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Dear Contributors and Authors,

We are delighted to announce the release of the latest issue of Montenegrin Journal of Sports Science and Medicine. This publication would not have been possible without the invaluable contributions and dedication of each one of you. Your research, insights, and scholarly work have enriched our journal and advanced the discourse in our respective fields.

We extend our heartfelt gratitude to all contributors and authors for their hard work and commitment to excellence. Your efforts have significantly contributed to the academic community and have helped us maintain the high standards of our publication.

In addition to celebrating the release of our new issue, we are excited to take this opportunity to introduce our upcoming 21st Annual Scientific Conference of Montenegrin Sports Academy scheduled for 18-21 April, which will be held in Cavtat/Dubrovnik, Croatia. The conference will provide a platform for researchers, scholars, and professionals to come together, exchange ideas, and discuss the latest advancements in our fields of study.

Details regarding the conference, including the theme, keynote speakers, are available at conference website (https://csakademija.me/conference/index.html). We encourage all of you to consider participating in this enriching event and to share your valuable insights with our academic community.

Once again, we extend our sincere appreciation to each one of you for your contributions to our journal. Your dedication to advancing knowledge and scholarship is truly commendable, and we look forward to our continued collaboration and success.

Warm regards,
Prof. dr. Dusko Bjelica
Prof. dr. Damir Sekulic

ORIGINAL SCIENTIFIC PAPER

Influence of Pre-Shooting Activity on Three-Points Jump Shot Parameters Between Junior and Senior Regional Level Basketball Players

Mladen J. Mikić[1,2], Igor Vučković[3], Nikola Andrić[1,2], Tatjana Jezdimirovic-Stojanovic[1,2], Laslo Ratgeber[4], Marko DM. Stojanović[1,2]

Affiliations: [1]Training Expertise Lab, Faculty of Sport and Physical Education, University of Novi Sad, Serbia, [2]Faculty of Sport and Physical Education, University of Novi Sad, Serbia, [3]University of Banja Luka, Faculty of Sport and Physical Education, Banja Luka, Bosnia and Herzegovina, [4]Faculty of Health Sciences, University of Pecs, Pecs, Hungary

Correspondence: M. DM. Stojanović. Faculty of Sport and Physical education, Lovcenska 16, Novi Sad, 21000, Serbia. E-mail: marko.ns.stojanovic@gmail.com

Abstract

The aims of this study were: 1. to investigate the influence of pre-shooting activity on the three-point jump shot entry angle and release time in regional level basketball players; 2. to examine age related differences in these parameters between juniors and seniors. Thirty three perimeter players , were assigned to juniors (n=16, age=17.34±0.54 years; height=191.3±8.18 cm; weight= 77.08±7.41 training experience=6.75±2.30 years) and seniors (n=17, age=22.79±4.47 years; height =194.4±7.47 cm; weight= 80.42±7.45d; training experience=12.18±3.17 years) had three sets of 5 shots, with a different preparatory phase for every set: 1. spot shot, 2. after two forward steps, or 3. after one dribble. Only successful shots (n= 233) were analyzed. The difference between groups was determined with ANOVA, while the differences in shot accuracy were determined by the chi-square test. Study results reported no statistically significant differences in entry angle and release time for 3 different pre-shooting patterns. Seniors had significantly higher shooting accuracy (X2=3.097; p=0.048, φ=-0.089) higher entry angle (p < 0.001) and lower release time (p < 0.001) than juniors for all successful shots combined, and significantly higher (p < 0.001) entry angle for every set independently. Significant difference in shooting accuracy with medium effect size (X2= 6.645; p=0.010, φ=-0.20) was observed in shots after movement. Seniors had statistically lower release time for set 1 (p=0.004) and 2 (p=0.002) independently. Age-related group differences in shooting parameters should be considered to optimize training prescription for basketball players.

Keywords: *entry angle; shot release time; basketball shot; shooting accuracy; 94Fifty®*

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Introduction

To succeed in elite basketball, it is required of players to possess an optimal level of a variety of performance factors, with physical fitness, physiological and psychological aspects repeatedly addressed in literature (Ziv & Lidor, 2009). Basketball players are required to also have a technical-tactical skillset (Trninić & Dizdar, 2000) adequate to the competitive level. Among these, shooting has been found to be crucial for players' success, with field goal percentage extensively proclaimed as the crucial game-related statistic that discriminate between winning and losing (Okazaki et al., 2015). Mandic et al. (2019) have revealed the jump shot as being the most efficient and frequently used shooting technique by players. Hence, exploring the jump shot is important to improve our understanding about the key factors considered essential for the shooting accuracy and consequently to enhance both players and team's basketball performance.

The jump-shooting motion is the most complex basketball technique (Okazaki et al., 2015). It has been theorized that the ball should leave the hand within 0.65s with optimal velocity and angle of entry into the basket following the moment the ball was received, at or close to the end of ascending phase of vertical jump (Dobovičnik et al., 2015). A basketball shot released with an angle entry close to 50 seems superior as it enables a large enough area for the ball and the smallest possible release time (Brancazio, 1981; Miller & Bartlett, 1993; Okazaki & Rodacki, 2012). The angle at which ball leaves the shooter's hand is directly related to the angle at which the ball passes through the hoop (Miller & Bartlett, 1993), and the release angle of 55-60° leads to an entry angle of 45-50 degrees (Brancazio, 1981). The ball entry-angle has been recognized as the leading determinant of shooting accuracy (Miller & Bartlett, 1993; Okazaki & Rodacki, 2012), found also to be distance-dependent (Brancazio, 1985).

