al., 2018; Jerkovic et al., 2022; Redwood-Brown et al., 2018), which appears to be associated with lower referees' physical demands. In contrast, in regular football, referees tend to increase their physical demands when the GD exceeds two goals (Fan et al., 2025). However, GD between winning and losing teams is generally larger in CP football, so such situations are less common compared to regular football. Moreover, such GD in regular football is often reached near the end of the match, thus influencing only a small portion of the match (Redwood-Brown et al., 2012).

On the other hand, it is worth noting that only two significant correlations were observed between the total number of goals and the referee´s physical demands variables (specifically, with MIR and low-intensity decelerations), while the vast majority showed no association. This confirms that referee physical demands are more strongly associated with goal difference than with total goals (Buchheit et al., 2018), reflecting the impact of match competitiveness and scoreline uncertainty. In a match where both teams score many goals but maintain a close score, the physical demands on the referee may be even greater than in a low-scoring match with a clear imbalance, reinforcing the relevance of contextual factors that can interact in a game (Henríquez, Reina, et al., 2024).

This study is not exempt of limitations that should be acknowledged when interpreting the results. First, the sample size was relatively small (n=13), with an unequal distribution between genders (10 men and 3 women), which limits the ability to generalize the findings to the broader refereeing population, particularly regarding female officials. Second, the dataset includes multiple match observations from the same referee, ranging from one to five matches per official. Although the statistical analyses treated all observations as independent, this approach does not model intra-subject dependency. While linear mixed-effects models were considered to address this issue, the highly unbalanced nature of the repeated measures and relatively small cluster sizes resulted in unstable model estimations. Consequently, the reported relationships reflect these global match demands, and readers are advised to interpret the associated p-values with this methodological constraint in mind. Moreover, the data were collected exclusively during male international-level competitions, meaning it is unknown whether these physical demand patterns are applicable to female CP football or domestic leagues with different competitive levels. Methodologically, the study focused solely on external load metrics quantified via GPS devices, without monitoring internal load variables (such as heart rate or rating of perceived exertion), which would have provided a more comprehensive understanding of the physiological strain associated with varying goal differences. While match outcome variables were analyzed, other potential contextual factors that could influence physical demands were not controlled for. As referee physical demands are likely associated with numerous additional variables, future research should account for factors such as the specific match period, team quality, match importance, and specific environmental conditions to provide a more holistic understanding of officiating demands. Finally, the absolute speed thresholds utilized to categorize running intensities were based on conventional football intensities. The authors acknowledge that given the unique functional and motor characteristics of players with CP, these standard thresholds may not accurately reflect the relative physiological demands of the sport. Therefore, future research should focus on establishing and validating specific speed thresholds specifically adapted to the CP football population.

Conclusions

The results of the present study show that closely contested matches involve greater physical demands for CP football referees. This trend, documented in professional and conventional football, is also observed in CP football, suggesting that match competitiveness is a key factor associated with referees' physical demands, regardless of whether the match is in regular or CP football. These findings highlight the importance of considering match context in performance analysis and underscore the need for specific preparation to handle high-demand situations, especially in matches with uncertain outcomes. From a practical perspective, these results provide actionable insights for referee physical coaches, tournament organizers, and the referees themselves. From an applied perspective, referee training programs should replicate the specific high-intensity demands of closely contested matches—such as repeated sprints, rapid changes of direction, and explosive accelerations—to minimize fatigue-related errors. Furthermore, from an organizational standpoint, refereeing committees must consider these findings when making match appointments during demanding international tournaments. Specifically, organizers should strategically rotate officials by considering whether a referee has recently officiated a closely contested match, as the associated physical demands may require longer recovery periods. Consequently, recovery strategies must be individualized, ensuring that referees involved in high-stress, narrow-margin matches receive more intensive regeneration protocols before their next assignment.

References

Aquino, R., Gonçalves, L. G., Galgaro, M., Maria, T. S., Rostaiser, E., Pastor, A., Nobari, H., Garcia, G. R., Moraes-Neto, M. V., & Nakamura, F. Y. (2021). Match running performance in Brazilian professional soccer players: comparisons between successful and unsuccessful teams. *BMC Sports Science, Medicine and Rehabilitation*, *13*(93), 1–9. https://doi.org/10.1186/S13102-021-00324-X

Bao, R., Wang, X., Shi, Y., & Gómez Ruano, M. Á. (2025). Research on cerebral palsy football: a scoping review. *BMC Sports Science, Medicine and Rehabilitation 2025*, *17*(381), 1–27. https://doi.org/10.1186/S13102-025-01436-4

Bastida-Castillo, A., Gómez-Carmona, C. D., De la Cruz Sánchez, E., & Pino-Ortega, J. (2018). Accuracy, intra- and inter-unit reliability, and comparison between GPS and UWB-based position-tracking systems used for time-motion analyses in soccer. *European Journal of Sport Science*, *18*(4), 450–457. https://doi.org/10.1080/17461391.2018.1427796

Buchheit, M., Modunotti, M., Stafford, K., Gregson, W., & Di Salvo, V. (2018). Match running performance in professional soccer players effect of match status and goal difference. In *Sports Performance & Science Reports* (Vol. 21). https://sportperfsci.com/match-running-performance-in-professional-soccer-players-effect-of-match-status-and-goal-difference/

Castagna, C., Abt, G., & D'Ottavio, S. (2007). Physiological Aspects of Soccer Refereeing Performance and Training. *Sports Medicine*, *37*(7), 625–646. https://doi.org/10.2165/00007256-200737070-00006

Castillo, D., Iturricastillo, A., Yanci, J., Reina, R., & Henríquez, M. (2025). Match-Running Differences Among International Regional Tournaments and the World Cup in Male Para-Footballers With Cerebral Palsy. *Adapted Physical Activity Quarterly*, *42*(3), 366–382. https://doi.org/10.1123/APAQ.2024-0081

Dehghansai, N., Pinder, R. A., & Baker, J. (2022). Talent Identification and Development in Paralympic Contexts: Current Challenges. *Frontiers in Sports and Active Living*, *4*(926974), 1–5. https://doi.org/10.3389/FSPOR.2022.926974

Fan, M., Deng, Y., Chen, X., Cao, A., & Zhang, H. (2025). What are the characteristics of professional league referees' running performance in different situations? *BMC Sports Science, Medicine and Rehabilitation*, *17*(153), 1–11. https://doi.org/10.1186/s13102-025-01227-x

Gamonales, J. M., Muñoz-Jiménez, J., Gómez-Carmona, C. D., & Ibáñez, S. J. (2022). Comparative external workload analysis based on the new functional classification in cerebral palsy football 7-a-side. A full-season study. *Research in Sports Medicine*, *30*(3), 295–307. https://doi.org/10.1080/15438627.2021.1888105

Henríquez, M., Ozaeta, E., Castillo, D., Reina, R., Cornejo, M. I., Iturricastillo, A., Arthur-Banning, S., & Yanci, J. (2024). Assessing the Match Physical Responses of

 DOI 10.26773/mjssm.260907

International Referees for Footballers with Cerebral Palsy: A Tournaments and Halves Comparative Analysis. *Sensors*, *24(5), 1595*. https://doi.org/10.3390/s24051595

Henríquez, M., Peña-González, I., Albaladejo-García, C., Sadarangani, K. P., & Reina, R. (2023). Sex differences in change of direction deficit and asymmetries in footballers with cerebral palsy. *Scandinavian Journal of Medicine & Science in Sports*, *33*(8), 1519–1530. https://doi.org/10.1111/SMS.14383

Henríquez, M., Reina, R., Castillo, D., Iturricastillo, A., & Yanci, J. (2024). Contextual factors and match-physical performance of international-level footballers with cerebral palsy. *Science and Medicine in Football*, *8*(3), 232–241. https://doi.org/10.1080/24733938.2023.2206384

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise*, *41*, 3–13. https://doi.org/10.1249/mss.0b013e31818cb278

International Federation of Cerebral Palsy Football. (2023). *Modifications to the IFAB Laws of the Game*.

Jerkovic, Z., Modric, T., & Versic, S. (2022). Analysis of the Associations between Contextual Variables and Match Running Performance in Croatian First Division Soccer. *Sport Mont*, *20*(2), 125–130. https://doi.org/10.26773/SMJ.220619

Lago-Peñas, C., García-Calvo, T., López Del Campo, R., Resta, R., & Ponce-Bordón, J. C. (2024). Match running performance is similar in lower and higher competitive standards of Spanish professional soccer accounting for effective playing time. *Biology of Sport*, *41*(3), 39–46. https://doi.org/10.5114/BIOLSPORT.2024.132993

Mara, J. K., Thompson, K. G., Pumpa, K. L., & Morgan, S. (2017). Quantifying the high-speed running and sprinting profiles of elite female soccer players during competitive matches using an optical player tracking system. *Journal of Strength and Conditioning Research*, *31*(6), 1500–1508. https://doi.org/10.1519/JSC.0000000000001629

Martin-Sanchez, M. L., Oliva-Lozano, J. M., Garcia-Unanue, J., Felipe, J. L., Moreno-Pérez, V., Gallardo, L., & Sánchez-Sánchez, J. (2022). Physical demands in Spanish male and female elite football referees during the competition: a prospective observational study. *Science and Medicine in Football*, *6*(5), 566–571. https://doi.org/10.1080/24733938.2022.214501

O'Donoghue, P., & Tenga, A. (2001). The Effect of Score-line on Work Rate in Elite Soccer. *Journal of Sports Sciences*, *19*(1), 25–26.

Oliva-Lozano, J. M., Rojas-Valverde, D., Gómez-Carmona, C. D., Fortes, V., & Pino-Ortega, J. (2021). Impact of contextual variables on the representative external load profile of Spanish professional soccer match-play: A full season study. *European Journal of Sport Science*, *21*(4), 497–506. https://doi.org/10.1080/17461391.2020.1751305

Peña-González, I., Maggiolo, J. F., Henríquez, M., Cervelló, E., & Moya-Ramón, M. (2025). Exploring physical performance and coaches' expectations to understand the international selection process in cerebral palsy football. *Sport Sciences for Health*, *21*(3), 2185–2194. https://doi.org/10.1007/s11332-025-01451-5

Peña-González, I., Maggiolo, J. F., Javaloyes, A., & Moya-Ramón, M. (2022). Analysis of scored goals in the cerebral palsy football World Cup. *Journal of Sports Sciences*, *40*(22), 2509–2516. https://doi.org/10.1080/02640414.2023.2167257

Poli, R., Ravenel, L., & Besson, R. (2018). *Competitive balance: A spatio-temporal comparison*. https://football-observatory.com/Competitive-balance-a-spatio-temporal-comparison

Reche-Soto, P., Cardona-Nieto, D., Diaz-Suarez, A., Bastida-Castillo, A., Gomez-Carmona, C., Garcia-Rubio, J., & Pino-Ortega, J. (2019). Player Load and Metabolic Power Dynamics as Load Quantifiers in Soccer. *Journal of Human Kinetics*, *69*(1), 259–269. https://doi.org/10.2478/HUKIN-2018-0072

Redwood-Brown, A., O'Donoghue, P., Nevill, A. M., Saward, C., Dyer, N., & Sunderland, C. (2012). Score-line effect on work-rate in english FA premier league soccer. *International Journal of Performance Analysis in Sport*, *12*, 258–271. https://doi.org/10.1080/24748668.2016.11868938

Redwood-Brown, A., O'Donoghue, P., Nevill, A. M., Saward, C., Dyer, N., & Sunderland, C. (2018). Effects of situational variables on the physical activity profiles of elite soccer players in different score line states. *Scandinavian Journal of Medicine and Science in Sports*, *28*(12), 2515–2526. https://doi.org/10.1111/sms.13271

Reina, R., Iturricastillo, A., Castillo, D., Urbán, T., & Yanci, J. (2020). Activity limitation and match load in para-footballers with cerebral palsy: An approach for evidence-based classification. *Scandinavian Journal of Medicine & Science in Sports*, *30*(3), 496–504. https://doi.org/10.1111/sms.13583

Romeo, D. M., D'Amario, G., Brunozzi, G., Napoli, V., Villa, M., Arpaia, C., Velli, C., Sini, F., & Brogna, C. (2024). Sports Activities in Children with Cerebral Palsy: A Narrative Review. *Medicina*, *60(3), 457*. https://doi.org/10.3390/medicina60030457

Weston, M., Drust, B., & Gregson, W. (2011). Intensities of exercise during match-play in FA Premier League referees and players. *Journal of Sports Sciences*, *29*(5), 527–532. https://doi.org/10.1080/02640414.2010.543914

Zhou, F., Zhang, W., Huang, K., Jiang, Y., & Zhou, C. (2025). Examining the correlation between referee physical fitness, in-game performance metrics, and team dynamics in the Chinese super league. *PLOS ONE*, *20*(5), 1–15. https://doi.org/10.1371/journal.pone.0318643

ORIGINAL SCIENTIFIC PAPER

Team Teaching Models in Physical Education and Their Impact on Physical Fitness in Primary School Children

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Abstract

Addressing inconsistencies in effective instructional delivery, this quasi-experimental study investigated the effect of various team teaching models in primary school physical education (PE) on the physical fitness of children. A sample of N =266 students (grades 1–4, mean age 7.68 years) from the Bratislava region participated in a five-month PE intervention. Intact classes were assigned to one of five instructional configurations: a single PE teacher (PET-only) and four team teaching models: Generalist Teacher + Sports Coach (GT+C), GT+PET, Assistant Teacher + PET (AT+PET), and GT+AT. Physical fitness was assessed pre- and post-intervention using the Standing Long Jump, Shuttle Run, Sit-and-Reach, and Pull-up Hold tests. To investigate the association between physical fitness and self-perceived physical literacy, PLAYself questionnaire was applied. The Kruskal-Wallis H-test showed significant differences in the magnitude of change across all four physical fitness components ($p< .01$). Most importantly, no single team teaching model demonstrated superiority across all domains; however, configurations involving PET or assistant support (GT+PET, AT+PET, GT+AT) generally showed more favourable gains in strength and endurance components. Crucially, self-perceived physical literacy showed a weak alignment with objective fitness, with only one of eight correlations (Pull-up Hold: $\rho = .177$, $p = .009$) reaching statistical significance at baseline. Conversely, out-of-school organized sport participation, particularly its frequency and competitive involvement, showed moderate to strong positive correlations with better physical fitness outcomes. These findings suggest that the composition of the teaching team and organized out-of-school sport participation influence physical fitness levels. The study supports the potential of certain collaborative instructional structures to enhance physical fitness in primary school children but also highlights the complexity of connecting self-perception of physical literacy with objectively measured performance in this age group.

Keywords: *tandem teaching, elementary school, physical education, physical fitness, physical literacy*

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Introduction

Team teaching, also known as co-teaching or tandem teaching, is a collaborative instructional model where two professionals jointly instruct students in a single classroom (Cook & Friend, 1995, 2010). At its core, this approach is a dynamic partnership based on shared responsibility and mutual goals, which requires continuous communication (Hargreaves & O'Connor, 2018). As a key component of educators' professionalism, effective team teaching positively influences instructional choices and student outcomes (Strogilos et al., 2023). This collective teaching facilitates "activating learning" by enabling educators to provide equal attention, better address various learning needs, and engage all learners more quickly (Abrami et al., 2015; Veteska et al., 2020).

This flexible approach is adaptable to all school subjects, including Physical Education (PE), and encompasses various distinct models. Initially categorized into five approaches (Cook & Friend, 1995), the framework was later refined into six models (Friend et al., 2010). The specific model utilized is often influenced by teacher training and professional experiences (Pancsofar & Petroff, 2016; Colson et al., 2021), with the "One Teach, One Assist" model being most frequent due to lower joint planning demands (Arias, 2024). Team teaching is known to provide students with richer learning experiences and diverse perspectives (Baeten & Simons, 2016), and it fosters an inclusive culture by increasing curriculum access for all learners (Cook & McDuffie-Landrum, 2019).

The use of team teaching is gaining traction in primary school PE in several contexts, including the UK (Jones & Green, 2015; Dockerty & Pritchard, 2023) and Ireland (Ní Chróinín & O'Brien, 2019). Crucially, similar trends are emerging in Central and Eastern Europe, such as Slovakia (Luptáková et al. 2025a; Balga et al., 2024) and North Macedonia (Klincarov et al., 2018; Popeska, 2022). This growth is primarily driven by concerns that generalist teachers often lack the necessary competence to provide Quality Physical Education (Duncombe et al., 2018; Spittle et al., 2022; Dockerty & Pritchard, 2023; Randall, 2023; Petračić, 2023). Consequently, policies in countries like Italy (Aliberti et al., 2025), Croatia (Gerovac et al., 2025), and North Macedonia (Luptáková et al., 2025b) are shifting to entrust PE to trained specialists (such as PE teachers or sports coaches). The implementation of specialized instruction, however, varies significantly by country: In Croatia, a solo instruction model is utilized where PE kinesiologists teach the subject instead of the generalist teacher. Gerovac et al. (2025) found that students taught by kinesiologists significantly outperformed the control group taught by generalist teachers in motor skills. Conversely, North Macedonia has adopted national legislation making the team teaching approach mandatory at the primary level, which involves a PE teacher working alongside the generalist classroom teacher (Luptáková et al., 2025b). Meanwhile, Slovakia implements the 'Coaches in Schools' initiative, integrating certified sports coaches into primary school PE instruction (Balga, 2024). The inclusion of these professionals ensures evidence-based pedagogical approaches that promote holistic development (Aliberti et al., 2025).

Following the examination of instructional methods, it is important to consider how the effectiveness of these models is evaluated. To objectively evaluate the effectiveness of these collaborative instructional models, it is crucial to monitor changes in key health-related outcomes, particularly physical fitness. Physical fitness assessments are vital for monitoring a subject's physical condition and the effects of physical activity (González-Rico & Ramírez-Lechuga, 2018). PE teachers play a vital role in this process, leveraging fitness monitoring as an educational tool to foster students' physical literacy (PL) and lifelong physical activity (Sepahvand et al., 2025). Objective assessment tools for children and adolescents include test batteries such as ALPHA-Fitness (Ruiz et al., 2011), EUROFIT (Adam et al., 1988), or the more recent FitBACK (Ortega et al., 2023). Since physical fitness (or motor competence) is only one component of the broader complex of PL (Whitehead, 2010), the subjective component must also be considered (Pastor-Cisneros et al., 2021). Objectively measured and self-perceived motor competence are both important factors influencing physical activity levels (Chai et al., 2023).

Previous research supports a direct relationship between objectively measured fitness and self-perceived fitness (Ortega et al., 2011; Štefan et al., 2019), suggesting a higher self-perceived level is associated with higher PL. Studies also demonstrate a relationship between PL and self-perceived physical fitness in children, linking it to motivation, self-concept, and self-esteem (Pastor-Cisneros et al., 2021). Importantly, cardiorespiratory fitness has been identified as one of the most relevant and influential factors in total PL scores (Pastor-Cisneros et al., 2021; Nezondet et al., 2023).

Despite the fact that the benefits of both team teaching and specialized instruction are evident, and the components of physical literacy are well-defined, there remains a lack of experimental evidence directly comparing the efficacy of different team teaching models on objective physical fitness gains and their alignment with self-perceived physical literacy in primary school children. Therefore, the primary aim of this quasi-experimental study was twofold: to investigate the effect of various team teaching models in primary school PE on children's physical fitness gains; and to investigate the association between these objectively measured outcomes and students' self-perceived physical literacy.

Materials and methods

Participants and design

A sample of N=266 primary school students (grades 1–4) participated in this investigation. The cohort consisted of n=143 boys and n=123 girls, with an average age of 7.68 years (SD = 1.10). The study recruited convenience samples from three primary schools within the Bratislava area that volunteered to engage in the research. The project adopted a cluster-based, quasi-experimental design, where the intact classroom served as the assignment unit. This methodology was chosen to maintain the ecological validity of the five-month PE intervention in real-world school settings; the intervention involved the standard school curriculum delivered over two 45-minute sessions each week from T1 to T2. However, this cluster-based, non-random assignment introduced the potential for selection bias and confounding variables. Indeed, preliminary analysis confirmed statistically significant baseline differences across groups regarding age, height, and all four physical fitness components ($p < .05$). This non-randomization was not feasible to avoid due to mandatory school administrative and scheduling constraints, which required the preservation of intact class structures for the duration of the study.

All procedures involving minors were executed only after securing parental or legal guardian written informed consent. The study was reviewed and received favourable ethical clearance (Approval no. 10/2024, dated 21.6.2024) from the Ethics

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Committee of the Faculty of Physical Education and Sports, Comenius University in Bratislava, Slovakia. All research activities conformed to the established guidelines of the Declaration of Helsinki.

The primary aim was to investigate the effect of instructional structure on students' physical fitness. Accordingly, pre-existing classes were non-randomly assigned to one of five instructional arrangements. These arrangements included a baseline condition (single PE teacher) and four variants of team teaching. The five teaching configurations represent the manipulated variable in this design. Detailed participant characteristics for each configuration are outlined in Table 1, and the specific composition of the teaching teams, including qualifications and defined roles, is provided in Table 2.

Table 1. Participant Demographics by Teaching Models

Teaching model	n (students)	Mean age (years)	SD
PE teacher-only	48	7.44	1.27
Generalist teacher + Coach	48	6.58	.54
Generalist teacher + PE teacher	44	7.66	1.54
Assistant teacher +PE teacher	82	7.70	1.21
Generalist teacher +Assistant teacher	44	7.68	.64

Table 2. Operational Definitions of Teaching Models

Teaching model	Teacher composition	Key teacher qualifications	Intended roles
PET	Single Certified PE Teacher	Master's in PE; single-teacher group.	PET (All instructional roles)
GT+C	Generalist Teacher + Sports Coach	GT (Primary Ed Master's); Coach (Sport Science/License; national program).	Lead: Coach (skill execution). Support: GT (classroom management/pedagogy).
GT+PET	Generalist Teacher + PE Teacher	GT (Primary Ed Master's); PET (PE Master's).	Lead: PET (motor skill development). Support: GT (pedagogy/class management).
AT+PET	Assistant Teacher + PE Teacher	AT (Pedagogical Sciences; after-school); PET (PE Master's).	Lead: PET (motor skill development). Support: AT (management/individual assistance).
GT+AT	Generalist Teacher + Assistant Teacher	GT (Primary Ed Master's); AT (Pedagogical Sciences; after-school).	Lead: GT (lesson delivery). Support: AT (supervision/behavior management).

The intervention utilized the standard state-mandated PE curriculum for the primary level in Slovakia. Crucially, the specific lesson content and pedagogical choices were not standardized, mandated, or monitored by the research team across the five instructional groups. The study aimed to investigate the efficacy of the different teacher configurations operating in their typical, naturalistic environment. This decision reflects a commitment to ecological validity, but it must be acknowledged that lesson content variability represents an uncontrolled confounding factor in the interpretation of the subsequent results.

Prior to the intervention, all participating teachers were individually or collectively briefed by the research team regarding the study's requirements. This communication focused on the research rationale, the importance of adhering to the intervention timeline, and general guidance on leveraging specialized expertise consistent with the intended roles in Table 2. Consequently, specific team teaching roles were neither formally prescribed nor monitored, meaning the instructional fidelity of the team teaching process remains an unmeasured variable in this study.

Procedures

Assessment occurred at two key time points. Baseline data (T1) were collected in October 2024, immediately preceding the commencement of the five-month PE intervention. Post-intervention data (T2) were gathered in April 2025, marking the conclusion of the experimental period.

Four components of physical fitness were evaluated using standardized tests from the EUROFIT handbook (Council of Europe, 1993). These tests included: the Standing Long Jump, the Shuttle Run test, the Sit-and-Reach test, and the Pull-up Hold.

To investigate the associations between students' physical fitness levels and self-reported physical literacy, the Physical Literacy Assessment for Youth-Self (PLAYself) questionnaire (Physical Literacy Canada, 2023) was administered at both T1 and T2. The questionnaire underwent a rigorous forward-backward translation process to ensure accuracy in the Slovak language. The instrument was administered by teachers to students in Grades 1 and 2, while students in Grades 3 and 4 completed it via self-administration. The internal consistency of the chosen subscale was confirmed at baseline ($\alpha = .72$). For this study, the Physical Literacy Self-Description subscale was used for analysis, as it specifically captures a child's self-efficacy related to participation in physical activity.

To provide contextual insight into the students' overall activity levels, out-of-school physical activity was assessed exclusively at T2. This information was gathered using a non-validated, context-specific questionnaire administered by the teachers. The instrument focused on three primary areas of participation outside the school curriculum: Frequency of Organized Physical Activity, Competitive Involvement (yes/no), and Sport Type (individual or collective sports). This data was intended to complement the findings obtained within the school setting.

Statistics

Data management and analysis were executed using IBM SPSS Statistics Version 21 for Windows. Before the main analyses, the distributional properties of the data, specifically the change scores (Δ), were evaluated for normality using the Shapiro-Wilk test. Given the observed non-normality in these scores and the study's quasi-experimental, cluster-based design, a reliance on non-parametric statistical methods was adopted. We explicitly acknowledge the presence of a cluster effect (students nested within classes), which is typical of educational interventions. While multilevel modeling (MLM), such as mixed effects models, is the ideal approach for nested data, we determined that our sample size (specifically the low number of clusters) was insufficient to reliably implement this advanced analysis.

The established threshold for statistical significance across all tests was set at $\alpha = .05$ (two-tailed).

The primary objective—determining the comparative effectiveness of the five distinct instructional groups—was addressed through a two-step analytical procedure:

1. Analysis of Within-Group Development

To quantify the growth or change achieved within each teaching configuration, the mean difference (Δ) between the baseline (T1) and post-intervention (T2) physical fitness scores was computed for every group. The extent of this change was presented using the 95% Confidence Interval (CI) for the mean difference. Statistical evidence of significant development within a group was established when the 95% CI did not encompass zero.

2. Analysis of Between-Group Differences

To formally test for significant overall differences among the five instructional groups concerning the magnitude of change (T1 to T2 scores), the Kruskal-Wallis H-test was employed. This test was selected as the appropriate methodology to compare independent groups when distributional assumptions (normality) were violated and due to the inherent characteristics of the dependent fitness variables. This analysis was performed separately for each physical fitness outcome measure.

Additionally, Spearman's rank-order correlation (ρ) coefficients were calculated to explore the interrelationships between the measured constructs and to furnish crucial contextual information. Firstly, correlations were computed between the children's self-perceptions of physical literacy and their scores on the objectively measured physical fitness tests. These correlations were calculated independently for both the initial (T1) and final (T2) assessments to observe potential shifts in self-awareness over the intervention period. Secondly, to gauge the potential impact of external factors, correlations were determined between the Out-of-School Physical Activity (OOSPA) variables (categorized by frequency, competitive involvement, and sport type) and the post-intervention physical fitness test results. This step aimed to quantify the influence of habitual external activity on the study's primary outcomes.

Effect sizes were reported for all inferential tests: for within-group changes, $r = Z / \sqrt{N}$; for Kruskal–Wallis tests, $\varepsilon 2$ was computed. Effect sizes and Spearman correlation coefficients were interpreted using conventional cut-offs (.10 = weak, .30 = moderate, .50 = strong), following Cohen's guidelines (Cohen, 1988).

Results

Effects of Team Teaching Models on Physical Fitness Components

To evaluate the effects of different instructional configurations on students' physical fitness, four standardized tests were conducted at both the beginning and end of the intervention. The Kruskal-Wallis H-test revealed statistically significant differences in the magnitude of change across all four physical fitness components.

The strongest differentiation between groups was observed in flexibility (Sit-and-Reach) ($H(4) = 59.07$, $p < .01$), with a large effect size ($\eta^2 = .26$). The Generalist Teacher + Coach

Table 3. Changes in Physical Fitness by Instructional Group

Groups		Mean	95% Confidence Interval for Mean		Std. Deviation	Median	Minimum	Maximum	Interquartile range
			Lower Bound	Upper Bound					
Sit-and-Reach [cm]	PET	.03	-2	2.07	3.68	0	-9.5	6	4.5
	GT+C	1.19	.45	1.93	1.83	1.5	-3	3	4
	GT+PET	-3.17	-6.96	.62	10.52	1	-32	12	11.13
	AT+PET	-9.92	-13.49	-6.36	10.85	-11.5	-36	17	10.75
	GT+AT	-7.26	-11.18	-3.35	9.05	-6	-32	12	10
Standing Long Jump [cm]	PET	3.67	-2.76	10.09	11.6	3	-20	33	10
	GT+C	.35	-4.51	5.21	12.03	0	-28	27	14.75
	GT+PET	3.75	-.01	7.51	10.42	2.5	-18	38	10.75
	AT+PET	13.45	9.18	17.71	12.97	13.5	-8	44	18
	GT+AT	2.96	-3.01	8.92	13.8	3	-31	30	20
Pull-up Hold [s]	PET	1.05	-4.56	6.67	10.14	2.1	-19.3	20.5	2.8
	GT+C	-1.19	-2.43	.05	3.07	-.85	-8.62	4.88	3.48
	GT+PET	6.59	3.74	9.44	7.9	3.69	-3.1	29.1	12.61
	AT+PET	1.86	-.72	4.44	7.85	1.74	-13.03	31.85	9.52
	GT+AT	2.15	.93	3.36	2.81	1.24	-.78	8.62	4.07
Shuttle Run [m]	PET	6.67	-18.33	31.67	45.15	20	-60	80	80
	GT+C	-140	-245.38	-34.62	260.89	-40	-920	80	195
	GT+PET	-83.13	-153.83	-12.42	196.1	10	-700	80	230
	AT+PET	18.42	-15.8	52.64	104.12	0	-240	460	65
	GT+AT	52.17	7.41	96.94	103.53	40	-180	380	100

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Table 4. Mean Ranks and Effect Sizes (η^2) for Changes in Physical Fitness Components by Instructional Group

Test Statistics[a,b]				
	Sit-and-Reach [cm]	Standing Long Jump [cm]	Pull-up Hold [s]	20-meter Shuttle Run [m]
Chi-Square	59.066	15.999	29.770	30.578
df	4	4	4	4
Asymp. Sig.	,000	,003	,000	,000

a. Kruskal Wallis Test; b. Grouping Variable: Group: 1 - PET 2 - GT+C 3 - GT+PET 4 - AT+PET 5 - GT+AT

(GT+C) group achieved the highest mean rank (143.91) and was the only configuration to achieve a statistically significant absolute gain (Δ = +1.19 cm; 95% CI: .45, 1.93). In contrast, the AT+PET and GT+AT groups experienced significant declines, while the PET-only group (Mean Rank 136.99) maintained baseline levels with no significant change.

Group differences in lower-body explosive strength (Standing Long Jump) were significant with a medium effect size (H(4) = 16.00, $p < .01$, η^2 = .06). The Assistant Teacher + PE Teacher (AT+PET) group demonstrated the highest mean rank (136.17) and the most substantial absolute improvement (Δ = +13.45 cm), which was statistically significant (95% CI: 9.18, 17.71). While the PET-only and GT+PET groups showed positive trends, their confidence intervals crossed zero, indicating these changes were not statistically significant within the groups.

Significant differences were found in upper-body endurance development (Pull-up Hold) (H(4) = 29.77, $p < .01$), representing a large effect size (η^2 = .12). The GT+PET group achieved the highest mean rank (144.96) and the largest significant improvement in performance (Δ = +6.59 s; 95% CI: 3.74, 9.44). The GT+AT group also recorded a significant gain (Δ = +2.15 s). Conversely, the PET-only group (Mean Rank 104.86) showed no statistically significant change (95% CI: –4.56, 6.67), suggesting that the solo-specialist model did not induce measurable gains in this domain.

Table 5. Kruskal-Wallis Test Statistics for Between-Group Differences in Physical Fitness

Ranks				
Group: 1 - PET 2 - GT+C 3 - GT+PET 4 - AT+PET 5 - GT+AT		N	Mean Rank	η^2
Sit-and-Reach [cm]	Physical Education Teacher	36	136.986	.261
	Generalist Teacher and Coach	47	143.915	
	Generalist Teacher and Physical Education Teacher	41	126.476	
	Assistant Teacher and Physical Education Teacher	59	69.237	
	Generalist Teacher and Assistant Teacher	33	74.848	
	Total	216		
Standing Long Jump [cm]	Physical Education Teacher	36	96.223	.057
	Generalist Teacher and Coach	47	98.330	
	Generalist Teacher and Physical Education Teacher	41	97.780	
	Assistant Teacher and Physical Education Teacher	59	136.169	
	Generalist Teacher and Assistant Teacher	33	100.227	
	Total	216		
Pull-up Hold [s]	Physical Education Teacher	36	104.861	.123
	Generalist Teacher and Coach	45	75.844	
	Generalist Teacher and Physical Education Teacher	41	144.963	
	Assistant Teacher and Physical Education Teacher	59	99.144	
	Generalist Teacher and Assistant Teacher	33	121.939	
	Total	214		
20-meter Shuttle Run [m]	Physical Education Teacher	37	103.892	.127
	Generalist Teacher and Coach	42	77.452	
	Generalist Teacher and Physical Education Teacher	40	90.05	
	Assistant Teacher and Physical Education Teacher	59	118.297	
	Generalist Teacher and Assistant Teacher	36	147.958	
	Total	214		

The teaching models significantly influenced endurance outcomes (Shuttle Run) (H(4) = 30.58, $p < .01$), with a medium effect size (η^2 = .13). The GT+AT group achieved the highest mean rank (147.96) and displayed the most effective development, with a significant mean increase of +52.17 m (95% CI: 7.41, 96.94). The GT+C group had the lowest mean rank (77.45) and a severe decline in performance (Δ = -140.00 m), though this was skewed by outliers. The PET-only group again showed no significant change (95% CI: –18.33, 31.67).

Associations Between Physical Fitness and Self-Perceived Physical Literacy

Secondly, the association between physical fitness and self-perceived physical literacy was investigated. At the initial testing, the PLAYself total score demonstrated a statistically significant positive correlation with the pull-up hold ($\rho = .177$, $p < .01$). However, no significant associations were found with sit-and-reach ($\rho = -.093$), standing long jump ($\rho = .017$), or the 20-meter shuttle run ($\rho = .069$). At final testing, no significant associations emerged between self-perceived physical literacy and any of the physical fitness measures (all $p > .05$) (Table 6). With only one of the eight correlations reaching statistical significance after the intervention, these findings suggest that children's self-reported perceptions of their physical literacy are not broadly aligned with their objectively measured physical fitness (Table 7).

Table 6. Associations Between Physical Fitness and Self-Perceived Physical Literacy – Pre intervention

	PLAYself		
	Correl. Coeff.	Sig.	N
Sit-and-Reach	-.093	.173	218
Standing Long Jump	.017	.806	218
Pull-up Hold	.177	.009	218
Shuttle Run	.069	.318	212

Table 7. Associations Between Physical Fitness and Self-Perceived Physical Literacy – Post intervention

	PLAYself		
	Correl. Coeff.	Sig.	N
Sit-and-Reach	.03	.685	185
Standing Long Jump	-.054	.468	184
Pull-up Hold	.067	.364	185
Shuttle Run	.006	.936	190

Associations Between Physical Fitness and Organized Out-of-School Sport Participation

In addition to above-mentioned association, the correlations between physical fitness components and organized out-of-school physical activity participation are presented in Table 8. Frequency of participation in organized sport showed moderate to strong positive correlations with several physical performance metrics. Notably, it was positively associated with standing long jump performance ($\rho = .357$, $p < .01$), pull-up hold ($\rho = .238$, $p < .01$), and shuttle run ($\rho = .220$, $p < .01$). Our data confirm that students who engage more frequently in organized physical activity outside of school tend to display greater levels of physical fitness components.

In contrast, competitive involvement (coded such that higher values reflect less frequent participation in competitive settings) was negatively associated with key outcomes. Significant inverse relationships were observed with standing long jump ($\rho = -.412$, $p < .01$), pull-up hold ($\rho = -.281$, $p < .01$), and shuttle run ($\rho = -.200$, $p < .01$), indicating that children regularly engaged in competitive sport settings exhibited better physical performance compared to their peers.

Table 8. Associations Between Physical Fitness and Organized Out-of-school Participation

		Sit-and-Reach	Standing Long Jump	Pull-up Hold	Shuttle Run
OOSPA - Frequency	Correl. Coeff.	-.02	.357	.238	.220
	Sig.	.763	<.001	<.001	<.001
	N	235	235	235	235
OOSPA - Competitive Involvement	Correl. Coeff.	.098	-.412	-.281	-.200
	Sig.	.135	<.001	<.001	.002
	N	235	235	235	235
OOSPA - Sport Type	Correl. Coeff.	-.126	.11	.253	.122
	Sig.	.054	.094	<.001	.062
	N	235	235	235	235

As part of the background assessment, children reported the type of organized sport they engaged in outside school. Overall, 43.0% participated in collective sports, 39.5% in individual sports, 1.2% in both, and 16.3% reported no participation. This variable demonstrated a statistically significant positive correlation with pull-up hold ($\rho = .253$, $p < .01$). However, associations with sit-and-reach ($\rho = -.126$), standing long jump ($\rho = .110$), and shuttle run ($\rho = .122$) did not reach statistical significance. These findings suggest that while the type of sport may have some influence, the frequency and competitiveness of participation are more consistent predictors of physical fitness.

Discussion

Main Findings

The primary aim of this quasi-experimental study was to

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investigate the efficacy of various team teaching models in primary PE on the objective physical fitness development of children, and to explore the alignment between these objective gains and students' self-perceived physical literacy (PL). The findings provide novel evidence directly comparing different instructional configurations. Consequently, rather than identifying a single 'gold standard' model, the findings reveal that instructional efficacy is not universal, but strictly dependent on the specific fitness domain being targeted. In fact, our results unequivocally demonstrate that the instructional configuration is a crucial determinant of student physical fitness gains, with statistically significant differences observed across all four measured EUROFIT components. The strongest and most crucial insight is not that one model wins, but that different collaborative structures maximize different physiological outcomes. This finding supports the broader literature that effective teaching practice, often facilitated by collaborative models, positively influences student outcomes (Strogilos et al., 2023). This complex pattern of differentiated gains stands in marked contrast to the parallel study on the same cohort (Luptáková et al., 2025c), which found no comparative difference between instructional groups for broad measures of Motor Competence (MC), assessed by MOBAK. The contrasting results indicate that the instructional structure's influence may be highly specific to the physical dimension being measured - fitness versus motor skill. This suggests that unlike motor competence, which appears robust to instructional variation, physical fitness is a highly sensitive adaptation that relies strictly on the specific expertise and pedagogical focus provided by the collaborative team.

The primary finding is the consistent observation that team teaching configurations involving a specialist professional yielded superior outcomes compared to the single PE teacher model across three of the four fitness domains measured: upper-body endurance, lower-body explosive strength, and aerobic endurance. Therefore, it is concluded that the combination of a specialist's pedagogical and content knowledge with the generalist's classroom management and student knowledge—a core benefit of team teaching (Cook & Friend, 2010)—creates a synergistically effective learning environment. This finding is particularly salient because the PE Teacher-only configuration failed to produce any statistically significant change in three out of four fitness components. While this contrasts with recent findings favouring solo kinesiologists (Gerovac et al., 2025), our data crucially suggest that a specialist's expertise is not a self-sufficient guarantee of success, but a resource that requires the collaborative scaffolding of a second educator to be fully realized. Our data strongly challenge the assumption that simply having a trained PE specialist is sufficient for measurable gains in primary school PE. Instead, the results demonstrate that the collaborative component of team teaching is the critical factor for improved outcomes. This effect likely stems from the practical advantages of having two adults, such as the capacity to offer more personalized attention, enhance classroom management for a larger group, and increase opportunities for continuous progress monitoring (Gardiner, 2010; Thousand et al., 2006). Ultimately, the collaborative structure acts as the essential catalyst, unlocking the specialist's expertise to drive physical gains that a solo educator—even a specialist—cannot achieve alone.