Studies elaborating on shooting kinematics are scarce in basketball, examining the shooting accuracy (Oudejans et al., 2012; Slawinski et al., 2018), biomechanical and proprioception parameters of shooting performance (Miller & Bartlett, 1993), and even nutritional interventions and their influence on shooting achievements (Baker et al., 2007). Most of them used complex kinematic analysis with 3-D motion capture systems analyzing well known biomechanical parameters such as release height, center of mass displacement, joint angles etc. (Okazaki et al., 2015). However, new trends in basketball practice show an increasing interest in innovative technologies which enable quick interpretation of dominantly ball trajectory kinematics such as ball release time, release angle or entry angle (Marty & Lucey, 2017). At least 2500 middle and high USA schools' athletes regularly train with this innovative technology (Noah Basketball Shooting System), clearly indicating its potential for everyday practice (Marty & Lucey, 2017).

Only a few studies reported the players' jump-shot release time, with a total time of 0.62 s reported in a 2 players sample-size study (Fontanella, 2006). Dobovičnik et al. (2015) registered durations of 0.76, s for guards with a sample of 7 youth Serbian basketball teams plus Serbian U20 national team, while Stojanović et al. (2019) showed no differences in terms of release time and entry angle between centers and other playing positions in elite male Serbian basketball players. However, to the best of our knowledge differences in shooting parameters in various age groups have not been reported yet. More studies seems prudent. to develop age-specific guidelines for basketball practice. Furthermore, inferring differences in aforementioned parameters between groups might have practical application with research-derived coaching cues (release the ball faster/slower, increase/decrease release angle) likely inducing specific shooting technique- corrections and adopting more optimal shooting pattern in basketball players.

Shooting varies as a function of time, competitive standard, and playing experience (Erčulj & Štrumbelj, 2015). A greater speed of the ball at release and greater accuracy have been reported in experienced field hockey and soccer players compared with recreational players (Anderson & Sidaway, 1994; Kerr & Ness, 2006). Information's are lacking in basketball, with only one study reporting greater consistency in the kinematic patterns of free throw for experienced vs. unexperienced players (Button et al., 2003). Three point -jump shot have become prevalent in modern basketball, (Mandić et al., 2019), with over 50% shots unopposed and shooting accuracy during final stages of the game showed to be a major determinant of success (Ardigò et al., 2018). Moreover, pre-shooting movement pattern has been shown to influence shooting kinematics (Okazaki et al., 2015), indicating that elaborating kinematic parameters of jump-shooting with various preparatory movements has practical merit due to high ecologic validity.

The first aim of the present study was to evaluate influence of pre-shooting activity on three-points jump shot parameters in junior and senior regional-level basketball players. The second aim was to examine differences in three-point jump shooting-parameters (entry angle and release time) between junior and senior regional level basketball players. We assumed that there would be statistically significant differences in jump shot-parameters between three distinct pre-shooting patterns and that senior players would demonstrate superior shooting-parameters values in all jump-shooting variants.

Methods

Participants

Thirty-three perimeter male basketball players (n=33; age=20.15±4.21 years; height=192.91±7.86; training experience=9.55±3.88 years), members of the teams participating to the highest national League (Serbia First League) were recruited for this study and divided in two groups. The first group (juniors) consisted of 16 players, (n=16, age=17.34±0.54 years; height=191.3±8.18 cm; weight= 77.08±7.41 training experience=6.75±2.30 years), competing in the Serbian Quality Junior league. The second group (seniors) consisted of 17 senior players (n=17, age=22.79±4.47 years; height =194.4±7.47 cm; weight= 80.42±7.45d; training experience=12.18±3.17 years). The inclusion of solely perimeter players was deliberate because of their three-point shooting proficiency (Sindik & Jukiç, 2011). The participants trained 7.5 hours per week (5* 1.5 hours), with an additional basketball game every weekend.

The participants were with more than 4 years of training experience, injury free for 6 months and at least 10 games played for 15+ minutes during the season. They were asked to abstain from heavy training, alcohol, tobacco and caffeine use and to avoid sleep deprivation for at least 2 days before the testing sessions. All players were familiar with the purpose of the research and accepted to participate in the study after signing a consent form. The protocol was reviewed and approved by the ethics committee of University of Novi Sad, Serbia. (Ref. No. 44-01-02/2019-3)

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Procedures

The 94Fifty smart sensor basketball (InfoMotion Sports Technologies, Inc.) was used to measure the shooting-parameters. This ball contains 9 accelerometers that measure force, speed, ball rotation and ball arc. The parameters collected in this study were the entry angle and release time (angle at which the ball enters into the basket, and time from the moment the shooters catches the ball to the moment ball leaving shooter's hands). Abdelrasoul et al. (2015) and Rupčić et al. (2016) confirmed high reliability of measurements using a 94Fifty ball, comparing it to Dartfish and Kinovea software, respectively.

A standardized warm up (5 min jogging and 5 minutes of basketball specific dynamic warm up) with an addition of five trial three-point jump shots was carried out before each data collection. After a 2-3 minutes rest a test protocol consisting of 3 series of 5 three-point jump-shots, with a 3-minute of rest period between each series, was submitted. Three sets of shooting differentiate considering the jump-shot preparation phase. In the first set players received the ball in spot, without moving, and shot immediately. In the second set players performed two steps toward the three-point line, receive the ball and deliver a shot. In the last set, players received the ball around 1.5 m from the three-point line, and shot after one dribble towards the basket. For all shots, the ball was received in triple-threat position with an immediate proceeding with predetermined task, as fast as possible game-like shot or dribble. In total out of 495 recorded shots, an amount of 233 successful shots were obtained for release time and entry angle and were used for further analysis. Accuracy was entered by the tester into the table, along with the entry angle and the release time.