While the team configurations involving the PE teacher excelled in strength and power, the remaining two fitness domains demonstrated the differentiated efficacy of models not relying on the traditional PE specialist. The outcome for Flexibility measured via Sit-and-Reach was particularly distinct: the Generalist Teacher + Coach (GT+C) group was the only configuration to achieve a significant gain. This finding implies that success in specific fitness components may rely less on conventional PE expertise and more on the specialized training of the co-teacher. Coaches, with their typically specific, structured training in physical preparation and mobility routines, may introduce dedicated flexibility work that generalist and PE teachers might otherwise overlook. Conversely, the significant declines observed in the AT+PET and GT+AT groups, alongside the non-significant change for the PET-only group, demonstrate that flexibility development is not an inherent or incidental outcome of a typical, general primary PE curriculum and requires intentional, targeted focus within the lesson content.

The most surprising finding emerged in the outcomes for the Shuttle Run. The greatest improvement was observed in the Generalist Teacher + Assistant Teacher (GT+AT) group, a configuration entirely devoid of a PE specialist or a sports coach. This is a highly significant contrast to the established literature, which consistently emphasizes the importance of specialist training for the provision of Quality Physical Education (QPE) in primary schools (Duncombe et al., 2018; Spittle et al., 2022; Dockerty & Pritchard, 2023). While policy shifts are often driven by concerns over generalist teachers' competence (Petračić, 2023; Randall, 2023), in our study the GT+AT model demonstrated the most effective development in cardiorespiratory fitness. This unexpected success highlights the potential influence of several uncontrolled confounding factors. The most prominent among these is the varied lesson content. For example, the GT+AT team may have focused heavily on high-intensity, continuous physical activities, such as specific running games or circuits that effectively targeted cardiorespiratory fitness. Ultimately, this suggests that unmeasured implementation dynamics—specifically teacher enthusiasm, collaborative fidelity, and student compliance—can act as potent determinants of physical fitness that override the lack of specialist qualifications.

Association Between Physical Fitness and Self-Perceived Physical Literacy

The study secondly sought to investigate the relationship between objectively measured physical fitness and children's self-perception of their Physical Literacy (PL), a construct influencing lifelong physical activity (Whitehead, 2010). The results indicated a lack of alignment between the children's self-reported PL (PLAYself) and their objective physical fitness scores at both T1 and, more decisively, at T2. Only one weak, positive correlation was found at baseline in the Pull-up Hold, and no significant associations emerged post-intervention.

This broad lack of alignment between self-reported PL and objective fitness scores is a critical finding and points to a fundamental difference when comparing physical fitness (EUROFIT) with fundamental movement skills (FMS). Specifically, the companion study using the same cohort (Luptáková et al., 2025c) revealed that self-perceived PL did show a weak but consistent association with objectively measured Motor Competence (MOBAK). At initial testing (T1), positive correlations were found with MOBAK Object-Movement and Self-Movement, relationships that persisted and slightly strengthened at final testing (T2). Therefore, our combined results suggest that while self-perception is disconnected from general physical fitness, children's self-reported literacy is most closely aligned with their proficiency in fundamental manipulative skills. This confirms that a child's physical self-concept is not constructed from abstract physiological metrics, but is anchored exclusively in the tangible, visible mastery of fundamental skills.

Our finding contrasts with some previous research supporting a direct relationship between objectively measured and self-perceived fitness (Ortega et al., 2011; Štefan et al., 2019). However, it is strongly supported by developmental literature focusing on early to middle childhood. Previous literature shows that children in this period undergo rapid physical and mental development, and perceived motor competence changes quickly with age (Barnett et al., 2008). In early childhood, children's perception accuracy is poor, and they tend to overestimate their competence (Chai et al., 2023). This inability to accurately estimate abilities is expected, as children are believed to be able to make sound judgments about their physical competence only after the age of eight (Harter, 1982). Prior to this age, children are less likely to recognize their actual physical competence and do not generally begin to compare their abilities with peers until they are older (Fox & Whitehead, 2010). This developmental shift in self-perception usually occurs within public settings, such as PE and organized sport (Kirk, 2005), making children susceptible to humiliation or embarrassment when they realize their performance is inferior to that of their peers (Washburn & Kolen, 2018). As this study included a large number of students under the age of eight in Grades 1–4, this developmental immaturity likely accounts for the lack of objective-subjective alignment. Consequently, relying on self-reports for this age group yields limited insight, as these students lack the requisite cognitive maturity to distinguish their actual physical limits from their aspirational self-image.

Association Between Physical Fitness and Organized Out-of-School Physical Activity

To provide essential context for interpreting the school-based intervention effects, the study examined the influence of Organized Out-of-School Physical Activity (OOSPA) on post-intervention physical fitness. The results showed that the frequency of organized participation and competitive involvement were moderate to strong predictors of better performance across key fitness metrics.

This robust association is further supported by the companion study using the MOBAK assessment with the same cohort (Luptáková et al., 2025c), which found that OOSPA-Frequency showed significant, albeit weak, positive correlations with both subscales of basic motor competence, both object- and self-movement. Furthermore, higher competitive involvement was significantly linked to better Object Movement skills. In contrast to the objective performance metrics, none of the dimensions of OOSPA demonstrated a statistically significant correlation with self-reported physical literacy. This suggests that while external organized sport participation is clearly linked to actual physical competence—what a child can do—it is not strongly predictive of self-efficacy, or what a child believes they can do, in this young cohort.These observations underscore the substantial impact of activities outside the school environment on physical fitness levels. It suggests that the two 45-minute PE lessons per week are necessary but often insufficient drivers of comprehensive fitness gains for all children. This finding aligns with evidence emphasizing the foundational role of extra-curricular activities: studies examining the influence of extra-curricular sports programs on motor abilities in preschool-aged children (Caput-Jogunica et al., 2009) have shown that the development of sufficient motor proficiencies in early childhood positively correlates with club sport participation and total time spent in sport later in life (Fransen et al., 2014). Therefore, school PE must function not merely as an isolated fitness intervention, but as a motivational catalyst that actively propels students toward the out-of-school participation necessary for lifelong health.

Study Limitations

The findings of this study should be interpreted considering several limitations. First, as a consequence of the quasi-experimental design utilizing intact classes, baseline equivalence across the instructional groups could not be established. Significant pre-intervention differences were observed in students' age, height, and physical fitness levels, which introduces selection bias as a potential confounding factor affecting the comparative magnitude of change. Second, to prioritize ecological validity, the specific lesson content and pedagogical styles were not standardized or mandated by the research team. Consequently, variability in the intensity and focus of physical activities (e.g., a focus on running games vs. gymnastics) likely occurred across groups, representing an uncontrolled variable.

Third, while the study defined specific team teaching roles, the instructional fidelity—the degree to which teachers adhered to these collaborative models versus defaulting to a "one teach, one assist" approach—was not formally monitored. Fourth, regarding the statistical analysis, the study acknowledges a cluster effect (students nested within classes); however, the sample size did not yield a sufficient number of clusters to reliably employ multilevel modeling (MLM). Finally, regarding the subjective measures, the sample included a high proportion of students in early childhood (grades 1–2), a developmental stage characterized by poor accuracy in self-perceiving motor competence, which may limit the reliability of the self-reported physical literacy data.

Practical Implications

The findings of this study offer critical guidance for educational policy and practice. First, the results challenge the growing legislative trend of simply replacing generalist teachers with specialists. Our data indicate that the presence of a specialist alone (PET-only) does not guarantee superior fitness outcomes. Instead, policymakers should prioritize funding and training for collaborative team teaching models, as the synergy between a specialist's content knowledge and a generalist's pedagogical rapport appears to be the primary driver of physical development.

Second, schools should adopt a flexible approach to staffing. Since no single model proved superior across all domains, administrators might consider targeted partnerships—for instance, integrating sports coaches specifically to enhance conditioning and flexibility, while relying on PE teachers for fundamental motor skill development.

Finally, given the strong link between out-of-school sport participation and fitness levels, educators must view PE not just as physical training, but as a gateway to lifelong activity. Teachers should focus on cultivating the affective components

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of physical literacy (confidence and motivation) during lessons to encourage students to engage in organized sport outside of school, as the standard dosage of two PE lessons per week is insufficient to drive comprehensive fitness gains on its own.

Conclusions

This study provides quasi-experimental evidence that the instructional configuration in primary physical education is a significant determinant of student physical fitness development. The results indicate that no single team teaching model is universally superior across all fitness domains; rather, different collaborative structures appear to maximize different physiological outcomes. However, a consistent trend emerged: collaborative teaching models—whether involving a PE teacher, a sports coach, or an assistant—generally yielded greater improvements in strength, endurance, and flexibility compared to the traditional single-PE teacher format.

These findings challenge the assumption that the mere presence of a specialist ensures quality outcomes. Instead, the data suggest that the collaborative mechanism itself—the synergy between two educators—is the critical factor. By combining a specialist's content knowledge with a generalist's or assistant's pedagogical support, schools can create more effective learning environments that surpass what a solo educator can achieve, even if that educator is a specialist.

Furthermore, the study highlights a distinct disconnect between objective physical fitness and self-perceived physical literacy in early to middle childhood. The lack of alignment between children's actual performance and their self-assessment suggests that students in grades 1–4 have not yet developed the cognitive maturity to accurately evaluate their physical capacities. Consequently, physical education programs must prioritize not only physical conditioning but also the development of accurate self-awareness and motivation.

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Conflicts of Interest

The authors declare no conflict of interest.

References

Abrami, P. C., Bernard, R. M., Borokhovski, E., Waddington, D. I., Wade, C. A., & Persson, T. (2015). Strategies for Teaching Students to Think Critically: A Meta-Analysis. *Review of Educational Research*, *85*(2), 275–314. https://doi.org/10.3102/0034654314551063

Adam, C., Klissouras, V., Ravassolo, M., Renson, R., Tuxworth, W., Kemper, H., Van Mechelen, W., Hlobil, H., Beunen, G., & Levarlet-Joye, H. (1988). *Handbook for the EUROFIT test of physical fitness*. Edigraf Editoriale Gráfica.

Aliberti, S., Kaçurri, A., Kasa, A., & Giardullo, G. (2025). Stakeholders' opinions on teaching movement education in primary schools: A cross-sectional study. *Journal of Physical Education and Sport*, *25*(2), 423–431. https://doi.org/10.7752/jpes.2025.02047

Arias, K. (2024). Evaluación de la co-enseñanza en educación diferencial: principales fortalezas, limitaciones y desafíos. *REVISTA META: AVALIAÇÃO*, *16*(51), 307–332. https://doi.org/10.22347/2175-2753v16i51.4293

Baeten, M., & Simons, M. (2014). Student Teachers' Team Teaching: Models, Effects, and Conditions for Implementation. *Teaching and Teacher Education*, *41*, 92–110. https://doi.org/10.1016/j.tate.2014.03.010

Balga, T., Luptáková, G., Cihová, I., & Dovičák, M. (2024). Evaluating the impact of tandem teaching with coaches and generalist teachers on primary school students' perceptions in physical education. *Collegium Antropologicum*, *48*(3), 161–166. https://doi.org/10.5671/ca.48.3.4

Caput-Jogunica, R., Lončarić, D., & De Privitellio, S. (2009). Extracurricular sport activities in preschool children: Impact on motor achievements and physical literacy. *Hrvatski športskomedicinski vjesnik*, *24*, 82–87.

Chai, H., Xue, R., Yao, L., Miao, M., & Han, B. (2023). Configurations of actual and perceived motor competence among elementary school children in China: differences in physical activity. *Frontiers in Public Health*, *11*, Article 1280643. https://doi.org/10.3389/fpubh.2023.1280643

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Lawrence Erlbaum Associates.

Colson, T., Xiang, Y., & Smothers, M. (2021). How Professional Development in Co-teaching Impacts Self-Efficacy Among Rural High School Teachers. *The Rural Educator*, *42*(1), 20–31. https://doi.org/10.35608/ruraled.v42i1.897

Cook, L., & Friend, M. (1995). Co-teaching: Guidelines for creating effective practices. *Focus on Exceptional Children*, *28*(3), 1–16.

Cook, L., & Friend, M. (2004). Co-Teaching: Principles, Practices, and Pragmatics. *New Mexico Public Education Department Quarterly Special Education Meeting*.

Cook, S. C., & McDuffie-Landrum, K. (2019). Integrating Effective Practices Into Co-Teaching: Increasing Outcomes for Students With Disabilities. *Intervention in School and Clinic*, *55*(4), 221–229. https://doi.org/10.1177/1053451219855739

Council of Europe. (1993). *EUROFIT: Handbook for the EUROFIT tests of physical fitness* (2nd ed.).

Dockerty, F., & Pritchard, R. (2023). Reconsidering models-based practice in primary physical education. *Education 3-13*. https://doi.org/10.1080/03004279.2023.2263470

Duncombe, R., Cale, L., & Harris, J. (2018). Strengthening 'the foundations' of the primary school curriculum. *Education 3-13: International Journal of Primary, Elementary and Early Years Education*, *46*(1), 76–88. https://doi.org/10.1080/03004279.2016.1185137

Fox, K., & Whitehead, M. (2010). The physical self and physical literacy. In M. Whitehead (Ed.), *Physical literacy: Throughout the lifecourse* (pp. 71–81). Routledge.

Fransen, J., Deprez, D., Pion, J., Tallir, I. B., D'Hondt, E., Vaeyens, R., Lenoir, M., & Philippaerts, R. M. (2014). Changes in physical fitness and sports participation among children with different levels of motor competence: a 2-year longitudinal study. *Pediatric Exercise Science*, *26*(1), 11–21. https://doi.org/10.1123/pes.2013-0005

Friend, M., Cook, L., Hurley-Chamberlain, D., & Shamberger, C. (2010). Co-Teaching: An Illustration of the Complexity of Collaboration in Special Education. *Journal of Educational and Psychological Consultation*, *20*(1), 9–27. https://doi.org/10.1080/10474410903535380

Gardiner, W. (2010). Mentoring two student teachers: Mentors' perceptions of peer placements. *Teacher Education*, *21*(2), 233–246. https://doi.org/10.1080/10476210903342102

Gerovac, A., Emeljanovas, A., Petrusic, T., & Novak, D. (2025). Generalist vs physical education specialist elementary school teacher: do teacher characteristics matter? *Kinesiologia Slovenica: Scientific Journal on Sport*, *31*(1), 84–99. https://doi.org/10.52165/kinsi.31.1.84-99

González-Rico, R., & Ramírez-Lechuga, J. (2018). Revisión de las pruebas de evaluación de la condición física en Educación Secundaria. *Ágora Para la Educación Física y el Deporte*, *19*(3), 355–367.

Hargreaves, A., & O'Connor, M. T. (2018). Solidarity with solidity: The case for collaborative professionalism. *Phi Delta Kappan*, *100*(1), 20–24.

Harter, S. (1982). The perceived competence scale for children. *Child Development*, *53*(1), 87–97.

Jones, L., & Green, K. (2015). Who Teaches Primary PE? Change and Transformation Through the Eyes of Subject Leaders. *Sport, Education and Society*, *22*(6), 759–771. https://doi.org/10.1080/13573322.2015.1061987

King-Sears, M. E., Jenkins, M. C., & Brawand, A. (2018). Co-teaching perspectives from middle school algebra co-teachers and their students with and without disabilities. *International Journal of Inclusive Education*, *24*(4), 427–442. https://doi.org/10.1080/13603116.2018.1465134

Kirk, D. (2005). Physical education, youth sport and lifelong participation: The importance of early learning experiences. *European Physical Education Review*, *11*(3), 239–255. https://doi.org/10.1177/1356336X05056649

Klincarov, I., Popeska, B., Mitevski, O., Nikovski, G., Mitevska-Petrusheva, K., & Majeric, M. (2018). Tandem teaching in physical and health education classes from teacher's perspective. In L. A. Velickovska (Ed.), *3rd International Scientific Conference Research in Physical Education, Sport, and Health* (pp. 255–262). Ss. Cyril and Methodius University in Skopje, Faculty of Physical Education, Sport, and Health.

Luptáková, G., Argajová, J., Balga, T., Augustovičová, D., Sobotová, P., Balint, G., & Antala, B. (2025c). Team Teaching Models in Primary Physical Education: Effects on Basic Motor Competencies and Self-Reported Physical Literacy. *Children*, *12*(12), 1595. https://doi.org/10.3390/children12121595

Luptáková, G., Balga, T., Antal, B., Cihová, I., Argajová, J., Dovičák, M., Sližik, M., Gurský, T., & Macháček, J. (2025a). Collaborative instruction with external providers in primary physical education: A three-year comparative analysis of generalist teacher perspective. *Kinesiologia Slovenica*, *31*(1), 21–34. https://doi.org/10.52165/kinsi.31.1.21-34

Luptáková, G., Popeska, B., Ristevska, H., Balga, T., Klincarov, I., & Antala, B. (2025b). Tandem Teaching for Quality Physical Education: Primary Teachers' Preparedness and Professional Growth in Slovakia and North Macedonia. *Education Sciences*, *15*(10), 1397. https://doi.org/10.3390/educsci15101397

Nezondet, C., Gandrieau, J., Nguyen, P., & Zunquin, G. (2023). Perceived Physical Literacy Is Associated with Cardiorespiratory Fitness, Body Composition and Physical Activity Levels in Secondary School Students. *Children*, *10*(4), Article 712. https://doi.org/10.3390/children10040712

Ní Chróinín, D., & O'Brien, N. (2019). Primary school teachers' experiences of external providers in Ireland: Learning lessons from physical education. *Irish Educational Studies*, *38*(3), 327–341. https://doi.org/10.1080/03323315.2019.1606725

Ortega, F. B., Leskošek, B., Blagus, R., Gil-Cosano, J. J., Mäestu, J., Tomkinson, G. R., Ruiz, J. R., Mäestu, E., Starc, G., Milanovic, I., Tammelin, T. H., Soric, M., Scheuer, C., Carraro, A., Kaj, M., Csányi, T., Sardinha, L. B., Lenoir, M., Emeljanovas, A., & Jurak, G. (2023). European fitness landscape for children and adolescents: updated reference values, fitness maps and country rankings based on nearly 8 million test results from 34 countries gathered by the FitBack network. *British Journal of Sports Medicine*, *57*(5), 299–310. https://doi.org/10.1136/bjsports-2022-106176

Ortega, F. B., Ruiz, J. R., España-Romero, V., Vicente-Rodriguez, G., Martínez-Gómez, D., Manios, Y., Béghin, L., Molnar, D., Widhalm, K., Moreno, L. A., & et al. (2011). The International Fitness Scale (IFIS): Usefulness of self-reported fitness in youth. *International Journal of Epidemiology*, *40*(3), 701–711. https://doi.org/10.1093/ije/dyr019

Pancsofar, N., & Petroff, J. G. (2016). Co-teaching in the inclusive classroom: A literature review. *International Journal of Inclusive Education*, *20*(10), 1058–1094. https://doi.org/10.1080/13603116.2016.1145264

Pastor-Cisneros, R., Carlos-Vivas, J., Muñoz-Bermejo, L., Adsuar-Sala, J. C., Merellano-Navarro, E., & Mendoza-Muñoz, M. (2021). Association between Physical Literacy and Self-Perceived Fitness Level in Children and Adolescents. *Biology*, *10*(12), Article 1358. https://doi.org/10.3390/biology10121358

Petračić, T. (2023). *The relationship between factors and the quality of physical education teaching in primary school* [Doctoral dissertation, University of Zagreb]. Faculty of Kinesiology, University of Zagreb.