Statistical Analysis

Data was presented as mean and standard deviation. Kolmogorov-Smirnov test showed normal distribution for the entry angle (p=0.052) and release time (p=0.075). Levene's test for the assessment of homoscedasticity was applied. The one-way ANOVA was used to analyze the difference between groups. Partial eta-squared (η2p) was used as a measure of effect size, and values were interpreted as no effect ($\eta 2p < 0.04$), minimum effect ($0.04 < \eta 2p < 0.25$), moderate effect ($0.25 < \eta 2p < 0.64$), and strong effect ($\eta 2p > 0.64$). The significance of the difference in shooting accuracy between groups was analyzed by using 2 × 2 contingency chi-squared analysis. Magnitude of these differences was evaluated with Cramer's phi (φ) according to the following criteria: $\varphi < 0.3$ was considered as a small, φ = 0.3–0.5 as a medium, and $\varphi > 0.5$ as a large effect.

The significance for all statistical tests was set as $p < 0.05$. All statistical analyses were performed using the SPSS (Version 20 for Windows; IBM, Armonk, NY, USA).

Results

When comparing the influence of the pre-shooting activity for all successful shots, juniors and seniors combined, there were no statistically significant differences in entry angle and release time (Table 1). In addition, there was no difference in shooting accuracy between three distinct sets of three-point jump shots (45.5% vs 49.1% vs 46.7%; spot shots vs shots after movement vs shots after dribble, respectively; X2= 0.454; p=0.797).

Table 1. Differences related to pre-shooting activity for all successful shots

	Entry Angle			Release Time		
	Spot shot	Shot after movement	Shot after dribble	Spot shot	Shot after movement	Shot after dribble
N	75	81	77	75	81	77
Mean	45.25	45.89	45.92	0.90	0.90	0.87
SD	3.91	3.55	3.46	0.14	0.09	0.17
Min	38	39	40	0.65	0.67	0.60
Max	55	53	54	1.30	1.20	1.34
Sig. Between Groups		0.443			0.187	

N—number of successful shots; Mean—arithmetic mean; SD—standard deviation; Min—Minimum; Max—Maximum; Sig.—statistical significance of the differences

For the spot shots, significant differences with minimum effect size were observed for both release time ($p < 0.001$; η2p = 0.110) and entry angle (p =0.000; η2p = 0.221) (Table 2). In addition, no significant difference (X2 = 0.040; p=0.842) in shooting accuracy was observed (46.3% vs 44.7%, juniors vs seniors, respectively).

Table 2. Differences between juniors and seniors in kinematic parameters according to pre-shooting activity

		Category						
		Juniors			Seniors			
		N	Mean	SD	N	Mean	SD	Sig.
Spot shots	Entry angle	37	43.41	2.64	38	47.05	4.17	0.001
	Release time	37	0.95	0.13	38	0.86	0.12	0.004
Shots after movement	Entry angle	31	43.97	2.74	50	47.08	3.49	0.001
	Release time	31	0.94	0.81	50	0.88	0.94	0.002
Shots after dribble	Entry angle	34	44.06	2.32	43	47.40	3.52	0.001
	Release time	34	0.91	0.19	43	0.84	0.17	0.55

N—number of successful shots; Mean—arithmetic mean; SD—standard deviation; Sig.—statistical significance of the differences

For the three point jump-shots after movement (Table 2), seniors showed significantly higher entry angle ($p < 0.001$; η2p = 0.184; 47.08°±3.49 vs 43.97°±2.74), and faster release time (p=0.002; η2p = 0.117; 0.88±0.94s vs 0.94±0.81s, respectively), with minimum effect sizes. Significant difference in shooting accuracy (38.8% vs 58.8%, juniors vs seniors, respectively), with medium effect size (X2= 6.645; p=0.010, φ =-0.20) was also observed.

Seniors showed significantly higher results compared to juniors for entry angle ($p < 0.001$; η2p = 0.233; 47.40°±3.52 vs 44.06°±2.32, respectively) (Table 2), but not for release time (p =0,055) in three-point jump-shots after dribble. There was no difference (X2 = 1.083; p=0.298) in shooting accuracy (42.5% vs 50.6%, junior vs seniors, respectively).

When comparing the influence of the pre-shooting activity for all successful shots, juniors and seniors combined, there were no statistically significant differences in entry angle and release time (Table 3). There was no difference in shooting accuracy between three distinct sets of three-point jump shots (45.5% vs 49.1% vs 46.7%; spot shots vs shots after movement vs shots after dribble, respectively; X2= 0.454; p=0.797).

Significant differences with minimum effect for release time ($p < 0.001$; η2p = 0.212) and entry angle ($p < 0.001$; η2p = 0.212) for all successful shots were registered (Table 3). Juniors had a significantly lower shooting accuracy, (42.5% vs 51.4%) with small effects size (X2=3.097; p=0.048, φ =-0.089) .

Table 3. Differences between juniors and seniors for entry angle and release time for all successful shots.

	Category						
	Juniors			Seniors			
	N	Mean	SD	N	Mean	SD	Sig.
Entry angle	102	43.79	2.56	131	47.18	3.67	0.001
Release time	102	0.93	0.14	131	0.86	0.13	0.001

N—number of successful shots; Mean—arithmetic mean; SD—standard deviation; Sig.—statistical significance of the differences

Discussion

This study aimed to: 1. investigate potential influence of pre-shooting activity on the three-point jump shot entry angle and release time in junior and senior regional level basketball players; and 2. examine age related differences in three-point jump shooting-parameters (entry angle and release time) . The first finding of this research showed that there was no influence of pre-shooting activity on the observed three-point jump shot parameters nor shooting accuracy. The second finding showed a statistically significant difference in favor of seniors for both jump shooting parameters with entry angle and release time closer to optimal values of 50° and 0.7s (Rupčić et al., 2016), and shooting accuracy for all three jump-shot protocols combined. Moreover, seniors were found to have significantly higher entry angle for each jump-shot protocol separately, as well as faster release time for two out of three jump-shot protocols (jump-shot after receiving ball in spot and jump-shot after two steps towards the ball). Finally, seniors proved to have significantly better shooting accuracy of jump shots after movement.

The stability of the three-point jump-shot parameters irrespective of pre-shooting activity we found is contrary to some previous findings (Mack, 2001; Oudejans et al., 2012). It is reasonable to assume that extensive training enforces stable shooting technique with similar shooting mechanics irrespective of pre-shooting movement strategy. Slawinsky et al. (2018) reported no changes in the three point jump-shot kinematics ($p > 0.05$), or the ball release variables ($p > 0.05$) following fatiguing protocol in young basketball players (age: 16.3±1.2 years), supporting our reasoning for the obtained results. It has been previously reported that players with less accurate shooting technique release a ball with lower entry angle compared to proficient players (Okazaki & Rodacki, 2018). Hence, we can speculate that senior players are more proficient in shooting biomechanics due to training history (12.18 vs 6.75years), as previously suggested (Okazaki & Rodacki, 2018). In addition, it is reasonable to assume that the senior players are physically superior to the junior ones, with fitness attributes proved to be related to enhanced shooting performance, especially with increasing shot-distance (Justin et al., 2006). A clear positive relationship between several fitness attributes and basketball-specific shooting accuracy was recently presented (Pojskic et al.,2011; Pojskic et al., 2018). Our results are in line with some previous studies done on similar populations (Okazaki et al., 2015; Okazaki & Rodacki, 2012; Stojanović et al., 2019). It has been presented that elite Serbian basketball players performed jump-shot entry angles of 40.54±4.76°, similar to our study findings for young players but lower in comparison to seniors and shot release times of 1.10±0.23s which is substantially different than we found. A 0.62s average jump shot release time was reported by Fontanella (2006), with little slower release time of 0.76, s for guards, reported in young Serbian basketball players (Dobovičnik et al., 2015). Also, the lower entry angle of the subjects in the mentioned study indicates lower release angle during shot, which affects both the release time and accuracy. Both these studies reported faster jump-shot release times compared to those obtained in our study.

Such discrepancy could be attributed to the superior shooting technique of study participants. It has been shown that top level players tend to both substantially decrease preparatory phase for the shot and prolong shooting hand-ball contact time (Podmenik et al., 2017). This enables them to fine tune shooting mechanics using visual and proprioceptive feedback and increase likelihood of scoring, while still producing shorter release time as net effect (Podmenik et al., 2017). Also, the jump-shot release time is proved to be strength-dependent (Pojskic et al., 2018). Altogether, in our study the senior players released the ball faster than juniors. In addition, seniors had significantly higher entry angle for every set of shots independently, along with significantly lower release time reported when they were shooting immediately after receiving the ball in spot and after two steps toward the ball. These somewhat surprising findings could also be attributed to differences in training experience between seniors and juniors. Miller and Bartlett (1996) argued that guards, compared to centers, demonstrated less variable shooting mechanics for greater distance as a consequence of experience.

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Spot shot accuracy was similar (46.3% vs 44.7%, juniors vs seniors, respectively), but juniors shot slower and at a lower entry angle. It is reasonable to assume that experienced players were able to master the technique and execute movement patterns more efficiently and faster, especially the preparatory phase of the shot, which represents a 60% of the total shot time (Pojskic et al., 2011). Consequently, these players will receive the ball in a better body position and with an impulse that will finally produce faster jump-shots and reduced release time. The difference found in spot jump-shot is generally in line with the aforementioned explanation. The specific way of stopping after two steps requires players to lower the body before he catches the ball, which affects the time of the shot, but also significantly affects the accuracy of the shot (38.8% vs 58.8%, juniors vs seniors, respectively). It seems beneficial for young players to adopt the correct preparation for receiving the ball so they can continue in the jump-shot immediately after receiving the ball.

During the three-point shot after a dribble, the players were asked to make a longer step forward when dribbling. We can speculate that junior players mastered the jump-shot after dribbling with a high level of proficiency, which enabled them to be as good as seniors in release time. On the other hand, juniors lower body strength deficits could lead to specific jump-shot mechanics, with ball release in ascending phase of jump shot in order to optimize ball propulsion (Brancazio, 1981). This specific way of shooting produces higher entry angles as well as faster release times, but it may affect the accuracy of shooting (42.5% vs 50.6%, junior vs seniors, respectively).

A limitation of this study was the recruitment of a small sample size. Moreover, the study design did not consider other shooting parameter-determinants that could affect the performance (lower and upper body strength, vertical jump etc.), nor other important shooting-kinematics parameters (release height, joint angles etc.). Finally, only unopposed three-point jump shots were considered.