Physical Literacy Canada. (2023). *PLAYself workbook* [Instrument]. https://physicalliteracy.ca/wp-content/uploads/2023/09/PLAYself_workbook_2023_EN_WEB.pdf

Popeska, B. (2022). *Tandem teaching in physical education: Current experiences and possibilities for improvement*. Goce Delcev University—Stip, North Macedonia. https://eprints.ugd.edu.mk/31137/

Randall, V. (2023). 'We want to, but we can't': Pre-service teachers' experiences of learning to teach primary physical education. *Oxford Review of Education*, *49*(2), 209–228. https://doi.org/10.1080/03054985.2022.2040471

Ruiz, J. R., España Romero, V., Castro Piñero, J., Artero, E. G., Ortega, F. B., Cuenca García, M., & Castillo, M. J. (2011). Batería ALPHA-Fitness: Test de campo para la evaluación de la condición física relacionada con la salud en niños y adolescentes. *Nutrición Hospitalaria*, *26*(6), 1210–1214.

Sepahvand, H., Leskosek, B., Meh, K., Besal, S., & Jurak, G. (2025). Developing an instrument to assess physical education teachers' competencies in using fitness monitoring to promote physical literacy. *Education Sciences*, *15*(4), Article 466. https://doi.org/10.3390/educsci15040466

Simons, M., Coetzee, S., Baeten, M., Van Acker, F., & Engels, N. (2020). Measuring learners' perceptions of a team-

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taught learning environment: development and validation of the Learners' Team Teaching Perceptions Questionnaire (LTTPQ). *Learning Environments Research*, *23*, 45–58. https://doi.org/10.1007/s10984-019-09290-1

Spittle, S., Spittle, M., Encel, K., & Itoh, S. (2022). Confidence and motivation to teach primary physical education: A survey of specialist primary physical education pre-service teachers in Australia. *Frontiers in Education*, *7*, Article 1061099. https://doi.org/10.3389/feduc.2022.1061099

Štefan, L., Paradžik, P., & Sporiš, G. (2019). Sex and age correlations of reported and estimated physical fitness in adolescents. *PLoS ONE*, *14*(7), Article e0219217. https://doi.org/10.1371/journal.pone.0219217

Strogilos, V., & King-Sears, M. E. (2019). Co-teaching is extra help and fun: Perspectives on co-teaching from middle school students and co-teachers. *Journal of Research in Special Educational Needs*, *19*(2), 92–102. https://doi.org/10.1111/1471-3802.12427

Strogilos, V., King-Sears, M. E., Tragoulia, E., Voulagka, A., & Stefanidis, A. (2023). A meta-synthesis of co-teaching students with and without disabilities. *Educational Research Review*, *38*, Article 100504. https://doi.org/10.1016/j.edurev.2022.100504

Thousand, J., Villa, N., & Nevin, A. (2006). The Many Faces of Collaborative Planning and Teaching. *Theory Into Practice*, *45*(3), 239–248. https://doi.org/10.1207/s15430421tip4503_6

Veteska, J., Kursch, M., Svobodova, Z., Tureckiova, M., & Paulovcakova, L. (2022). Longitudinal Co-teaching Projects: Scoping Review. In D. Ifenthal, P. Isaías, & D. G. Sampson (Eds.), *Orchestration of learning environments in the digital world. Cognition and exploratory learning in the digital age*. Springer, Cham. https://doi.org/10.1007/978-3-030-90944-4_3

Washburn, R., & Kolen, A. (2018). Children's self-perceived and actual motor competence in relation to their peers. *Children*, *5*(6), 72. https://doi.org/10.3390/children5060072

Whitehead, M. (2010). *Physical literacy: Throughout the lifecourse*. Routledge.

ORIGINAL SCIENTIFIC PAPER

Understanding Legal Anti-Doping Literacy in Sport: The Roles of Coaching, Sport Context, and Regulatory Socialization

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Abstract

Adequate legal anti-doping knowledge promotes informed decision-making, reduces the risk of unintentional rule violations, and supports the integrity and fairness of sport. The aim of this study was to examine (i) whether legal anti-doping knowledge differs between athletes and coaches and (ii) whether such differences are specific to sport type by comparing participants involved in team and individual sports. The participants were 188 athletes and 35 coaches involved into team sports (112 athletes and 18 coaches) and individual-combat sports (76 athletes and 17 coaches). The variables included legal anti-doping knowledge (LADK; evaluated via previously validated questionnaire tools), age, experience in sport, sport success, and experience in anti-doping testing (as an athlete/coach). Independent t tests revealed better LADK in coaches than in their athletes for the total sample (t test = 4.57, $p < 0.001$) and in individual/combat sports (t test = 5.58, $p < 0.01$). Univariate logistic regression revealed that participants with higher LADK scores were more likely to belong to the coach group than to the athlete group in the total sample (OR = 1.87, 95%CI: 1.42–2.47) and in both subsamples (OR = 1.19, 95%CI: 1.01–1.40; OR = 2.31, 95%CI: 1.55–3.44 for team sports and individual/combat sports, respectively). However, when controlling for covariates (age, experience in sport, sport success, and experience in antidoping testing), significant associations were detected for the total sample (OR = 1.78; 95%CI: 1.25–2.65) and for combat/individual sports (OR = 2.11; 95%CI: 1.34–3.11). The findings suggest that legal anti-doping literacy is shaped not only by stakeholder role but also by sport-specific socialization and regulatory exposure. From a legal standpoint, these results indicate that being a coach should not automatically be regarded as evidence of adequate regulatory competence.

Keywords: *doping, sports, regulations, laws, social context, influence*

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Introduction

Doping remains among the most important problems in modern sports, undermining both the principles of fair play and the health of athletes (Tahiraj, Zenic, Musa, Zeljko, & Rodek, 2024). Despite decades of global fight against doping, anti-doping rule violations are still reported across different sports and competitive levels. In response to this global challenge, anti-doping efforts have been largely harmonized through the World Anti-Doping Code (WADC), which serves as the central regulatory framework governing prohibited substances, testing procedures, sanctions, and appeal mechanisms (WADA, 2026). In the past decade or two, there has been an increasing opinion that doping should not be observed solely as a medical or ethical issue but also as a matter of legal regulation and institutional governance (Marinelli et al., 2022; Mazzucco & Brehaut, 2024). As a result, anti-doping regulation is being increasingly incorporated into the legislative frameworks and statutory provisions of numerous countries worldwide (Read, Skinner, Smith, Lock, & Stanic, 2024).

Athletes, coaches, medical professionals, and sport organizations are expected to comply with clearly defined rights, responsibilities, and procedural obligations associated with WADC (Sinkovic, Pivalica, Jukic, Pehar, & Sekulic, 2026). However, the effective implementation of WADC and associated policies depends on coordinated action among anti-doping agencies, sport federations, laboratories, arbitration bodies, and national authorities. Consequently, participation in contemporary sports increasingly requires the navigation of a complex legal environment in addition to performance-related demands. Therefore, understanding the legal issues of anti-doping policy is essential for maintaining the fairness and effectiveness of global anti-doping efforts (Kačer & Kačer, 2018; Stankovic, Sinkovic, Sekulic, Jelicic, & Rodek, 2022).

Anti-doping regulations are based on specific legal principles that directly determine the rights, obligations, and responsibilities of all sport stakeholders (Star & Kelly, 2021). Specifically, one of the most important principles of WADC is "strict liability", according to which "athletes are personally responsible for any prohibited substance found in their body regardless of intent or negligence" (WADA, 2026). Additionally, anti-doping proceedings involve different procedural safeguards (i.e., notification standards, sample analysis procedures, the right to review evidence, and the right to appeal disciplinary decisions). It is clear that insufficient understanding of these legal mechanisms may expose athletes to unintentional rule violations or negatively affect their ability to protect their procedural rights. These aspects of WADC are particularly relevant in contemporary sports, where athletes are expected to make decisions regarding the consumption of dietary supplements, the use of medications, and/or cooperation during testing procedures. The question that arises is, are the athletes and supporting personnel equipped with a sufficient level of legal knowledge (legal literacy) with regard to anti-doping policy?

Previous studies have developed and validated original instruments for assessing legal anti-doping knowledge among both athletes and athlete support personnel (Sinkovic, Pivalica, Jukic, Pehar, & Sekulic, 2026; Stankovic et al., 2022). The findings consistently indicated meaningful differences according to sex, competitive experience, and exposure to anti-doping testing procedures. Furthermore, intervention-based studies have demonstrated that targeted educational programs can significantly improve legal anti-doping knowledge among athletes and athlete support personnel (ASP) (Sinkovic, Pivalica, Jukic, Pehar, Pivalica, et al., 2026; Sinkovic, Pivalica, Pivalica, Jukic, & Sekulic, 2025). However, although knowledge increased as a result of specifically designed education, the improvements in legal literacy were not accompanied by changes in doping-related attitudes, suggesting that legal literacy represents only one component of broader anti-doping behavior (Sinkovic, Pivalica, Jukic, Pehar, Pivalica, et al., 2026; Sinkovic et al., 2025).

ASPs (i.e., coaches, physicians, and nutritionists) occupy a particularly important position within the anti-doping system because they are often the primary source of guidance for athletes in everyday training and competition environments, with coaches being definitively the most important ones (Sankey, Wallace, & Caperchione, 2023; Shanmuganathan-Felton, Felton, & Jowett, 2022). In many cases, athletes rely on coaches when they make decisions related to supplements, medications, recovery strategies, and communication with sport authorities (Sung, Lee, & Lee, 2024). Moreover, the World Anti-Doping Code explicitly recognizes coaches as stakeholders who must be knowledgeable of and comply with applicable anti-doping rules. Therefore, insufficient legal knowledge among coaches may create risks for their own professional responsibility but also for the legal position of their athletes (Sinkovic et al., 2025).

Despite the recognized importance of doping-related knowledge, research has rarely compared athletes and coaches within the same framework; however, to the best of our knowledge, no study has examined this problem while specifically emphasizing the legal issues of anti-doping. Therefore, the aim of this study was to examine whether legal anti-doping knowledge differs between athletes and coaches and to determine whether such differences are specific to sport type by comparing participants involved in team and individual/combat sports. We hypothesized that coaches will possess greater legal literacy about anti-doping policies, regardless of the type of sport (e.g., team and individual/combat sports).

Methods

Participants

The participants in this study were 188 athletes and 35 coaches from Croatia and Bosnia and Herzegovina, of whom 112 athletes (42 females) and 18 coaches (6 females) were involved in team sports, while 76 athletes (49 females) and 17 coaches (4 females) were involved in individual/combat sports. For the purpose of the present study, only participants from sport settings in which meaningful athlete vs. coach comparisons could be established were included in the analyses. Therefore, the study sample was restricted to sports for which data were available for both athletes and coaches from the same competitive context. Specifically, team sports are known to be specific with respect to team cooperation, whereas combat sports were intentionally observed as a separate category because of their comparable competitive structure, coaching dynamics, and sport-specific anti-doping context. Other individual sports were not included in the comparative analyses because of an insufficient number of coaches and substantial heterogeneity across disciplines. By applying these selection criteria, we aimed to ensure greater ecological validity and more interpretable athlete–coach comparisons within relatively homogeneous sport environments. Consequently, all subsequent analyses were conducted separately for the total sample and separately for team sports and individual combat sports.

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The study was initiated by contacts with sport federations and was approved by the Ethics Committee of the Faculty of Kinesiology, University of Zagreb.

Variables

Legal anti-doping knowledge among athletes was assessed using the previously validated Questionnaire on Legal Anti-Doping Regulations (Q-LADR). The instrument was specifically developed to evaluate athletes' understanding of key legal aspects of anti-doping policy, including rights and obligations under the World Anti-Doping Code, testing procedures, and selected procedural safeguards. The final version of the questionnaire consisted of 10 true/false items, with an additional "not sure" response option provided for each statement. Each correct answer was scored one point, resulting in a theoretical score ranging from 0 to 10, where higher values indicated greater legal anti-doping knowledge. Previous studies have confirmed the acceptable reliability and validity of the tool in samples of senior-level athletes. Details on questionnaire development and validation are available elsewhere (Stankovic et al., 2022)

For coaches, legal anti-doping knowledge was assessed using the adapted Questionnaire on Legal Anti-Doping Regulations for Athlete Support Personnel (Q-LADR-ASP). This version was developed from the original athlete-focused instrument, with modifications introduced to reflect the specific legal responsibilities and practical roles of coaches and other support staff within the anti-doping system. Like the athlete version, the final questionnaire included 10 true/false items with a "not sure" option. The items covered domains such as rights and obligations under anti-doping regulations, procedural aspects of doping control, and responsibilities of support personnel. Correct responses were scored with one point, resulting in a total score ranging from 0 to 10, with higher scores representing better legal anti-doping knowledge. Previous validation procedures have indicated the satisfactory reliability and criterion validity of the Q-LADR-ASP in samples of coaches and sport support personnel (Sinkovic, Pivalica, Jukic, Pehar, & Sekulic, 2026).

Despite their specificities, both questionnaires (Q-LADR and Q-LADR-ASP) contain ten items covering equivalent legal domains. Minor wording adaptations were introduced to reflect the legal role of the respondent (athlete vs. athlete support personnel) while preserving conceptual equivalence. The specifics are briefly presented in Table 1.

Table 1. Comparison of the measurement tools used for athletes (Q-LADR) and for athletes' support personnel (Q-LADR-ASP)

Domain	Q-LADR	Q-LADR-ASP
WADA Prohibited List	✓	✓
Testing frequency	✓	✓
Strict liability	✓ (athlete responsibility)	✓ (athletes' support personnel perspective)
Whereabouts obligations	✓	✓
Therapeutic Use Exemptions	✓	✓
Doping control procedures	✓	✓
Sample collection	✓	✓
B-sample rights	✓	✓
Appeals	✓	✓
Sanctions/reduction of sanction	✓	✓

Although both instruments were designed to assess comparable domains of legal anti-doping literacy, they were originally developed for different target populations and included role-specific item adaptations. Therefore, to allow a more appropriate comparison between athletes and coaches, the results of the present study were transformed into standardized z scores. This procedure enabled comparisons of relative standing in legal anti-doping knowledge across groups while reducing bias related to potential differences in questionnaire content and measurement characteristics. The z scores were used for calculations of the statistical analyses, but the results are presented here as raw scores (on a scale of 1–10) for better understanding.

Statistics

After the data were analyzed by the Kolmogorov–Smirnov test, descriptive statistics were reported as the means and standard deviations for continuous variables and as frequencies with percentages for categorical variables.

Differences between groups of interest (athletes vs. coaches, individual combat sport vs. team sports) in legal literacy were calculated by t test for independent samples. The primary analysis of the associations included calculations of the binary logistic regression models, with the criterion variable—stakeholder status (coded as athlete = 0 and coach = 1). The main predictor was legal anti-doping knowledge, expressed as standardized z scores. In the second phase, to control for potential confounding effects, age, experience in sport, number of anti-doping tests, and highest level of competitive achievement were entered into the models as covariates. Separate binary logistic regression models were calculated for (i) the total sample, (ii) team sports and (iii) individual combat sports. Odds ratios (ORs) with 95% confidence intervals (CIs) were calculated to estimate the likelihood of belonging to the coach group in relation to changes in predictor variables. The z scores were used in the calculation of the logistic regressions. Statistical significance was set at $p < 0.05$. All analyses were performed using Statistica version 13.5 (TIBCO Inc., Palo Alto, CA, USA).

Results

Table 2 presents descriptive statistics for the study variables. As is evident, a significant number of athletes and coaches achieved advanced competitive levels. With regard to doping testing, the majority of athletes had no experience with it and were never tested on the doping substances themselves.

Table 2. Descriptive statistics for the study variables (F – count, % - percentage) for combat sports (individual sports) and team sports

	Combat sports (individual sports)				Team sports			
	Athletes		Coaches		Athletes		Coaches	
	(n = 76)		(n = 17)		(n = 112)		(n = 18)	
	F	%	F	%	F	%	F	%
Experience in sport (as an athlete/coach)*								
< 5 years	9	12.0	5	29.4	17	15.2	5	27.8
6-10 years	40	53.3	3	17.6	66	58.9	3	16.7
> 10 years	27	36.0	9	52.9	29	25.9	9	50.0
Missing**	0	0.0	0	0.0	0	0.0	1	5.6
Sport success (as an athlete/coach)*								
National level competition	18	23.7	6	35.3	22	19.6	5	27.8
National level achievement (medal)	34	44.7	7	41.2	49	43.8	9	50.0
European and/or World Championship (participation and/or medal)	22	28.9	3	17.6	39	34.8	3	16.7
Olympic Games (participation and/or medal)	1	1.3	1	5.9	2	1.8	1	5.6
Missing**	1	1.3	0	0.0	0	0.0	0	0.0
Participation in anti-doping testing (as an athlete/coach)*								
Never	41	53.9	6	35.3	68	60.7	9	50.0
1-2 times	14	18.4	7	41.2	24	21.4	5	27.8
3-5 times	17	22.4	2	11.8	17	15.2	3	16.7
> 5 times	3	3.9	1	5.9	2	1.8	1	5.6
Missing**	1	1.3	1	5.9	1	0.9	0	0.0

Legend: * Coaches gave responses considering their coaching career only (apart from their eventual experience when being athletes); ** Missing values were not included in later calculations of logistic regressions

With respect to the total sample, the legal knowledge on doping and anti-doping regulations (legal anti-doping knowledge - LADK) was significantly greater among coaches than among athletes (6.67±1.36 and 5.25±1.57 for coaches and athletes, respectively; t test = 4.57; $p < 0.001$). Additionally, compared with their athletes, coaches involved in combat sports achieved better results on LADK (7.54±0.81 and 5.62±1.44 for coaches and athletes, respectively; t test = 5.58; $p < 0.001$). No significant difference in LADK was found between the athletes and coaches involved in team sports (5.75±1.01 and 5.00±1.62 for coaches and athletes, respectively; t test = 1.87; $p > 0.05$). Athletes involved in combat sports had better knowledge of legal anti-doping issues than their peers from team sports did (5.62±1.44 and 5.00±1.62 for combat sports and team sports, respectively; t test = 2.68; $p < 0.01$). Additionally, a significant difference in LADK was found between coaches involved in team sports and combat sports, with better results in combat sports (7.65±0.88 and 5.75±1.10 for combat sports and team sports, respectively; t test = 2.68; $p < 0.01$) (Figure 1).

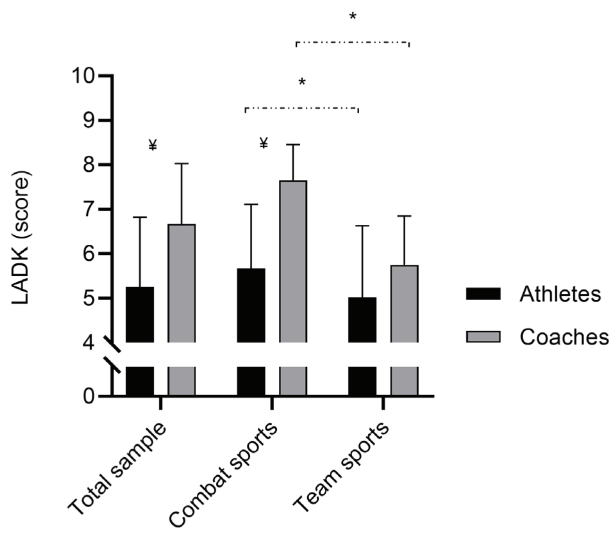

Figure 1. Descriptive statistics (means ± standard deviations) for legal anti-doping knowledge (LADK) among athletes and coaches, with t test differences between corresponding groups (* indicates t test significance of $p < 0.05$ between sports, ¥ indicates t test significance of $p < 0.05$ between athletes and coaches)

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Table 3 presents the results of the binary logistic regression analyses calculated for athlete/coach status as the criterion variable. Univariate binary logistic regression revealed a significant association between LADK status as a predictor and athlete/coach status, with higher odds of being a coach among participants who achieved better LADK scores in the total sample (OR = 1.87, 95% CI: 1.42–2.47), as well as when they were stratified for team sports (OR = 1.19, 95% CI: 1.01–1.40) and combat sports (OR = 2.31, 95% CI: 1.55–3.44). In practical terms, participants with higher LADK scores were more likely to belong to the coach group than to the athlete group, with this association being notably stronger in combat sports than in team sports.

When multivariate logistic regressions were performed, adjusting for age, sport experience, sport success, and experience in anti-doping testing, the significant association between LADK and the criterion variable remained evident in the total sample (OR = 1.78, 95% CI: 1.25–2.65) and in combat sports (OR = 2.11, 95% CI: 1.34–3.11). These findings indicate that higher LADK scores independently increased the likelihood of being a coach rather than an athlete, even after controlling for relevant covariates. Moreover, the stronger association observed in combat sports suggests that LADK may be a particularly relevant distinguishing factor between coaches and athletes in this sport category.

Table 3. Results of the logistic regressions at the univariate and multivariate levels for the criterion variable - athlete/coach status (OR = odds ratio, CI – confidence interval)

	Total		Team sports		Combat sports	
	OR	95%CI	OR	95%CI	OR	95%CI
Univariate level						
Legal anti-doping knowledge	1.87	1.42-2.47	1.19	1.01-1.40	2.31	1.55-3.44
Multivariate level						
Age	1.77	1.23-2.41	1.61	1.09-2.13	1.51	0.90-2.21
Experience	1.66	1.02-2.21	1.51	0.90-1.91	1.41	0.57-2.40
Sport success	1.41	0.88-2.13	1.48	0.71-2.34	1.67	0.61-2.63
Experience in doping testing	1.47	1.11-1.76	1.37	1.05-1.72	1.59	1.05-2.14
Legal anti-doping knowledge	1.78	1.25-2.65	1.11	0.96-1.55	2.11	1.34-3.11

Discussion

There are several important findings of the study. First, legal anti-doping knowledge generally significantly predicted athlete-coach status, with coaches having higher levels of legal literacy than athletes did. However (second), these findings were consistent for individual/combat sports, irrespective of the influence of confounders (age, experience, sport success, and participation in anti-doping testing), but not for team sports. Therefore, our initial study hypothesis can be partially accepted.

Legal anti-doping knowledge differentiates coaches from athletes

At the univariate level, compared with athletes, coaches demonstrated greater LADK (legal anti-doping literacy). Such findings are generally expected, given that (i) coaches spend longer periods within organized sport systems (as athletes and later as coaches) and (ii) are more often exposed to some type of regulatory demands throughout their careers in sport (Engelberg, Moston, & Blank, 2019). Indeed, in addition to their technical and performance-related responsibilities, coaches are frequently involved in issues related to competition eligibility, supplement use, testing procedures, and communication with sport authorities (Sinkovic et al., 2025). Consequently, they are more familiar even with anti-doping rules and legal obligations than athletes are, whose primary focus is more commonly directed toward training and competitive performance. Therefore, our results support the view that coaches should be considered important reservoirs of antidoping legal knowledge within a sport society. Moreover, it must be noted that coaches often serve as the first point of consultation when athletes face decisions involving potential regulatory risk.

From the perspective of anti-doping policy, these findings are particularly important. Specifically, regulations related to anti-doping policies are continuously evolving and are being revised (WADA, 2026). Therefore, coaches are expected to operate within the World Anti-Doping Code, updates of the prohibited list, therapeutic use exemption procedures, and national legislative amendments. Greater LADK among coaches may act as an important protective factor against doping. Coaches who are familiar with current rules are more likely to recognize regulatory risks. Such coaches are more likely to respond appropriately during testing procedures and guide athletes toward the whole anti-doping process. This is directly supportive of opinions that coaches' capacity to follow legal and procedural changes may contribute to reducing unintentional anti-doping rule violations and procedural misunderstandings (Star & Kelly, 2021). Therefore, advanced coaches' LADK may represent an efficient strategy for improving regulatory compliance across sport systems.

The present findings may be interpreted from the perspective of sociological theories explaining knowledge acquisition within professional communities. Specifically, the "communities of practice" framework proposes that professional knowledge is progressively developed through long-term participation in shared social environments and repeated practical interactions (Lave & Wenger, 1991). In sport settings, coaches are continuously exposed to anti-doping-related procedures, regulatory communication, and decision-making situations. Consequently, they develop their legal anti-doping literacy through everyday participation in sport-specific regulatory practices. Moreover, from the perspective of "role theory", coaches are expected to assume responsibilities that extend beyond technical preparation (Biddle, 1986). Such socially constructed role expectations may additionally motivate coaches to develop greater familiarity with anti-doping rules, procedures, and legal obligations.

Specificity of the team sports

When team sports were analyzed within the multivariate model (after adjustment for covariates), LADK did not differentiate coaches from athletes. This finding indicates that the higher knowledge initially observed among coaches was largely explained by age, sport experience, and competitive exposure rather than by coaching status itself. Such findings are logical, since coaches in team sports are (i) typically older and (ii) have spent more years within organized sport systems than active athletes have. Longer involvement in professional sports increases opportunities to meet certain types of anti-doping procedures, educational activities, and regulatory communication. Therefore, in team sports, higher legal anti-doping knowledge among coaches appears to reflect accumulated experience.

From a legal perspective, these findings suggest that LADK in team sports may be connected to long-term participation in sport as a system and not to the formal coaching function itself. It is logical that legal anti-doping literacy may be improved through repeated contact with officiating structures, federation procedures, disciplinary mechanisms, and, consequently, accumulated knowledge. However, the fact that the multivariate model did not reveal a significant association between LADK and coaching position has important normative implications. Specifically, it can be said that appointment to a coaching position in team sports does not automatically ensure an adequate understanding of anti-doping obligations, liability standards, or procedural safeguards. Consequently, younger and unexperienced coaches could possess a position of "theoretical authority" while lacking the level of necessary legal competence. When unaware of this lack of knowledge, young and unexperienced coaches can be at risk of inaccurate guiding regarding their athletes with regard to anti-doping. Additionally, it is not uncommon that in such situations, coaches (and athletes) seek nonformal experience-based learning (Daher, El Khoury, & Dwyer, 2021; Sekulic et al., 2016). This approach may create additional problems with regard to acquiring knowledge of LADK. Therefore, anti-doping policy in team sports should not presume regulatory competence on the basis of coaching status alone.

Specificity of combat sports

In combat sports, coaching status was positively associated with LADK even after adjustment for covariates (i.e., age, experience, and status). These results suggest that coaches in combat sports develop legal anti-doping literacy through mechanisms that are independent of simple accumulation of sport experience. Therefore, LADK in combat/individual sports may be observed as a more role-specific competence directly linked to the coaching function itself, including the practical interpretation, everyday application, and risk management of anti-doping regulations. Several plausible explanations may account for these findings.

First, it is well known that coaches in combat sports are frequently former athletes from the same sport discipline (Behr & Kuhn, 2019). As a result, many of them have already been exposed to anti-doping procedures, testing protocols, and regulatory requirements during their own competitive careers. This may be particularly relevant in combat sports, where the prevalence of doping and anti-doping surveillance have often been recognized as relatively pronounced (Damjanovic et al., 2025). Consequently, future coaches may begin to accumulate practical legal anti-doping knowledge long before they enter the coaching profession itself. Their later coaching role may therefore build upon regulatory knowledge initially acquired as athletes, including familiarity with notification procedures, testing obligations, sanctions, and procedural rights under anti-doping rules.

The second explanation may be related to the continuity of coach–athlete relationships, which is characteristic of many combat sports. Coaches in these disciplines often accompany athletes from the earliest phases of their career. Consequently, they are repeatedly exposed to anti-doping matters arising across different phases of athlete development. This includes educational activities, testing procedures, supplement-related decisions, therapeutic issues, and, most likely, communication with regulatory bodies. Continuous involvement in such processes may allow coaches to progressively expand and refine their LADK over time. In practical terms, each anti-doping-related situation concerning the athlete may simultaneously function as a learning opportunity for the coach. This type of cumulative knowledge development is likely less common in team sports, where coaching changes are frequent and athletes are commonly supervised by multiple coaches throughout their careers (König, 2013).

Third, the strong sense of personal responsibility that often develops between coaches and athletes in combat sports may also contribute to the present findings. As stated previously, coaches in combat sports frequently guide athletes over many years, and their role naturally includes mentorship or even some kind of parental support. In such circumstances, coaches are likely to perceive the athlete's successes and failures as their own responsibility. Consequently, any careless decision related to anti-doping procedures could compromise the relationship between the athlete and coach (in combat sports, often referred to as the "master"). This heightened sense of accountability may motivate coaches to become better informed about anti-doping rules, legal obligations, and procedural requirements. Therefore, greater LADK among combat sport coaches may partly reflect a stronger perceived duty of care toward the athletes they supervise ("The master is to be a teacher and educator") (Cynarski, 2020).

Finally, a more controversial explanation may be related to weight-management practices that are common in many combat sports because of weight-category competition systems. In such environments, rapid body mass reduction strategies (called "weight cutting") may include the misuse of diuretics and related substances (Barley, Chapman, & Abbiss, 2019; Crighton, Close, & Morton, 2016)(Cadwallader, De La Torre, Tieri, & Botrè, 2010). Coaches involved in combat sports are likely aware of these methods and their regulatory consequences under anti-doping rules. Consequently, some coaches may develop greater LADK precisely because they are required to navigate the boundary between common sport practices and prohibited conduct. Although this possibility should be interpreted cautiously, it may partly contribute to the higher LADK observed among coaches in combat sports.

Some elements of the present findings may additionally correspond to concepts of socialization theory (Berger & Luckmann, 1991; Coakley & Pike, 2009). As already stated, individuals involved in combat sports are often socialized into highly specific sport cultures characterized by strong interpersonal ties, long-term coach–athlete loyalty, and in-

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tensive everyday interaction. Through prolonged exposure to such environments, coaches may gradually internalize not only technical and tactical norms but also regulatory practices, anti-doping procedures, and attitudes toward legal responsibility in sport. Consequently, LADK in combat sports may partly represent a product of long-term socialization within the specific cultural environment of these sports.

Limitations

This study is not without limitations. First, we must acknowledge that although both questionnaires used (Q-LADR and Q-LADR-ASP) were developed within the same conceptual framework and assess equivalent legal domains, they are not identical instruments. Consequently, despite score standardization, some influence of role-specific item wording on between-group comparisons cannot be completely excluded. Furthermore, the study was conducted in Croatia and Bosnia and Herzegovina, and the findings should therefore be interpreted within this specific regional context. In addition, only Olympic sports were included in the present investigation. As these sports operate under well-established World Anti-Doping Code implementation and are generally characterized by structured anti-doping education and regulatory oversight, the findings may not be directly applicable to non-Olympic sports or sporting environments with less developed anti-doping governance. Finally, the relatively small number of coaches included in the study may have reduced the statistical power of between-group comparisons, particularly in the sport-specific subgroup analyses. Therefore, these findings should be interpreted with appropriate caution and confirmed in larger coach samples.

Conclusion

The results suggest that legal anti-doping literacy is dependent on the specific characteristics of the sport environment, with evident differences between team sports and individual/combat sports. Therefore, coaching status itself should not be automatically equated with sufficient regulatory competence in regard to doping and doping regulations, which is particularly evident in team sports. Therefore, anti-doping governance frameworks should include structured and continuous legal education for coaches in team sports, with particular emphasis on younger and less experienced professionals.

The findings support the view that legal anti-doping literacy should be observed as a systemic rather than exclusively individual characteristic. In sport settings where coaches function as long-term and primary support figures, such as in individual combat sports, their regulatory competence may directly influence athlete protection, procedural fairness, and prevention of unintentional anti-doping rule violations. Consequently, future anti-doping policies should adopt sport-specific educational strategies that recognize differences in the distribution of legal responsibility across sporting contexts. In doing so, anti-doping systems may become both more effective and more equitable.

Future research should examine legal anti-doping literacy in larger and more diverse samples of coaches and athletes across different countries and sporting contexts to determine whether the present sport-specific patterns are generalizable across anti-doping systems.

References

Barley, O. R., Chapman, D. W., & Abbiss, C. R. (2019). The current state of weight-cutting in combat sports. *Sports, 7*(5), 123. https://doi.org/10.3390/sports7050123

Behr, K., & Kuhn, P. (2019). Key factors in career development and transitions in German elite combat sport athletes. *Martial Arts Studies, 7*, 19-35. https://doi.org/10.18573/mas.73

Berger, P. L., & Luckmann, T. (1991). *The Social Construction of Reality: A Treatise in the Sociology of Knowledge*: Penguin Adult.

Biddle, B. J. (1986). Recent developments in role theory. *Annual review of sociology, 12*(1), 67-92.

Cadwallader, A. B., De La Torre, X., Tieri, A., & Botrè, F. (2010). The abuse of diuretics as performance-enhancing drugs and masking agents in sport doping: pharmacology, toxicology and analysis. *British journal of pharmacology, 161*(1), 1-16. https://doi.org/10.1111/j.1476-5381.2010.00789.x

Coakley, J. J., & Pike, E. (2009). *Sports in Society: Issues and Controversies*: McGraw-Hill Education.

Crighton, B., Close, G. L., & Morton, J. P. (2016). Alarming weight cutting behaviors in mixed martial arts: a cause for concern and a call for action. In (Vol. 50, pp. 446-447): BMJ Publishing Group Ltd. and British Association of Sport and Exercise Medicine.

Cynarski, W. J. (2020). Coach or sensei? His group relations in the context of tradition. *Physical Culture and Sport. Studies and Research, 88*(1), 41-48. https://doi.org/10.2478/pcssr-2020-0024

Daher, J., El Khoury, D., & Dwyer, J. J. (2021). Education interventions to improve knowledge, beliefs, intentions and practices with respect to dietary supplements and doping substances: A narrative review. *Nutrients, 13*(11), 3935. https://doi.org/10.3390/nu13113935

Damjanovic, S., Rossi, C., Manolopoulos, N., Matijevic, T., Korpak, D., Kurtanovic, A., . . . Roklicer, R. (2025). Doping in combat sports: a systematic review. *The Physician and sportsmedicine, 53*(2), 103-111. https://doi.org/10.1080/00913847.2025.2449812

Engelberg, T., Moston, S., & Blank, C. (2019). Coaches' awareness of doping practices and knowledge about anti-doping control systems in elite sport. *Drugs: Education, Prevention and Policy, 26*(1), 97-103. https://doi.org/10.1080/09687637.2017.1337724

Kačer, H., & Kačer, B. (2018). (Neke) pravne dvojbe u svezi s dopingom (in Croatian). *Collected Papers of the Faculty of Law in Split/Zbornik Radova Pravnog Fakulteta u Splitu, 55*(2).

König, S. (2013). Coaching performance and leadership behaviors in team sports. *Sportwissenschaft, 43*(4), 253-263. https://doi.org/10.1007/s12662-013-0309-5

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*: Cambridge university press.

Marinelli, S., Basile, G., Varì, M., Napoletano, G., Negro, F., & Tini, A. (2022). The evolution of European legislation on doping: new challenges in the age of NPS. *European review for medical and pharmacological sciences, 26*(18), 6405-6417. DOI: 10.26355/eurrev_202209_29740

Mazzucco, M., & Brehaut, J. (2024). The use of doping control data to administer sex-based eligibility regulations: an analysis of how the World Anti-Doping Agency and international sport federations violate data protection laws. *The International Sports Law Journal, 24*(2), 97-123.

Read, D., Skinner, J., Smith, A. C., Lock, D., & Stanic, M. (2024). The challenges of harmonizing anti-doping policy implementation. *Sport Management Review, 27*(3), 365-386. https://doi.org/10.1007/s40318-024-00276-7

Sankey, C., Wallace, L., & Caperchione, C. M. (2023). Understanding the role of coaches in supporting the mental health of elite athletes. *Journal of science and medicine in sport, 26*(8), 399-404. https://doi.org/10.1016/j.jsams.2023.06.012

Sekulic, D., Tahiraj, E., Zvan, M., Zenic, N., Uljevic, O., & Lesnik, B. (2016). Doping attitudes and covariates of potential doping behavior in high-level team-sport athletes; Gender specific analysis. *Journal of sports science & medicine, 15*(4), 606.

Shanmuganathan-Felton, V., Felton, L., & Jowett, S. (2022). It takes two: The importance of the coach-athlete relationship. *Frontiers for Young Minds, 10*(676115), 167-202. https://doi.org/10.3389/frym.2022.676115

Sinkovic, A., Pivalica, D., Jukic, I., Pehar, M., Pivalica, B., Cerkez Zovko, I., & Sekulic, D. (2026). The Effect of Educational Intervention on Legal Anti-Doping Knowledge and Doping Tendency in Elite Athletes. *Sports, 14*(1), 35. https://doi.org/10.3390/sports14010035

Sinkovic, A., Pivalica, D., Jukic, I., Pehar, M., & Sekulic, D. (2026). Measuring Legal Competence in Anti-Doping: Reliability and Validity of the Novel Measurement Tool Among Sport Officials. *Kinesiologia Slovenica: scientific journal on sport, 32*(1). https://doi.org/10.52165/kinsi.32.1.87-106

Sinkovic, A., Pivalica, D., Pivalica, B., Jukic, I., & Sekulic, D. (2025). Evaluating an Anti-Doping Education Program for Athlete Support Personnel: Knowledge Gains Without Behavioral Shift. *Sport Mont, 23*(3), 127-133. https://doi.org/10.26773/smj.251018

Stankovic, D. V., Sinkovic, A., Sekulic, D., Jelicic, M., & Rodek, J. (2022). Knowledge of the Legal Issues of Anti-Doping Regulations: Examining the Gender-Specific Validity of the Novel Measurement Tool Used for Professional Athletes. *Sustainability, 14*(19), 12883. https://doi.org/10.3390/su141912883

Star, S., & Kelly, S. (2021). A level playing field in anti-doping disputes? The need to scrutinize procedural fairness at first instance hearings. *The International Sports Law Journal, 21*(1), 94-117. https://doi.org/10.1007/s40318-020-00176-6

Sung, J.-Y., Lee, J.-H., & Lee, K.-L. (2024). Analysis of the diet, weight-loss behavior, and nutritional knowledge of athletes and coaches in weightclass sports: influence of a coach's nutritional knowledge on athletes. *Journal of the International Society of Sports Nutrition, 21*(1), 2405159. https://doi.org/10.1080/15502783.2024.2405159

Tahiraj, E., Zenic, N., Musa, M., Zeljko, I., & Rodek, J. (2024). Beyond Winning: Examining Sociodemographic and Sport Factors Associated with Doping Attitudes in High-Performance Sport Coaches Involved in Olympic Team Sports. *Montenegrin Journal of Sports Science & Medicine, 13*(2). https://doi.org/10.26773/mjssm.240904

WADA. (2026). https://www.wada-ama.org/en/resources/world-anti-doping-code-and-international-standards/world-anti-doping-code. accessed 01 June 2026

ORIGINAL SCIENTIFIC PAPER

Physical Predictors of Sprint Performance in Moroccan Female Football Players Across Competitive Levels

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Abstract

Physical performance profiling is essential for monitoring player development and guiding individualized training in women's football. However, multidimensional evidence from North African female football players remains limited. This study aimed to compare neuromuscular performance, sprint ability, change-of-direction speed, and maximal aerobic speed between Moroccan first- and second-division female football players. A total of 105 Moroccan female football players participated in this cross-sectional study, including 45 first-division and 60 second-division players. Participants completed a field-based testing battery including squat jump, countermovement jump, countermovement jump with free arms, drop jump, 10 m, 20 m, and 30 m sprint tests, a 20 m change-of-direction speed test, and the Vameval test. Between-division differences were examined using independent samples t-tests, while Pearson correlations, simple linear regressions, and multiple linear regression models were used to examine individual and combined associations with sprint performance. First-division players demonstrated superior performance in DJ ($p < .001$, $d = 1.05$), CMJ ($p < .001$, $d = 0.82$), CMJ-FA ($p < .001$, $d = 0.86$), 10 m sprint ($p = .044$, $d = 0.40$), 20 m sprint ($p = .013$, $d = 0.49$), 20 m change-of-direction speed test ($p = .002$, $d = 0.65$), and VMA ($p < .001$, $d = 0.86$). No significant differences were observed for squat jump or 30 m sprint performance. Countermovement jump was associated with sprint performance across all sprint distances. The 20 m change-of-direction speed test also predicted sprint performance across 10 m, 20 m, and 30 m, explaining 12.5%–21.7% of the variance. Competitive level in Moroccan women's football appears to be characterized by dynamic jump performance, short-distance acceleration, change-of-direction speed, and aerobic fitness rather than by a single isolated physical quality. Multidimensional field-based testing may help coaches monitor player development and individualize training, with CMJ performance and 20 m change-of-direction speed potentially representing useful field-based indicators of sprint ability and competitive level.