The present results show a significant difference in three-point jump shot shooting kinematics between junior and senior regional level basketball players, with superior entry angles and faster release times for seniors. There was no influence of pre-shooting activity on the release time and entry angle. Finally, seniors were proved to have significantly better shooting accuracy for all shots and jump shots after movement. These findings highlight that both three-point jump shot kinematic parameters differentiate between junior and senior players and provide comparative data for Serbian senior and junior basketball players. It seems that juniors could be advised to adopt shooting technique which enables increased entry angle and shorter release time in order to increase shooting accuracy.

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Disclosure statement

The authors declare that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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ORIGINAL SCIENTIFIC PAPER

Same Training for Everyone? Effects of Playing Positions on Physical Demands During Official Matches in Women's Handball

Carlos García-Sánchez[1], Claude Karcher[2,3,4], Rafael Manuel Navarro[5], Raúl Nieto-Acevedo[1], Enrique Cañadas-García[1], Alfonso de la Rubia[1]

Affiliations: [1]Deporte y Entrenamiento Research Group, Departamento de Deportes, Facultad de Ciencias de la Actividad Física y del Deporte (INEF), Universidad Politécnica de Madrid, C/Martín Fierro 7, 28040 Madrid, Spain, [2]University of Strasbourg, Faculty of Medicine, Mitochondria, Oxidative Stress and Muscular Protection laboratory (EA 3072), Strasbourg, France, [3]University of Strasbourg, Faculty of Sport Sciences, European Centre for Education, Research and Innovation in Exercise Physiology (CEERIPE), Strasbourg, France, [4]CREPS de Strasbourg, Centre de ressources, d'Expertises et de Performances Sportives, Strasbourg, France, [5]Faculty of Sports Sciences, European University of Madrid; 28670 Villaviciosa de Odón, Spain

Correspondence: C. García-Sánchez. Universidad Politécnica de Madrid, Deporte y Entrenamiento Research Group, Facultad de Ciencias de la Actividad Física y del Deporte (INEF), C/Martín Fierro 7, 28040 Madrid, Spain. E-mail: c.gsanchez@upm.es

Abstract

The purpose of this study was to analyze and compare the differences between playing positions on physical demands during official matches in women's handball. Twenty-two semi-professional female players (4 wings, 14 backs and 4 pivots) from the Spanish 2nd Division were monitored across 13 official home matches. Total distance covered (TDC), high-speed running distance (HSR), high-intensity breaking distance (HIBD), accelerations (ACC), decelerations (DEC) and PlayerLoad™ (PL) were collected in absolute and relative values (normalized by playing time) using a local positioning system (WIMU PRO™, Realtrack Systems S.L., Almería, Spain). Playing positions differences were determined by variance analysis one-way ANOVA with partial Eta-squared (ηp^2) or epsilon-squared (ε^2) and Cohen's effect size (ES). Wings covered more TDC (3414.5±1710.1 m), HSR (492.7±280.0 m) and HIBD (171.2±104.7 m) compared to backs and pivots ($p<0.05$; moderate-large effects). Wings also registered more total number of ACC (750.5±362.2) and PL (85.0±7.8 a.u.) compared to backs and pivots ($p<0.05$; moderate-large effects), whereas backs performed more ACC/min (19.9±1.1 $n \cdot min^{-1}$) than wings (18.9±1.4 $n \cdot min^{-1}$) and pivots (18.4±3.9 $n \cdot min^{-1}$) ($p<0.05$; moderate effects). In conclusion, physical demands differ between playing positions during official female competitions and these differences should be considered by practitioners to better prescribe and periodize training load and to design more individualized training programs.

Keywords: *handball; external load; tracking system; load monitoring; accelerometry*

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Introduction

Handball is an intermittent team-sport characterized by repeated high-intensity actions such as accelerations (ACC), decelerations (DEC), changes of direction (COD), sprints, jumps and throws with frequent and intense body contact against the opponents (Karcher and Buchheit, 2014). Consequently, the knowledge of the physical demands during official competitions is essential to maximize physical performance, minimize fatigue, and reduce injury risk (Karcher and Buchheit, 2014; Manchado et al., 2013). Nevertheless, previous research has shown that the physical demands greatly depending on gender, competition level and playing positions (García-Sánchez et al., 2023).

Traditionally, the assessment of physical demands in handball has been carried out mainly via time-motion analysis (TMA) (Manchado et al., 2013; Michalsik et al., 2014). However, the irruption of new tracking technologies with a good level of validity (Bastida-Castillo et al., 2019) and reliability (Luteberget et al., 2018), such as local positioning system (LPS) with ultra-wideband technology (UWB) and inertial measurement units (IMU), which record at 100 Hz, has created new opportunities to accurately investigate the external load in handball, especially to analyze high-intensity actions commencing from low velocity, such as a maximal acceleration from a stop position (Luteberget and Spencer, 2017; Wik et al., 2017).

At present, the investigation of the physical demands has focused predominantly on male handball players. Several studies have analyzed the physical demands in national (Font et al., 2021; Font et al., 2023) and international competitions (Cardinale et al., 2017; Manchado et al., 2020; Manchado et al., 2021), in simulated or friendly matches (Ortega-Becerra et al, 2020), and in training sessions (Corvino et al., 2014). Moreover, a recent systematic review (García-Sánchez et al., 2023) about external load during elite competitions reported that only 11.32% of the players included were female and the remaining 88.68% were male. Some studies developed with TMA showed that a female handball player covers from 2071 to 6943 meters during a match (Manchado et al., 2013; Michalsik et al., 2014; Bělka et al., 2016), specifically wings covered a moderately greater total distance than backs and pivots (Michalsik et al., 2014; Bělka et al., 2016). Recently, Luteberget and Spencer (2017) reported an average of 3.9±1.5 high-intensity events per minute during international matches, however backs showed the highest number followed by pivots and then by wings. Additionally, some studies indicated that PlayerLoad™ was similar for wings, backs and pivots (Luteberget and Spencer, 2017; Kniubaite et al., 2019).