Keywords: *women's football; sprint performance; countermovement jump; change-of-direction; maximal aerobic speed; physical profiling*

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Introduction

Women's football has undergone substantial growth, accompanied by increasing match intensity and higher physical preparation standards (Compton et al. 2025). Modern female football requires repeated accelerations, decelerations, sprints, changes of direction, jumps, duels, and rapid transitions between defensive and offensive phases (Stanković et al. 2025). Therefore, sprint capacity, lower-limb power, change-of-direction speed, and aerobic fitness are increasingly recognized as important components of competitive readiness (Mäkiniemi et al. 2023).

In female football, standardized physical profiling is particularly relevant because neuromuscular, biomechanical, and physiological characteristics may influence both performance interpretation and injury risk (Elliott-Sale et al. 2021; Hewett, Ford, and Myer 2006). Field-based testing batteries can therefore help identify individual strengths and weaknesses, guide training prescription, and support player development.

Sprinting is central to football performance because many decisive actions, such as pressing, defensive recovery, duels, and attacking transitions, occur over short acceleration distances of 5–20 m (Haugen et al. 2014; Haugen and Buchheit 2016). However, sprint ability is multidimensional and depends on lower-limb force production, neuromuscular power, braking ability, re-acceleration capacity, movement coordination, and sprint-specific technical factors (Haugen and Buchheit 2016; Zhang et al. 2022). Accordingly, 10 m and 20 m sprint tests are commonly used to assess initial and extended acceleration, whereas 30 m sprint performance provides additional information about longer linear sprint ability (Haugen, Breitschädel, and Seiler 2020).

Vertical jump tests may provide practical insight into sprint-related neuromuscular qualities. The squat jump mainly reflects concentric force-production capacity, whereas the countermovement jump and drop jump involve rapid eccentric-concentric actions and may provide indirect information about stretch-shortening cycle-related explosive performance (Bishop et al. 2022; Taube, Leukel, and Gollhofer 2012). These qualities are relevant to acceleration, which requires rapid force production within short ground-contact times (Haugen and Buchheit 2016). Previous studies have reported associations between vertical jump and sprint performance in football and team-sport athletes, although these relationships are not always strong because sprinting also depends on horizontal force application, mechanics, and technical efficiency (Loturco et al. 2015, 2019; Slimani et al. 2016).

Beyond linear sprinting and vertical jump performance, change-of-direction speed may represent an important field-based indicator of football-specific locomotor ability. Football sprint actions are rarely performed in purely linear conditions; they are often preceded or followed by braking actions, directional adjustments, re-accelerations, changes in body orientation, and duels (Chaabene et al. 2018; Zhang et al. 2022). Therefore, combining linear sprint tests with change-of-direction speed assessment may provide a more complete understanding of the physical qualities associated with sprint ability in female football players.

Aerobic fitness represents a complementary component of the female football player's physical profile. Match play requires players to sustain repeated high-intensity actions and recover efficiently between accelerations, sprints, and changes of direction (Bangsbo, Mohr, and Krustrup 2006; Baptista et al. 2022). Maximal aerobic speed, commonly assessed through field-based tests such as the Vameval, is useful for estimating aerobic fitness and prescribing individualized training intensities (Bok and Foster 2021). Although it is not expected to directly explain maximal linear sprint performance, it may indirectly support repeated high-intensity efforts through improved recovery capacity and repeated-effort tolerance (Gonçalves et al. 2021).

Taken together, previous studies suggest that sprint performance in football is associated with multiple physical qualities rather than a single isolated factor. Vertical jump performance has been related to sprint ability in football and team-sport athletes (Loturco et al. 2015, 2019; Slimani et al. 2016), while change-of-direction speed has been linked to acceleration, deceleration, and re-acceleration ability (Chaabene et al. 2018; Zhang et al. 2022). In adult female football players, repeated-sprint ability has also been associated with sprint performance, change-of-direction ability, vertical jump performance, and aerobic capacity (Gonçalves et al. 2021). However, these variables have rarely been examined together within the same multidimensional field-based testing battery, particularly across different sprint distances in female football players.

Despite the growing literature on women's football, several gaps remain. First, although previous studies have linked sprint performance with jump, change-of-direction, and aerobic-related variables, fewer have simultaneously considered these qualities within the same field-based testing battery (Compton et al. 2025; Gonçalves et al. 2021). Second, it remains unclear whether these variables are similarly associated with short acceleration and longer sprint performance, particularly in female football players (Haugen and Buchheit 2016; Loturco et al. 2019; Zhang et al. 2022). Third, evidence from North African female football players remains limited, restricting the development of context-specific benchmark values and limiting the transferability of findings from better-studied football contexts.

Accordingly, the aim of the present study was to compare physical performance profiles and examine the associations between neuromuscular performance, change-of-direction speed, maximal aerobic speed, and sprint performance in Moroccan first- and second-division female football players. A secondary aim was to determine the individual and combined predictive contribution of these variables to sprint performance over 10 m, 20 m, and 30 m. It was hypothesized that first-division players would demonstrate superior sprint, jump, change-of-direction speed, and aerobic performance compared with second-division players. It was also hypothesized that countermovement jump performance and 20 m change-of-direction speed would be significantly associated with sprint performance, whereas maximal aerobic speed would represent a complementary but distinct physical quality.

Materials and methods

Study Design

This study adopted a cross-sectional comparative design to examine differences in aerobic capacity, sprint performance, 20 m change-of-direction speed, and lower-limb neuromuscular performance between Moroccan first- and

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second-division female football players. In addition, correlational and regression analyses were conducted to explore the associations between jump performance, sprint ability, change-of-direction speed, and maximal aerobic speed. This design was selected to provide a multidimensional field-based physical performance profile of female football players competing at different national competitive levels.

Participants

A total of 105 Moroccan female football players participated in this study. Players were recruited from four teams competing in the Moroccan women's football championship, including two first-division teams and two second-division teams. Forty-five players competed in the first division and sixty players competed in the second division. All players were Moroccan, officially registered with their respective clubs, and regularly involved in structured football training. To ensure a minimum level of competitive and training exposure, participants were required to have at least three years of football experience and to complete at least four training sessions per week in addition to one official match per week during the competitive season.

First-division players had a mean age of 22.98 ± 4.69 years, whereas second-division players had a mean age of 21.42 ± 2.54 years. First-division players had a mean body mass of 59.40 ± 8.39 kg, height of 1.64 ± 0.05 m, and body mass index of 22.04 ± 2.58 $kg{\cdot}m^{-2}$. Second-division players had a mean body mass of 55.56 ± 7.33 kg, height of 1.63 ± 0.05 m and body mass index of 20.81 ± 2.64 $kg{\cdot}m^{-2}$. Playing positions were classified into four broad categories: goalkeepers, defenders, midfielders, and forwards. The sample included 10 goalkeepers (9.5%), 32 defenders (30.5%), 24 midfielders (22.9%), and 39 forwards (37.1%). In the first division, there were 4 goalkeepers, 15 defenders, 11 midfielders, and 15 forwards, whereas the second division included 6 goalkeepers, 17 defenders, 13 midfielders, and 24 forwards.

To be included in the study, players had to be officially registered with their club, have at least three years of football experience, complete at least four training sessions per week, regularly participate in official competition, and be free from injury at the time of testing. Players were excluded if they reported a recent musculoskeletal injury or any medical condition that could affect maximal physical effort or prevent completion of the full testing battery.

Ethical Approval

Prior to participation, all players were informed about the study procedures, potential risks, and benefits, and written informed consent was obtained from each participant. For players under 18 years of age, written informed consent was obtained from their legal guardians, and assent was obtained from the players. The study was approved by the Ethics Committee for Biomedical Research of the Faculty of Medicine and Pharmacy of Rabat, Morocco (CERB: 63/21; approved on October 23, 2023). All procedures ensured participant confidentiality, voluntary participation, and data protection.

Experimental Procedures

Testing was conducted during the middle of the competitive season over three consecutive morning sessions. The mid-season period was selected to reflect the players' regular competitive fitness status while minimizing the influence of early-season adaptation or end-season fatigue. All tests were performed under standardized field conditions and supervised by qualified strength and conditioning specialists.

Players were instructed to avoid strenuous physical exercise during the 24 hours preceding testing and to maintain their usual hydration and nutritional habits. Before each testing session, players completed a standardized warm-up consisting of light jogging, dynamic mobility exercises, lower-limb activation drills, progressive accelerations, and familiarization trials for the sprint and jump tests. Standardized warm-up routines are commonly recommended before maximal field-based testing because they improve neuromuscular readiness and reduce the risk of performance variability (McGowan et al. 2015).

The testing battery included linear sprint tests over 10 m, 20 m, and 30 m, a 20 m change-of-direction speed test, vertical jump assessments using the Optojump system, and maximal aerobic speed assessment using the Vameval test. Tests were performed in the following order: linear sprint tests, 20 m change-of-direction speed test, jump assessments, and the Vameval test. The Vameval test was performed last to minimize fatigue-related interference with sprint and jump performance. Similar field-based testing batteries have been used in football to assess sprint ability, lower-limb explosive power, change-of-direction-related speed, and aerobic fitness under applied conditions.

Sprint Performance Assessment

Linear sprint performance was assessed over 10 m, 20 m, and 30 m using Witty timing gates (Microgate, Bolzano, Italy). Players started from a standing position 0.5 m behind the first timing gate to avoid prematurely triggering the timing system, and were instructed to sprint maximally through the final timing gate. Sprint times were recorded in seconds. Each player performed two maximal trials for each sprint distance, with the best trial retained for statistical analysis. A recovery period of 2–3 minutes was provided between sprint trials to minimize fatigue effects. The 10 m sprint was interpreted as an indicator of initial acceleration, the 20 m sprint as an indicator of extended acceleration capacity, and the 30 m sprint as an indicator of longer linear sprint performance. Electronic timing gates are recommended for field-based sprint testing because they provide more precise measurements than manual timing and are widely used in football performance research (Haugen et al. 2020).

Change-of-Direction Speed Assessment

Change-of-direction speed was assessed using a 20 m change-of-direction speed test adapted from the field-based football testing procedure described by Cazorla et al. (2008). The test was designed to evaluate the player's ability to accelerate, brake, change direction, and re-accelerate rapidly without the ball. The course consisted of a marked running path including directional changes over a total running distance of 20 m. Although the straight-line distance between the start and finish was approximately 16.6 m, the imposed directional changes increased the total distance covered to 20 m. Players started from a standing position behind the start line and were instructed to complete the course as quickly as possible while respecting the marked trajectory. The test was performed without the ball, and completion time was recorded in seconds using Witty timing gates (Microgate, Bolzano, Italy). Each player completed two maximal trials separated by 2–3 minutes of passive recovery, and the best valid trial was retained for statistical analysis. A lower completion time indicated better change-of-direction speed performance. This test was included because football-specific high-speed actions are rarely performed in purely linear conditions and often involve acceleration, braking, directional adjustment, and re-acceleration under time constraints (Chaabene et al. 2018; Sporis et al. 2010; Zhang et al. 2022).

Jump Performance Assessment

Lower-limb neuromuscular performance was assessed using the Optojump system (Microgate, Bolzano, Italy). The jump battery included the squat jump, countermovement jump, countermovement jump with free arms, and drop jump. For the squat jump, players started from a static semi-squat position with hands placed on the hips and were instructed to jump vertically as high as possible without performing a countermovement. The SJ was used to assess concentric jump performance from a static starting position. For the countermovement jump, players began from an upright standing position and performed a rapid downward movement followed immediately by a maximal vertical jump. During the standard CMJ condition, players kept their hands on their hips to limit arm contribution. The CMJ was used as an indicator of lower-limb explosive jump performance during a rapid eccentric-concentric action. For the countermovement jump with free arms, players performed the same movement while allowing unrestricted arm swing. This condition was included to assess jump performance under a more functional movement condition involving unrestricted arm swing. For the drop jump, players stepped down from a 30 cm box and immediately performed a maximal vertical jump after ground contact. The DJ was used to assess field-based jump performance during a rapid landing-to-take-off action (Bishop et al. 2022).

Each jump test was performed twice, and the best valid trial was retained for analysis. A recovery period of 60–90 seconds was provided between trials. Trials were repeated if the technique was invalid or if the player failed to follow the required protocol. Vertical jump assessments were selected because SJ, CMJ, CMJ with free arms, and DJ provide complementary information regarding lower-limb jump performance under different movement conditions, including static, countermovement, arm-assisted, and landing-to-take-off actions. The Optojump system has demonstrated acceptable validity and reliability for estimating vertical jump height in applied sport settings (Glatthorn et al. 2011).

Maximal Aerobic Speed Assessment

Maximal aerobic speed was assessed using the Vameval test. The test was performed on a marked running area according to the audio-paced protocol. Players were required to maintain the imposed running rhythm for as long as possible as running speed progressively increased. The test ended when the player was no longer able to maintain the required pace despite verbal encouragement. Maximal aerobic speed was recorded in $km{\cdot}h^{-1}$ and used as an indicator of aerobic fitness. The Vameval test was selected because it is a practical field-based assessment for estimating maximal aerobic speed and prescribing individualized aerobic training intensities in intermittent team-sport athletes (Garcia-Retortillo et al. 2019).

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics. Descriptive statistics are reported as mean ± standard deviation (SD). Normality was assessed using the Shapiro–Wilk test, skewness and kurtosis values, and visual inspection of distributional characteristics. When variables showed deviations from normality, non-parametric sensitivity analyses were performed to verify the robustness of between-division comparisons. Differences between groups in neuromuscular performance, sprint performance, 20 m change-of-direction speed, and maximal aerobic speed were analyzed using independent samples Student's t-tests. When the assumption of homogeneity of variances was violated, Welch's correction was applied to ensure robustness of the results. Effect sizes were calculated using Cohen's d and interpreted as small (0.20), medium (0.50), and large (0.80), according to Cohen (1992).

Pearson correlation coefficients were used to examine the relationships between jump performances, sprint performance, change-of-direction speed, and maximal aerobic speed, in order to assess the strength and direction of linear associations among variables. Simple linear regression models were conducted to evaluate the individual predictive contribution of each physical performance variable to sprint performance over 10 m, 20 m, and 30 m. Each predictor was entered separately into the model. The coefficient of determination (R^2) was reported to indicate the proportion of explained variance. Multiple linear regression analyses were performed to examine the combined predictive contribution of selected physical variables to sprint performance over 10 m, 20 m, and 30 m. To avoid redundancy among highly related jump variables, CMJ, 20 m change-of-direction speed, and VMA were entered simultaneously as predictors using the enter method. Model fit was evaluated using R^2, adjusted R^2, F statistics, and p-values. Standardized beta coefficients were used to interpret the independent contribution of each predictor. Multicollinearity was assessed using tolerance and variance inflation factor values. Finally, a one-way analysis of variance (ANOVA) was performed to compare physical performance variables according to playing positions. Effect sizes were calculated using partial eta squared (ηp^2), interpreted as small (0.01), medium (0.06), and large (0.14). The level of statistical significance was set at $p < 0.05$.

Results

Descriptive statistics and distributional characteristics

Descriptive statistics, distributional characteristics, and Shapiro–Wilk normality test results are presented in Table 1. Shapiro–Wilk tests indicated deviations from normality for DJ, SJ, 20 m sprint, 30 m sprint, 20 m change-of-direction speed test, and VMA ($p < .05$), whereas CMJ-FA, CMJ, and 10 m sprint did not significantly deviate from normality. Non-parametric sensitivity analyses produced the same interpretation pattern as the parametric between-division comparisons; therefore, parametric results are reported for consistency.

Between-division differences

Between-division comparisons are presented in Table 2. First-division players showed significantly better per-

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Table 1. Descriptive statistics, distributional characteristics, and Shapiro–Wilk normality test results of aerobic, sprint, change-of-direction speed, and jump performance variables in female football players

Variable	Mean	SD	Skewness	Kurtosis	Shapiro–Wilk W	Shapiro–Wilk p
DJ (cm)	27.91	5.82	-0.46	1.76	0.954	.001
SJ (cm)	21.62	4.33	0.54	1.67	0.970	.017
CMJ-FA (cm)	28.06	5.11	0.14	0.41	0.978	.073
CMJ (cm)	23.09	4.21	-0.08	0.45	0.982	.166
10 m sprint (s)	2.01	0.12	0.61	0.89	0.977	.062
20 m sprint (s)	3.51	0.22	-0.46	4.39	0.943	< .001
30 m sprint (s)	5.01	0.39	-2.15	5.94	0.821	< .001
COD Speed (s)	5.93	0.57	-2.33	6.43	0.813	< .001
VMA ($km \cdot h^{-1}$)	12.22	1.22	-0.20	-0.32	0.973	.032

Values are presented as mean and standard deviation. DJ = drop jump; SJ = squat jump; CMJ = countermovement jump; CMJ-FA = countermovement jump with free arms; COD = change of direction; VMA = maximal aerobic speed.

formance in DJ, CMJ, CMJ-FA, 10 m sprint, 20 m sprint, 20 m change-of-direction speed test, and VMA compared with second-division players. The largest effect sizes were observed for DJ, CMJ-FA, CMJ, and VMA. No significant between-division differences were observed for SJ or 30 m sprint performance.

Table 2. Between-division differences in aerobic, sprint, change-of-direction speed, and jump performance among female football players

Variable	Division 1 (M ± SD)	Division 2 (M ± SD)	t	df	p-value	95% CI for mean difference	Cohen's d
DJ (cm)	30.96 ± 4.34	25.63 ± 5.76	5.196	103	p < .001	3.30 to 7.37	1.05 (large)
SJ (cm)	22.24 ± 3.89	21.16 ± 4.61	1.305	101.516	.195	-0.56 to 2.73	0.26 (small)
CMJ (cm)	24.92 ± 3.67	21.72 ± 4.09	4.145	103	p < .001	1.67 to 4.74	0.82 (large)
CMJ-FA (cm)	30.37 ± 4.89	26.32 ± 4.58	4.354	103	p < .001	2.20 to 5.89	0.86 (large)
10 m sprint (s)	1.99 ± 0.12	2.03 ± 0.11	-2.037	103	.044	-0.09 to -0.00	0.40 (small)
20 m sprint (s)	3.45 ± 0.24	3.56 ± 0.19	-2.525	103	.013	-0.19 to -0.02	0.49 (small)
30 m sprint (s)	4.98 ± 0.31	5.03 ± 0.44	-0.706	103	.482	-0.21 to 0.10	0.15 (small)
COD Speed (s)	5.74 ± 0.36	6.07 ± 0.65	-3.120	103	.002	-0.55 to -0.12	0.65 (medium)
VMA ($km \cdot h^{-1}$)	12.77 ± 1.07	11.81 ± 1.17	4.322	103	p < .001	0.52 to 1.40	0.86 (large)

Values are presented as mean ± standard deviation. DJ = drop jump; SJ = squat jump; CMJ = countermovement jump; CMJ-FA = countermovement jump with free arms; COD = change of direction; VMA = maximal aerobic speed; CI = confidence interval. Cohen's d was interpreted as small (0.20), medium (0.50), and large (0.80). Lower values indicate better performance for sprint and change-of-direction speed tests.

Correlations between jump, sprint, change-of-direction speed, and aerobic performance

The correlation matrix is presented in Table 3. Overall, jump variables were moderately interrelated and were generally associated with sprint times, indicating that higher jump performance tended to be related to faster sprint performance. CMJ showed the most consistent associations with sprint performance across 10 m, 20 m, and 30 m. The 20 m change-of-direction speed test was also associated with all sprint distances, whereas VMA showed no significant association with linear sprint performance.