As mentioned above, scientific evidence on physical demands in women's handball is currently limited. Consequently, this lack of knowledge represents a problem for practitioners and researchers because analyses of physical demands in male players may not be valid and accurate for prescribe training and manage workload in female players. Therefore, the aim of the present study was to analyze and compare the differences between playing positions on physical demands during official matches in women's handball.

Methods

Design

An observational study was conducted to analyze and compare the differences between playing positions on physical demands during official matches in women's handball. The reported results correspond to the average values of 13 official home matches from the Spanish 2nd Division during the 2021–2022 season (18th September 2021 – 2nd April 2022). In total, 153 individual LPS registers were collected (wings, n = 39; backs, n = 88; and pivots, n = 26). Players who participated for at least one minute in each game were included in the study (Wik et al., 2017). Goalkeepers were excluded (Ortega-Becerra et al, 2020).

Participants

Twenty-two semi-professional female handball players participated in the study. Playing positions were: wings (n = 4; age: 18.8±0.5 years; height: 162.0±3.8 cm; body mass: 55.5±4.3 kg), backs (n = 14; age: 20.9±3.6 years; height: 168.7±3.9 cm; body mass: 65.4±6.8 kg) and pivots (n = 4; age: 21.0±1.8 years; height: 171.3±4.8 cm; body mass: 79.1±11.0 kg). The weekly schedule consisted of 2 strength training sessions, 4 handball training sessions, and 1 match. All players were informed of the study requirements and provided written informed consent prior to the start of the study. Additionally, all the ethical procedures used in this study were in accordance with the Declaration of Helsinki (Harris & Atkinson, 2015) and were approved by the European University of Madrid Ethics Committee.

External load variables and procedures

A detailed description of each external load variable monitored is provided in Table 1. The LPS (WIMU PRO™, RealTrack System SL, Almería, Spain) was installed on the official handball court where the team played their home matches according to user manual and previous studies (Font et al., 2021; Font et al., 2023). The data was recording in real time and subsequently analysed using the manufacturer's specific software (SPRO™, version 958, RealTrack System SL, Almería, Spain). Raw data were exported in Excel format and imported into the statistical software for statistical analysis. Playing time was recorded only when the players were inside the court. Thereby, a specific software was used to calculate the perimeter of the court to determine the effective playing time. Thus, team time-outs (a maximum of three per team), periods when the game was interrupted (e.g., consultations between the referees or interruption to wipe the court) and the 2-minutes suspension were omitted.

Statistical analysis

Descriptive statistics are presented as means and standard deviations (M ± SD). Statistical significance level was set at $p<0.05$. The Kolmogorov-Smirnov test was performed to confirm data distribution normality and Levene's test for equality of variances. Playing positions differences were determined by variance analysis one-way ANOVA followed by Games–Howell or Tukey post hoc testing (parametric variables), or Kruskal-Wallis followed by the Dwass-Steel-Critchlow-Fligner test (non-parametric variables). Furthermore, two different effect sizes were calculated. For group effects, partial Eta-squared ($\eta p2$) or epsilon-squared (ε^2) was calculated with the following interpretation: small (0.010–0.059), moderate (0.060–0.139), and large effect (>0.14) (Cohen, 1988). For the post-hoc analysis, Cohen's d (ES) was calculated and interpreted using Hopkins' categorization criteria, where 0.2, 0.6, 1.2 and >2 are considered small, moderate, large and very large effects, respectively (Hopkins et al., 2009). Data analysis was performed using SPSS for Windows (Version 26, IBM Corp., Armonk, NY, USA).

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Table 1. Description of external load variables.

Variable	Unit	Description
Total distance covered (TDC)	m	Total distance covered by the player
Total distance covered/min (TDC/min)	m·min^{-1}	Total distance covered per minute by the player
High speed running (HSR)	m	Total distance covered above 18.1 km/h
High speed running/min (HSR/min)	m·min^{-1}	Total distance covered per minute above 18.1 km/h
High intensity break distance (HIBD)	m	Total distance covered with deceleration above 2 m·s^{-2}
High intensity break distance/min (HIBD/min)	m·min^{-1}	Total distance covered per minute with deceleration above 2 m·s^{-2}
Total distance covered by speed zones	m	Total distance covered by the player at different speed zones during the match: zone 1 (0–6.0 km·h^{-1}), zone 2 (6.1–12.0 km·h^{-1}), zone 3 (12.1–18.0 km·h^{-1}), zone 4 (18.1–21.0 km·h^{-1}) and zone 5 (> 21.1 km·h^{-1})
Accelerations	count	Total number of accelerations performed by the player
Accelerations/min	count·min^{-1}	Total number of accelerations per minute performed by the player
Accelerations by intensity zones	count	Total number of accelerations performed by the player at different intensities during the match: zone 1 (0 to 1 m·s^{-2}), zone 2 (1 to 2 m·s^{-2}), zone 3 (2 to 3 m·s^{-2}), zone 4 (3 to 4 m·s^{-2}), zone 5 (4 to 5 m·s^{-2}) and zone 6 (5 to 6 m·s^{-2})
Decelerations	count	Total number of decelerations performed by player
Decelerations/min	count·min–1	Total number of decelerations per minute performed by player
Decelerations by intensity zones	count	Total number of decelerations performed by the player at different intensities during the match: zone 1 (-1 to 0 m·s^{-2}), zone 2 (-2 to -1 m·s^{-2}), zone 3 (-3 to -2 m·s^{-2}), zone 4 (-4 to -3 m·s^{-2}), zone 5 (-5 to -4 m·s^{-2}) and zone 6 (-6 to -5 m·s^{-2})
PlayerLoad (PL)	a.u.	Is a vector magnitude expressed as the square root of the sum of the squared instantaneous rates of change in acceleration in each one of the three planes divided by 100, according to the next formula: $PlayerLoad_{t=n} \sum_{t=0}^{t=n} \sqrt{\frac{(Z_{t=i+1}-Z_{t=i})^2+(X_{t=i+1}-X_{t=i})^2+(Y_{t=i+1}-Y_{t=i})^2}{100}}$
PlayerLoad/min (PL/min)	a.u.·min–1	Is a vector magnitude expressed as the square root of the sum of the squared instantaneous rates of change in acceleration in each one of the three planes divided by 100 per minute