Table 3. Pearson correlation matrix between jump performance, sprint performance, change-of-direction speed, and maximal aerobic speed in female football players

Variable	DJ	SJ	CMJ-FA	CMJ	10 m	20 m	30 m	COD speed	VMA
DJ	1	.505**	.739**	.760**	-.299**	-.373**	-.175	-.260**	.231*
SJ		1	.717**	.719**	-.235*	-.247*	-.293**	-.136	.144
CMJ-FA			1	.853**	-.331**	-.391**	-.311**	-.291**	.228*
CMJ				1	-.423**	-.440**	-.323**	-.330**	.227*
10 m					1	.726**	.630**	.466**	-.181
20 m						1	.622**	.428**	-.132
30 m							1	.353**	-.093
COD speed								1	-.226*
VMA									1

DJ = drop jump; SJ = squat jump; CMJ = countermovement jump; CMJ-FA = countermovement jump with free arms; COD = change of direction; VMA = maximal aerobic speed. Sprint and change-of-direction speed variables are expressed as completion times; therefore, negative correlations with jump performance indicate that higher jump performance is associated with faster sprint or change-of-direction speed performance. *$p < .05$; **$p < .01$.

Simple linear regression analyses

Simple linear regression analyses were conducted to examine the individual predictive contribution of jump performance, 20 m change-of-direction speed, and VMA to sprint performance over 10 m, 20 m, and 30 m. The results are presented in Table 4.

Table 4. Simple linear regression analyses predicting sprint performance from jump performance, change-of-direction speed, and maximal aerobic speed

Dependent variable	Predictor	B	SE	β	t	p-value	R^2
Sprint 10 m (s)	DJ (cm)	-0.006	0.002	-0.299	-3.177	.002	.089
	SJ (cm)	-0.006	0.003	-0.235	-2.450	.016	.055
	CMJ (cm)	-0.012	0.002	-0.423	-4.744	< .001	.179
	CMJ-FA (cm)	-0.008	0.002	-0.331	-3.561	.001	.110
	COD Speed (s)	0.096	0.018	0.466	5.350	< .001	.217
	VMA (km·h^{-1})	-0.017	0.009	-0.181	-1.869	.064	.033
Sprint 20 m (s)	DJ (cm)	-0.014	0.003	-0.373	-4.074	< .001	.139
	SJ (cm)	-0.013	0.005	-0.247	-2.592	.011	.061
	CMJ (cm)	-0.023	0.005	-0.440	-4.978	< .001	.194
	CMJ-FA (cm)	-0.017	0.004	-0.391	-4.310	< .001	.153
	COD Speed (s)	0.165	0.034	0.428	4.811	< .001	.183
	VMA (km·h^{-1})	-0.024	0.018	-0.132	-1.356	.178	.018
Sprint 30 m (s)	DJ (cm)	-0.012	0.006	-0.175	-1.809	.073	.031
	SJ (cm)	-0.026	0.008	-0.293	-3.114	.002	.086
	CMJ (cm)	-0.030	0.009	-0.323	-3.461	.001	.104
	CMJ-FA (cm)	-0.024	0.007	-0.311	-3.315	.001	.096
	COD Speed (s)	0.242	0.063	0.353	3.835	< .001	.125
	VMA (km·h^{-1})	-0.029	0.031	-0.093	-0.945	.347	.009

B = unstandardized regression coefficient; SE = standard error; β = standardized regression coefficient; R^2 = explained variance. DJ = drop jump; SJ = squat jump; CMJ = countermovement jump; CMJ-FA = countermovement jump with free arms; COD = change of direction; VMA = maximal aerobic speed. Sprint and change-of-direction speed variables are expressed as completion times. Therefore, negative coefficients indicate that higher jump or aerobic values are associated with faster sprint times, whereas positive coefficients for the 20 m change-of-direction speed test indicate that slower change-of-direction speed performance is associated with slower sprint performance.

Multiple linear regression analyses

Multiple linear regression analyses were conducted to examine the combined predictive contribution of CMJ, 20 m change-of-direction speed, and VMA to sprint performance over 10 m, 20 m, and 30 m. As shown in Table 5, the models predicting 10 m, 20 m, and 30 m sprint performance were significant, explaining 30.0%, 28.4%, and 17.3% of the variance, respectively. CMJ and the 20 m change-of-direction speed test were significant predictors across all sprint distances, whereas VMA did not provide an independent predictive contribution. Collinearity diagnostics for the multiple regression models indicated no evidence of multicollinearity, with tolerance and variance inflation factor values within acceptable ranges.

Table 5. Multiple linear regression models predicting sprint performance

Dependent variable	Predictor	β	p-value	Model R^2	Adjusted R^2	F
10 m sprint	CMJ	–.297	.001	.300	.279	14.43
	COD speed	.361	< .001			
	VMA	–.032	.713			
20 m sprint	CMJ	–.339	< .001	.284	.263	13.37
	COD speed	.321	.001			
	VMA	.017	.847			
30 m sprint	CMJ	–.236	.017	.173	.149	7.05
	COD speed	.281	.005			
	VMA	.024	.796			

CMJ = countermovement jump; VMA = maximal aerobic speed; COD = Change of direction speed; β = standardized beta coefficient. Model R^2, adjusted R^2, and F values are reported for each dependent variable.

Positional differences

Descriptive performance data for each playing position are provided in Supplementary Table S1. These values are presented as exploratory positional reference data because playing positions were classified into broad categories and the number of goalkeepers was relatively small.

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One-way ANOVA results are presented in Table 6. No significant differences were observed across playing positions for any investigated variable, and effect sizes were small across all outcomes, indicating limited positional variation in jump performance, sprint performance, 20 m change-of-direction speed, and VMA within this sample.

Table 6. One-way ANOVA summary for performance differences across playing positions

Variable	F(df1, df2)	p-value	ηp^2
DJ (cm)	F(3,101) = 0.703	.552	.020
SJ (cm)	F(3,101) = 0.744	.528	.022
CMJ (cm)	F(3,101) = 0.251	.861	.007
CMJ-FA (cm)	F(3,101) = 0.622	.603	.018
10 m sprint (s)	F(3,101) = 0.190	.903	.006
20 m sprint (s)	F(3,101) = 0.315	.814	.009
30 m sprint (s)	F(3,101) = 0.794	.500	.023
COD Speed (s)	F(3,101) = 0.190	.903	.006
VMA ($km \cdot h^{-1}$)	F(3,101) = 1.709	.170	.048

ηp^2 = partial eta squared; DJ = drop jump; SJ = squat jump; CMJ = countermovement jump; CMJ-FA = countermovement jump with free arms; COD = change of direction; VMA = maximal aerobic speed.

Discussion

The aim of this study was to compare physical performance profiles and examine the associations between neuromuscular performance, change-of-direction speed, aerobic fitness, and sprint performance in Moroccan female football players competing at different competitive levels. The main findings were that first-division players outperformed second-division players in DJ, CMJ, CMJ-FA, 10 m sprint, 20 m sprint, 20 m change-of-direction speed test, and VMA, whereas no significant differences were observed for SJ or 30 m sprint performance. In addition, CMJ and the 20 m change-of-direction speed test showed the most consistent associations with sprint performance and remained significant predictors in the multiple regression models. These findings suggest that sprint performance in Moroccan female football players should be interpreted as a multidimensional quality involving neuromuscular, locomotor, and aerobic-related components rather than as the expression of a single isolated physical capacity.

Competitive level and neuromuscular profile

The between-division differences in jump performance indicate that competitive level was more clearly reflected in dynamic eccentric-concentric jump tasks than in the squat jump. First-division players showed superior CMJ, CMJ-FA, and DJ performance, while no significant difference was observed for SJ. This finding suggests that dynamic jump tests may be more sensitive to competitive level than isolated squat jump performance. This interpretation is consistent with the intermittent and dynamic nature of football, where accelerations, re-accelerations, duels, pressing actions, and jumping situations are rarely initiated from static conditions. Previous research has shown that vertical jump performance, particularly in tests involving countermovement or reactive actions, is associated with sprint-related neuromuscular qualities in football and team-sport athletes (Loturco et al. 2015, 2019; Slimani et al. 2016). However, these findings should be interpreted cautiously because the present study did not include direct biomechanical measures such as ground reaction force, contact time, stiffness, impulse, or eccentric braking variables. Therefore, the observed differences should be considered as better performance in field-based jump tasks involving stretch-shortening cycle-related actions, rather than as direct evidence of superior stretch-shortening cycle function (Santos et al. 2024). This is consistent with recommendations emphasizing that CMJ and DJ outcomes should be interpreted according to the selected metric and the specific performance quality being assessed (Bishop et al. 2022).

Sprint performance and change-of-direction speed

The sprint results showed that first-division players were faster over 10 m and 20 m, whereas no significant difference was observed over 30 m. This suggests that competitive-level differences in the present sample were mainly expressed during the early acceleration phase rather than over a longer linear sprint distance. In football, many decisive actions, such as pressing, defensive recovery, offensive transitions, and short runs into space, occur over relatively short distances. This may explain why 10 m and 20 m sprint performance were more sensitive to competitive level than 30 m sprint performance. Previous studies have also reported that sprint performance varies according to playing standard, sex, age, and positional demands (Armada-Cortés et al. 2022; Haugen et al. 2020; Haugen, Tønnessen, and Seiler 2012; Haugen and Buchheit 2016). Nevertheless, the absence of significant differences over 30 m should not be interpreted as indicating that longer sprint ability is unimportant, but rather that it was less discriminative of competitive level in this sample.

The associations between CMJ and sprint performance support previous evidence suggesting that vertical jump performance is related to sprint ability, although these relationships are generally moderate and cannot fully explain sprint performance (Loturco et al. 2015, 2019; Slimani et al. 2016). Sprinting is a complex task influenced not only by vertical neuromuscular qualities but also by horizontal force application, sprint mechanics, step kinematics, technical efficiency, and coordination of the acceleration pattern (Aloui et al. 2021; Haugen and Buchheit 2016). Therefore, CMJ may be considered a useful field-based marker of sprint-related neuromuscular qualities, but it should not replace direct sprint assessment.

The multiple regression models further clarified the combined contribution of the investigated variables to sprint performance. When CMJ, 20 m change-of-direction speed, and VMA were entered together, CMJ and the 20 m change-of-direction speed test remained significant predictors across 10 m, 20 m, and 30 m sprint performance, whereas VMA did not provide an independent predictive contribution. This suggests that sprint performance in this sample was more closely related to explosive jump performance and football-specific locomotor ability than to aerobic fitness. However, the explained variance was moderate for 10 m and 20 m sprint performance and lower for 30 m sprint performance, indicating that other factors not assessed in this study, such as horizontal force production, sprint technique, step kinematics, and neuromuscular coordination, may also contribute to sprint performance (Haugen and Buchheit 2016; Zhang et al. 2022).

The 20 m change-of-direction speed test was also associated with sprint performance across sprint distances. This finding supports the idea that football-specific speed involves more than linear acceleration alone. Change-of-direction speed requires the ability to accelerate, decelerate, brake efficiently, reorient the body, and re-accelerate rapidly. These qualities are highly relevant to football, where players rarely sprint in purely linear and isolated conditions. Previous research has shown that change-of-direction performance is influenced by acceleration, deceleration, braking capacity, and re-acceleration ability (Chaabene et al. 2018; Zhang et al. 2022). In adult female football players, repeated-sprint ability has also been associated with sprint performance, change-of-direction ability, vertical jump performance, and aerobic capacity (Gonçalves et al. 2021). The present findings add context-specific evidence by showing that change-of-direction speed may provide complementary information when profiling sprint-related physical qualities in Moroccan female football players.

Aerobic fitness as a complementary quality

VMA differentiated competitive level but was not significantly associated with linear sprint performance. This result is consistent with the physiological role of aerobic fitness in football. Aerobic capacity contributes to sustaining repeated high-intensity actions, tolerating training and match demands, and recovering between intense efforts, but it does not necessarily explain maximal acceleration or linear sprint speed (Bangsbo et al. 2006; Baptista et al. 2022). This distinction is important because a player may present a higher aerobic fitness level without necessarily being faster over short linear sprint distances, as these qualities depend on different physiological, neuromuscular, and mechanical mechanisms. Accordingly, VMA should be interpreted as a complementary marker of aerobic readiness rather than as a direct predictor of sprint performance. From an applied perspective, this supports the use of VMA for aerobic training prescription and monitoring, while confirming that sprint and neuromuscular assessments remain necessary when the objective is to evaluate acceleration and explosive performance (Bok and Foster 2021).

Position-based comparisons and contextual interpretation

The absence of significant positional differences should also be interpreted with caution. Although goalkeepers, defenders, midfielders, and forwards were included, positions were classified into broad categories, which may have reduced the sensitivity to detect meaningful role-specific differences. Previous studies have shown that physical match demands vary according to more specific positional roles in women's football, with differences in high-intensity running, accelerations, and match-related actions across playing positions (Baptista et al. 2022; Mäkiniemi et al. 2023). Therefore, grouping central defenders and full-backs together as "defenders", or considering all forwards as a single category, may have masked more specific positional demands. In addition, the relatively small number of goalkeepers may have limited the robustness of position-based comparisons, particularly because goalkeepers present specific physical and tactical demands that differ from those of outfield players (White et al. 2020). Future studies should use larger samples, match-running data, and more refined positional classifications.

Overall, the present study contributes to the development of contextualized physical profiling in Moroccan women's football. The findings suggest that competitive level may be better characterized through a combination of dynamic jump performance, short acceleration, change-of-direction speed, and aerobic fitness than through any isolated physical measure. This supports the use of multidimensional field-based testing batteries combining Optojump-derived jump assessments, short sprint tests, change-of-direction speed assessment, and Vameval-based aerobic profiling. Such an approach may help coaches identify individual performance needs, monitor player development, guide training prescription, and support more individualized conditioning models in Moroccan women's football.

Limitations

This study has several limitations. First, the cross-sectional design prevents causal interpretation of the relationships between physical performance variables, sprint performance, and competitive level. Second, although all field-based tests were performed using standardized procedures and two trials were completed for each test, within-session reliability indices were not calculated because only the best trial was retained in the final dataset. Future studies should retain all trial-level data and report intraclass correlation coefficients and coefficients of variation for sprint, jump, and change-of-direction speed assessments. Third, menstrual cycle phase and hormonal contraceptive use were not controlled, although these factors may influence neuromuscular and aerobic performance in female athletes. This limitation is relevant because methodological guidelines for studies involving women recommend reporting and controlling reproductive hormonal status where possible (Elliott-Sale et al. 2021). Fourth, match-running data and training-load measures were not included, limiting the ability to directly link field-test outcomes to competitive match demands. Finally, the sample was recruited from four Moroccan teams only, which may limit the generalizability of the findings to all female football players. In addition, playing positions were classified into broad categories, which may have reduced the sensitivity to detect role-specific differences between more specific sub-positions such as central defenders, full-backs, central midfielders, wide midfielders, wingers, forwards, and goalkeepers.

Practical Applications

The present findings support the use of multidimensional field-based testing batteries in Moroccan women's football. Coaches and strength and conditioning staff should monitor CMJ, DJ, 10 m and 20 m sprint performance, 20 m change-of-direction speed, and VMA to identify individual performance needs and guide training prescription. The 10 m and 20 m sprint tests appear particularly relevant for assess-

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ing short-distance acceleration, which differentiated first- and second-division players more clearly than 30 m sprint performance. CMJ and the 20 m change-of-direction speed test may be useful for monitoring sprint-related neuromuscular and locomotor qualities because they remained significant predictors of sprint performance in the multiple regression models. However, these tests should be used alongside direct sprint testing rather than as substitutes for sprint assessment. VMA should be considered a complementary marker of aerobic readiness and used mainly to guide aerobic training prescription rather than as a direct indicator of sprint ability. Overall, these assessments may help support individualized training prescription and player development monitoring, although their direct impact on long-term player development requires further longitudinal verification.

Conclusions

This study provides a multidimensional field-based physical profile of Moroccan female football players competing in the first and second divisions. First-division players demonstrated superior performance in dynamic jump tasks, 10 m and 20 m sprint performance, 20 m change-of-direction speed, and VMA, whereas SJ and 30 m sprint performance were less sensitive to competitive-level differences. CMJ and the 20 m change-of-direction speed test were the most consistent sprint-related indicators and remained significant predictors in the multiple regression models, while VMA did not independently predict linear sprint performance. These findings suggest that sprint performance in Moroccan female football players should be interpreted within a multidimensional profile, in which explosive jump performance, short-distance acceleration, change-of-direction speed, and aerobic readiness provide complementary information for training prescription and player monitoring.

Conflicts of Interest

The authors declare no conflict of interest.

References

Aloui, G., Hermassi, S., Hayes, L. D., Bouhafs, E., Chelly, M. S., & Schwesig, R. (2021). Loaded plyometrics and short sprints with change-of-direction training enhance jumping, sprinting, agility, and balance performance of male soccer players. *Applied Sciences, 11(12)*, 5587. https://doi.org/10.3390/app11125587

Armada-Cortés, E., Benítez-Muñoz, J. A., San Juan, A. F., & Sánchez-Sánchez, J. (2022). Evaluation of neuromuscular fatigue in a repeat sprint ability, countermovement jump and hamstring test in elite female soccer players. *International Journal of Environmental Research and Public Health, 19(22)*, 15069. https://doi.org/10.3390/ijerph192215069

Bangsbo, J., Mohr, M., & Krustrup, P. (2006). Physical and metabolic demands of training and match-play in the elite football player. *Journal of Sports Sciences, 24(7)*, 665–674. https://doi.org/10.1080/02640410500482529

Baptista, I., Winther, A. K., Johansen, D., Randers, M. B., Pedersen, S., & Pettersen, S. A. (2022). The variability of physical match demands in elite women's football. *Science and Medicine in Football, 6(5)*, 559–565. https://doi.org/10.1080/24733938.2022.2027999

Bishop, C., Turner, A., Jordan, M., Harry, J., Loturco, I., Lake, J., & Comfort, P. (2022). A framework to guide practitioners for selecting metrics during the countermovement and drop jump tests. *Strength and Conditioning Journal, 44(4)*, 95–103. https://doi.org/10.1519/SSC.0000000000000677

Bok, D., & Foster, C. (2021). Applicability of field aerobic fitness tests in soccer: Which one to choose? *Journal of Functional Morphology and Kinesiology, 6(3)*, 69. https://doi.org/10.3390/jfmk6030069

Cazorla, G., Ezzeddine-Boussaidi, L. B., Maillot, J., & Morlier, J. (2008). Physical qualities carried out on swerve sprint in team sports. *Science & Sports, 23*. https://doi.org/10.1016/j.scispo.2007.11.002

Chaabene, H., Prieske, O., Negra, Y., & Granacher, U. (2018). Change of direction speed: Toward a strength training approach with accentuated eccentric muscle actions. *Sports Medicine, 48(8)*, 1773–1779. https://doi.org/10.1007/s40279-018-0907-3

Cohen, J. (1992). Statistical power analysis. *Current Directions in Psychological Science, 1(3)*, 98–101. https://doi.org/10.1111/1467-8721.ep10768783

Compton, H. R., Lovell, R., Scott, D., Clubb, J., & Shushan, T. (2025). Benchmarking the physical performance qualities in women's football: A systematic review and meta-analysis across the performance scale. *Sports Medicine*. https://doi.org/10.1007/s40279-025-02251-0

Elliott-Sale, K. J., Minahan, C. L., De Jonge, X. A. K. J., Ackerman, K. E., Sipilä, S., Constantini, N. W., Lebrun, C. M., & Hackney, A. C. (2021). Methodological considerations for studies in sport and exercise science with women as participants: A working guide for standards of practice for research on women. *Sports Medicine, 51(5)*, 843–861. https://doi.org/10.1007/s40279-021-01435-8

Garcia-Retortillo, S., Javierre, C., Hristovski, R., Ventura, J. L., & Balagué, N. (2019). Principal component analysis as a novel approach for cardiorespiratory exercise testing evaluation. *Physiological Measurement, 40(8)*, 084002. https://doi.org/10.1088/1361-6579/ab2ca0

Glatthorn, J. F., Gouge, S., Nussbaumer, S., Stauffacher, S., Impellizzeri, F. M., & Maffiuletti, N. A. (2011). Validity and reliability of Optojump photoelectric cells for estimating vertical jump height. *Journal of Strength and Conditioning Research, 25(2)*, 556–560. https://doi.org/10.1519/JSC.0b013e3181ccb18d

Gonçalves, L., Clemente, F. M., Barrera, J. I., Sarmento, H., González-Fernández, F. T., Rico-González, M., & Carral, J. M. C. (2021). Exploring the determinants of repeated-sprint ability in adult women soccer players. *International Journal of Environmental Research and Public Health, 18(9)*, 4595. https://doi.org/10.3390/ijerph18094595

Haugen, T. A., Breitschädel, F., & Seiler, S. (2020). Sprint mechanical properties in soccer players according to playing standard, position, age and sex. *Journal of Sports Sciences, 38(9)*, 1070–1076. https://doi.org/10.1080/02640414.2020.1741955

Haugen, T. A., Tønnessen, E., Hisdal, J., & Seiler, S. (2014). The role and development of sprinting speed in soccer. *International Journal of Sports Physiology and Performance, 9(3)*, 432–441. https://doi.org/10.1123/ijspp.2013-0121

Haugen, T. A., Tønnessen, E., & Seiler, S. (2012). Speed and countermovement-jump characteristics of elite female soccer players, 1995–2010. *International Journal of Sports Physiology and Performance, 7(4)*, 340–349. https://doi.

org/10.1123/ijspp.7.4.340
Haugen, T., & Buchheit, M. (2016). Sprint running performance monitoring: Methodological and practical considerations. *Sports Medicine, 46(5)*, 641–656. https://doi.org/10.1007/s40279-015-0446-0
Hewett, T. E., Ford, K. R., & Myer, G. D. (2006). Anterior cruciate ligament injuries in female athletes: Part 2, A meta-analysis of neuromuscular interventions aimed at injury prevention. *The American Journal of Sports Medicine, 34(3)*, 490–498. https://doi.org/10.1177/0363546505282619
Loturco, I., Nakamura, F. Y., Kobal, R., Gil, S., Abad, C. C. C., Cuniyochi, R., Pereira, L. A., & Roschel, H. (2015). Training for power and speed: Effects of increasing or decreasing jump squat velocity in elite young soccer players. *Journal of Strength and Conditioning Research, 29(10)*, 2771–2779. https://doi.org/10.1519/JSC.0000000000000951
Loturco, I., Pereira, L. A., Kobal, R., Abad, C. C. C., Rosseti, M., Carpes, F. P., & Bishop, C. (2019). Do asymmetry scores influence speed and power performance in elite female soccer players? *Biology of Sport, 36(3)*, 209–216. https://doi.org/10.5114/biolsport.2019.85454
Mäkiniemi, J. K., Savolainen, E. H. J., Finni, T., & Ihalainen, J. (2023). Position-specific physical demands in different phases of competitive matches in national level women's football. *Biology of Sport, 40(3),* 629–637. https://doi.org/10.5114/biolsport.2023.118337
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
Santos, S., Oliveira, A., Costa, R., Nascimento, K., Alvares, P., Medeiros, F., Assumpco, C., Ramos, G., Banja, T., Veneroso, C., Claudino, J., & Cabido, C. (2024). Stretch-shortening cycle utilization in female and male soccer players: A systematic review. *Journal of Strength and Conditioning Research, 38(10)*, E600–E625. https://doi.org/10.1519/JSC.0000000000004904
Slimani, M., Chamari, K., Miarka, B., Del Vecchio, F. B., & Chéour, F. (2016). Effects of plyometric training on physical fitness in team sport athletes: A systematic review. *Journal of Human Kinetics, 53(1)*, 231–247. https://doi.org/10.1515/hukin-2016-0026
Sporis, G., Jukic, I., Milanovic, L., & Vucetic, V. (2010). Reliability and factorial validity of agility tests for soccer players. *Journal of Strength and Conditioning Research, 24(3)*, 679–686. https://doi.org/10.1519/JSC.0b013e3181c4d324
Stanković, M. N., Čaprić, I. M., Katanić, B. D., Radaković, R. Ž., Murić, B. B., Kahrović, I. H., & Jelaska, I. D. (2025). Effects of different strength training on sprint, jump and strength performance in female soccer players: A systematic review. *Medicina dello Sport, 78(1)*. https://doi.org/10.1728/4552.45504
Taube, W., Leukel, C., & Gollhofer, A. (2012). How neurons make us jump: The neural control of stretch-shortening cycle movements. *Exercise and Sport Sciences Reviews, 40(2)*, 106–115. https://doi.org/10.1097/JES.0b013e31824138da
White, A., Hills, S. P., Hobbs, M., Cooke, C. B., Kilduff, L. P., Cook, C. J., Roberts, C., & Russell, M. (2020). The physical demands of professional soccer goalkeepers throughout a week-long competitive microcycle and transiently throughout match-play. *Journal of Sports Sciences, 38(8)*, 848–854. https://doi.org/10.1080/02640414.2020.1736244
Zhang, Q., Dellal, A., Chamari, K., Igonin, P.-H., Martin, C., & Hautier, C. (2022). The influence of short sprint performance, acceleration, and deceleration mechanical properties on change of direction ability in soccer players: A cross-sectional study. *Frontiers in Physiology, 13*, 1027811. https://doi.org/10.3389/fphys.2022.1027811.

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Transfer of learning on a spatial memory task

Selcuk Akpinar[1], Stevo Popović[1,2], Sadettin Kirazci[1]

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Word count: 2,980

Abstract word count: 236

Number of Tables: 3

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When reporting experiments on human subjects, there must be a declaration of Ethics compliance. Inclusion of a statement such as follow in Methods section will be understood by the Editor as authors' affirmation of compliance: "This study was approved in advance by [name of committee and/or its institutional sponsor]. Each participant voluntarily provided written informed consent before participating." Authors that fail to submit an Ethics statement will be asked to resubmit the manuscripts, which may delay publication.

2.3.3 Statistics reporting

MJSSM encourages authors to report precise p-values. When possible, quantify findings and present them with appropriate indicators of measurement error or uncertainty (such as confidence intervals). Use normal text (i.e., non-capitalized, non-italic) for statistical term "p".

2.3.4. 'Acknowledgements' and 'Conflict of Interest' (optional)

All contributors who do not meet the criteria for authorship should be listed in the 'Acknowledgements' section. If applicable, in 'Conflict of Interest' section, authors must clearly disclose any grants, financial or material supports, or any sort of technical assistances from an institution, organization, group or an individual that might be perceived as leading to a conflict of interest.

2.4. References

References should be placed on a new page after the standard title written in upper and lower case letters, bold.

All information needed for each type of must be present as specified in guidelines. Authors are solely responsible for accuracy of each reference. Use authoritative source for information such as Web of Science, Medline, or PubMed to check the validity of citations.

2.4.1. References style

MJSSM adheres to the American Psychological Association 7th Edition reference style. Check the Publication Manual of the American Psychological Association (2019), Seventh Edition that is the official source for APA Style, to ensure the manuscripts conform to this reference style. Authors using EndNote® to organize the references must convert the citations and bibliography to plain text before submission.

2.4.2. Examples for Reference citations

One work by one author

- ✓ In one study (Reilly, 1997), soccer players…
- ✓ In the study by Reilly (1997), soccer players…
- ✓ In 1997, Reilly's study of soccer players…

Works by two authors

- ✓ Duffield and Marino (2007) studied…
- ✓ In one study (Duffield & Marino, 2007), soccer players…
- ✓ In 2007, Duffield and Marino's study of soccer players…

Works by three or more authors: cite only the name of the first author followed by et al. and the year

- ✓ Bangsbo et al. (2008) stated that…
- ✓ In one study (Bangsbo et al., 2008), soccer players…

Works by organization as an author: cite the source, just as you would an individual person

- ✓ According to the American Psychological Association (2000)…
- ✓ In the APA Manual (American Psychological Association, 2003), it is explained…

Two or more works in the same parenthetical citation: citation of two or more works in the same parentheses should be listed in the order they appear in the reference list (i.e., alphabetically); separated by a semi-colon

- ✓ Several studies (Bangsbo et al., 2008; Duffield & Marino, 2007; Reilly, 1997) suggest that…

2.4.3. Examples for Reference list

Works by one author

Borg, G. (1998). *Borg's perceived exertion and pain scales*: Human Kinetics.

Works by two authors

Duffield, R., & Marino, F. E. (2007). *Effects of pre-cooling procedures on intermittent-sprint exercise performance in warm conditions. European Journal of Applied Physiology, 100*(6), 727–735. https://doi.org/10.1007/s00421-007-0468-x

Works by three to twenty authors

Nepocatych, S., Balilionis, G., & O'Neal, E. K. (2017). Analysis of dietary intake and body composition of female athletes over a competitive season. *Montenegrin Journal of Sports Science and Medicine, 6*(2), 57–65. https://doi.org/10.26773/mjssm.2017.09.008

Works by more than twenty authors

Krustrup, P., Mohr, M., Amstrup, T., Rysgaard, T., Johansen, J., Steensberg, A.,… Bangsbo, J. (2003). The yo-yo intermittent recovery test: physiological response, reliability, and validity. *Medicine & Science in Sports & Exercise, 35*(4), 697–705. https://doi.org/10.1249/01.mss.0000058441.94520.32

Works by group of authors

NCD-RisC. (2017). Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128.9 million children, adolescents, and adults. *Lancet*, 390(10113), 2627-2642. https://doi.org/10.1016/s0140-6736(17)32129-3

Works by unknown authors

Merriam-Webster's collegiate dictionary (11th ed.). (2003). Merriam-Webster.

Journal article (print)

Scruton, R. (1996). The eclipse of listening. *The New Criterion, 15*(3), 5–13.

Journal article (electronic)

Aarnivala, H., Pokka, T., Soininen, R., Mottonen, M., Harila-Saari, A., & Niinimaki, R. (2020). Trends in age- and sex-adjusted body mass index and the prevalence of malnutrition in children with cancer over 42 months after diagnosis: a single-center cohort study. *European Journal of Pediatrics,* 179(1), 91-98. https://doi.org/10.1007/s00431-019-03482-w

Thesis and dissertation

Pyun, D. Y. (2006). *The proposed model of attitude toward advertising through sport*. [Unpublished Doctoral Dissertation]. The Florida State University.

Book

Borg, G. (1998). *Borg's perceived exertion and pain scales*: Human Kinetics.

Chapter of a book

Armstrong, D. (2019). Malory and character. In M. G. Leitch & C. J. Rushton (Eds.), *A new companion to Malory* (pp. 144-163). D. S. Brewer.

Reference to a Facebook profile

Little River Canyon National Preserve (n.d.). *Home* [Facebook page]. Facebook. Retrieved January 12, 2020 from https://www.facebook.com/lirinps/

2.5. Tables

All tables should be included in the main manuscript file, each on a separate page right after the Reference section.

Tables should be presented as standard MS Word tables.

Number (Arabic) tables consecutively in the order of their first citation in the text.

Tables and table headings should be completely intelligible without reference to the text. Give each column a short or abbreviated heading. Authors should place explanatory matter in footnotes, not in the heading. All abbreviations appearing in a table and not considered standard must be explained in a footnote of that table. Avoid any shading or coloring in your tables and be sure that each table is cited in the text.

If you use data from another published or unpublished source, it is the authors' responsibility to obtain permission and acknowledge them fully.

2.5.1. Table heading

Table heading should be written above the table, in Title Case, and without a full stop at the end of the heading. Do not use suffix letters (e.g., Table 1a, 1b, 1c); instead, combine the related tables. *See* example:

- ✓ **Table 1.** Repeated Sprint Time Following Ingestion of Carbohydrate-Electrolyte Beverage

2.5.2. Table sub-heading

All text appearing in tables should be written beginning only with first letter of the first word in all capitals, i.e., all words for variable names, column headings etc. in tables should start with the first letter in all capitals. Avoid any formatting (e.g., bold, italic, underline) in tables.

2.5.3. Table footnotes

Table footnotes should be written below the table.

General notes explain, qualify or provide information about the table as a whole. Put explanations of abbreviations, symbols, etc. here. General notes are designated by the word Note (italicized) followed by a period.

- ✓ *Note.* CI: confidence interval; Con: control group; CE: carbohydrate-electrolyte group.

Specific notes explain, qualify or provide information about a particular column, row, or individual entry. To indicate specific notes, use superscript lowercase letters (e.g. [a, b, c]), and order the superscripts from left to right, top to bottom. Each table's first footnote must be the superscript [a].

- ✓ [a]One participant was diagnosed with heat illness and n = 19.[b]n =20.

Probability notes provide the reader with the results of the texts for statistical significance. Probability notes must be indicated with consecutive use of the following symbols: * † ‡ § ¶ || etc.

- ✓ *P<0.05,†p<0.01.

2.5.4. Table citation

In the text, tables should be cited as full words. *See* example:

- ✓ Table 1 (first letter in all capitals and no full stop)
- ✓ ...as shown in Tables 1 and 3. (citing more tables at once)
- ✓ ...result has shown (Tables 1-3) that... (citing more tables at once)
- ✓ ....in our results (Tables 1, 2 and 5)... (citing more tables at once)

2.6. Figures

On the last separate page of the main manuscript file, authors should place the legends of all the figures submitted separately.

All graphic materials should be of sufficient quality for print with a minimum resolution of 600 dpi. MJSSM prefers TIFF, EPS and PNG formats.

If a figure has been published previously, acknowledge the original source and submit a written permission from the copyright holder to reproduce the material. Permission is required irrespective of authorship or publisher except for documents in the public domain. If photographs of people are used, either the subjects must not be identifiable or their pictures must be accompanied by written permission to use the photograph whenever possible permission for publication should be obtained.
Figures and figure legends should be completely intelligible without reference to the text.

The price of printing in color is 50 EUR per page as printed in an issue of MJSSM.

2.6.1. Figure legends

Figures should not contain footnotes. All information, including explanations of abbreviations must be present in figure legends. Figure legends should be written bellow the figure, in sentence case. *See* example:

- ✓ **Figure 1.** Changes in accuracy of instep football kick measured before and after fatigued. SR – resting state, SF – state of fatigue, *p>0.01, †p>0.05.

2.6.2. Figure citation

All graphic materials should be referred to as Figures in the text. Figures are cited in the text as full words. *See* example:

- ✓ Figure 1
- × figure 1
- × Figure 1.
- ✓ ….exhibit greater variance than the year before (Figure 2). Therefore…
- ✓ ….as shown in Figures 1 and 3. (citing more figures at once)
- ✓ ….result has shown (Figures 1-3) that... (citing more figures at once)
- ✓ ….in our results (Figures 1, 2 and 5)... (citing more figures at once)

2.6.3. Sub-figures

If there is a figure divided in several sub-figures, each sub-figure should be marked with a small letter, starting with a, b, c etc. The letter should be marked for each subfigure in a logical and consistent way. *See* example:

- ✓ Figure 1a
- ✓ …in Figures 1a and b we can…
- ✓ …data represent (Figures 1a-d)…

2.7. Scientific Terminology

All units of measures should conform to the International System of Units (SI).

Measurements of length, height, weight, and volume should be reported in metric units (meter, kilogram, or liter) or their decimal multiples.

Decimal places in English language are separated with a full stop and not with a comma. Thousands are separated with a comma.

Percentage	Degrees	All other units of measure	Ratios	Decimal numbers
✓ 10%	✓ 10º	✓ 10 kg	✓ 12:2	✓ 0.056
× 10 %	× 10 º	× 10kg	× 12 : 2	× .056

Signs should be placed immediately preceding the relevant number.		
✓ 45±3.4	✓ p<0.01	✓ males >30 years of age
× 45 ± 3.4	× p < 0.01	× males > 30 years of age

2.8. Latin Names

Latin names of species, families etc. should be written in italics (even in titles). If you mention Latin names in your abstract they should be written in non-italic since the rest of the text in abstract is in italic. The first time the name of a species appears in the text both genus and species must be present; later on in the text it is possible to use genus abbreviations. *See* example:

- ✓ First time appearing: *musculus biceps brachii*
- ✓ Abbreviated: *m. biceps brachii*

MONTENEGRIN SPORTS ACADEMY

Founded in 2003 in Podgorica (Montenegro), the Montenegrin Sports Academy (MSA) is a sports scientific society dedicated to the collection, generation and dissemination of scientific knowledge at the Montenegrin level and beyond.

The Montenegrin Sports Academy (MSA) is the leading association of sports scientists at the Montenegrin level, which maintains extensive co-operation with the corresponding associations from abroad. The purpose of the MSA is the promotion of science and research, with special attention to sports science across Montenegro and beyond. Its topics include motivation, attitudes, values and responses, adaptation, performance and health aspects of people engaged in physical activity and the relation of physical activity and lifestyle to health, prevention and aging. These topics are investigated on an interdisciplinary basis and they bring together scientists from all areas of sports science, such as adapted physical activity, biochemistry, biomechanics, chronic disease and exercise, coaching and performance, doping, education, engineering and technology, environmental physiology, ethics, exercise and health, exercise, lifestyle and fitness, gender in sports, growth and development, human performance and aging, management and sports law, molecular biology and genetics, motor control and learning, muscle mechanics and neuromuscular control, muscle metabolism and hemodynamics, nutrition and exercise, overtraining, physiology, physiotherapy, rehabilitation, sports history, sports medicine, sports pedagogy, sports philosophy, sports psychology, sports sociology, training and testing.

The MSA is a non-profit organization. It supports Montenegrin institutions, such as the Ministry of Education and Sports, the Ministry of Science and the Montenegrin Olympic Committee, by offering scientific advice and assistance for carrying out coordinated national and European research projects defined by these bodies. In addition, the MSA serves as the most important Montenegrin and regional network of sports scientists from all relevant subdisciplines.

The main scientific event organized by the Montenegrin Sports Academy (MSA) is the annual conference held in the first week of April.

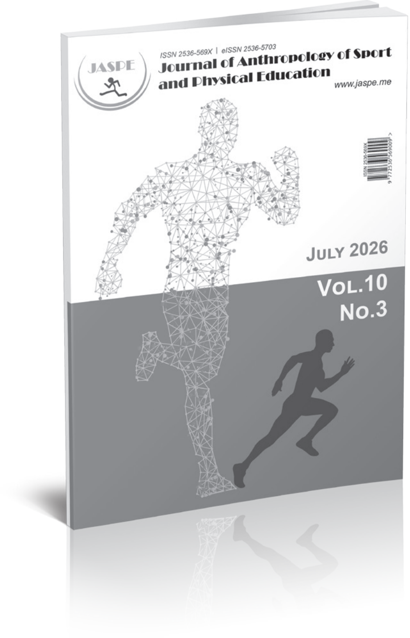
Annual conferences have been organized since the inauguration of the MSA in 2003. Today the MSA conference ranks among the leading sports scientific congresses in the Western Balkans. The conference comprises a range of invited lecturers, oral and poster presentations from multi- and mono-disciplinary areas, as well as various types of workshops. The MSA conference is attended by national, regional and international sports scientists with academic careers. The MSA conference now welcomes up to 200 participants from all over the world.

We are delighted to announce the Montenegrin Sports Academy's 25th International Scientific Conference on Sports Sciences, taking place April 08-11, 2027, at the beautiful Budva, Montenegro. Join us as leading experts gather to explore "Sport, Physical Activity, and Health – Contemporary Perspectives." Experience inspiring keynotes, cutting-edge research, and exciting cultural moments — including our special opening ceremony performance.

The conference is focused on very current topics from all areas of sports science and sports medicine including physiology and sports medicine, social sciences and humanities, biomechanics and neuromuscular (see Abstract Submission page for more information).

We do believe that the topics offered to our conference participants will serve as a useful forum for the presentation of the latest research, as well as both for the theoretical and applied insight into the field of sports science and sports medicine disciplines.

Journal of Anthropology of Sport and Physical Education



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