Results

Descriptive values and statistical differences for the external load variables according to playing positions are presented in Table 2. There were differences with moderate to large effect size between playing positions in TDC (p<0.001; ηp2 = 0.200), TDC/min (p=0.002; ε² = 0.08), HSR (p<0.001; ε² = 0.406), HSR/min (p<0.001; ε² = 0.412), HIBD (p<0.001; ηp2 = 0.374) and HIBD/min (p<0.001; ε² = 0.135). Wings covered largely more distance (3414.5±1710.1 m) compared to backs (2301.6±1119.0 m) and pivots (1449.6±1194.6 m)

Table 2. External load variables according to playing positions.

Variables	Backs	Pivots	Wings	Position Group Effect		
				p value	ηp²	ε²
TDC (m)	2301.6±1119.0 pp	1449.6±1194.6	3414.5±1710.1 bbb ppp	<0.001	0.200	-
TDC/min (m·min^{-1})	81.3±13.1	83.9±21.3	85.0±7.8 bb	0.002	-	0.080
HSR (m)	105.8±75.5 p	56.9±41.4	492.7±280.0 bbb ppp	<0.001	-	0.406
HSR/min (m·min^{-1})	4.1±3.1	4.6±5.5	12.0±3.5 bbb ppp	<0.001	-	0.412
HIBD (m)	76.2±44.0 pp	33.0±21.1	171.2±104.7 bbb ppp	<0.001	0.374	-
HIBD/min (m·min^{-1})	2.9±1.5	2.8±2.4	4.2±1.9 bbb pp	<0.001	-	0.135
Accelerations (n)	592.0±309.7 pp	357.6±343.7	750.5±362.2 b ppp	<0.001	0.128	-
Accelerations/min (n·min^{-1})	19.9±1.1 ppp w	18.4±3.9	18.9±1.4	<0.001	-	0.099
Decelerations (n)	456.7±272.6 pp	261.2±254.0	541.1±307.6 ppp	<0.001	0.096	-
Decelerations/min (n·min^{-1})	15.6±3.6 ww	14.3±4.4	13.4±3.4	0.005	-	0.070
PlayerLoad (a.u.)	38.4±19.2 p	25.1±17.7	57.1±30.4 bbb ppp	<0.001	0.186	-
PlayerLoad/min (a.u.·min^{-1})	1.8±0.7	1.9±0.9	1.9±0.8	0.86	-	0.001

Note. Significance level is indicated by the number of symbols: one symbol for p<0.05, two for p<0.01, and three for p<0.001; b significant differences with regard to backs; p significant differences with regard to pivots; w significant differences with regard to wings; TDC = Total distance covered; HSR = High-speed running (distance >18.1 km/h); HIBD = High Intensity Break Distance; a.u. = Arbitrary units.

(p<0.001, ES = 0.85; p<0.001, ES = 1.50, respectively). Furthermore, backs covered moderately more TDC than pivots (p<0.01, ES = 0.65). Wings covered slightly more TDC/min (85.0±7.8 m·min−1) than backs (81.3±13.1 m·min−1) (p<0.01; ES = 0.26). Additionally, wings covered largely more HSR distance (492.7±280.0 m) compared to backs (105.8±75.5 m) and pivots (56.9±41.4 m) (p<0.001, ES = 2.52; p<0.001, ES = 2.84, respectively). Also, backs covered slightly more HSR than pivots (p=0.011, ES = 0.31). Finally, HIBD was significantly different according to playing positions (p<0.001; ηp2 = 0.374). Wings covered largely HIBD (171.2±104.7 m) than backs (76.2±44.0 m) and pivots (33.0±21.1 m) (p<0.001, ES = 1.50; p < 0.001, ES = 2.19, respectively). Also, backs covered moderately more HIBD than pivots (p<0.01, ES = 0.68).

Figure 1 shows the total distance covered at different speeds zones according to playing positions. In zone 1 wings and backs covered largely more distance (1129.3±576.3; 900.3±467.9 m, respectively) than pivots (529.0±484.2 m) (p<0.001, ES = 1.20; p=0.003, ES = 0.74, respectively). Also, in zone 2 wings and backs covered largely more distance (936.8±472.7; 774.7±384.4 m, respectively) than pivots (441.4±342.6 m) (p<0.001, ES = 1.23; p=0.003, ES = 0.82, respectively). Moreover, in zones 3, 4 and 5 wings covered largely more distance (987.4±496.8; 240.0±140.9; 121.0±78.1, respectively) than backs (548.7±290.5; 57.5±43.8; 20.3±21.7, respectively) and pivots (436.4±380.3; 36.3±26.9; 6.5±8.5, respectively) (p<0.001, ES >1.2). Additionally, in zone 5 backs covered largely more distance than pivots (p<0.001).

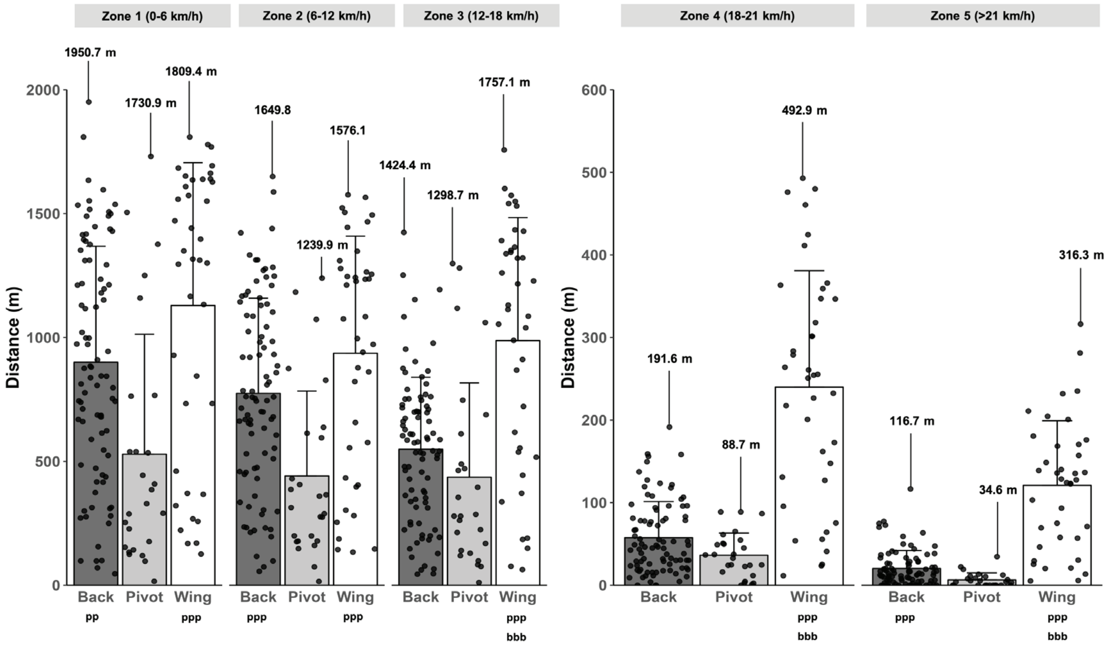

Figure 1. Total distance covered at different speed zones according to playing positions. Significance level is indicated by the number of symbols: one symbol for p < 0.05, two for p < 0.01, and three for p < 0.001; p significant differences compared to pivots; b significant differences compared to backs.

There were differences with moderate effect sizes between playing positions in the number of ACC (p<0.001, ηp2 = 0.128), decelerations (p<0.001, ηp2 = 0.096), ACC/min (p<0.001, ε^2 = 0.099) and DEC/min (p=0.005, ε^2 = 0.070). Wings performed slightly more number of ACC (750.5±362.2) compared to backs (592.0±309.7) and largely more compared pivots (357.6±343.7) (p=0.036, ES = 0.48; p<0.001, ES = 1.19, respectively). Also, backs performed moderately more ACC than pivots (p=0.005, ES = 0.71). Additionally, wings and backs performed moderately more number of DEC (541.1±307.6; 456.7±272.6, respectively) than pivots (261.2±254.0) (p<0.001, ES = 1.00; p=0.006, ES = 0.70, respectively). In contrast, backs performed moderately more ACC/min (19.9±1.1 n·min−1) than wings (18.9±1.4 n·min−1) and pivots (18.4±3.9 n·min−1) (p=0.024, ES = 0.50; p<0.001, ES = 0.82, respectively). In addition, backs performed moderately more DEC/min (15.6±3.6 n·min−1) than wings (13.4±3.4 n·min−1) (p=0.007, ES = 0.58).

Figure 2 present the total number of ACC by intensity zones according to playing positions. In zones 1 and 2, wings (466.3±226.4; 169.3±87.6, respectively) and backs (393.4±219.3; 139.7±73.3, respectively) performed moderately more ACC than pivots (244.3±268.2; 81.6±61.8, respectively) (p<0.05, ES = 0.64-1.16). Also, in zones 3 and 4, wings (74.4±38.0; 24.4±13.3, respectively) and backs (46.3±23.0; 9.6±6.5, respectively) performed moderately to large more ACC than pivots (25.9±17.3; 3.0±2.6, respectively) (p<0.01, ES = 1.04-2.54). Finally, in zones 5 and 6, wings (7.5±6.9; 4.5±5.7, respectively) performed largely more ACC than backs (2.3±3.2; 1.0±1.9, respectively) and pivots (1.1±1.9; 0.5±0.8, respectively) (p<0.001, ES = 1.07-1.48).

Figure 3 present the total number of DEC by intensity zones according to playing positions. In zones 1 and 2, wings (338.1±194.4; 121.9±75.0, respectively) and backs (307.2±196.7; 100.8±60.4, respectively) performed moderately more DEC than pivots (179.8±196.6, 60.3±50.2, respectively) (p<0.05, ES = 0.64-0.97). In zones 3, 4, 5 and 6 wings (48.5±25.8; 18.7±11.5; 7.1±5.8; 2.9±3.2, respective-

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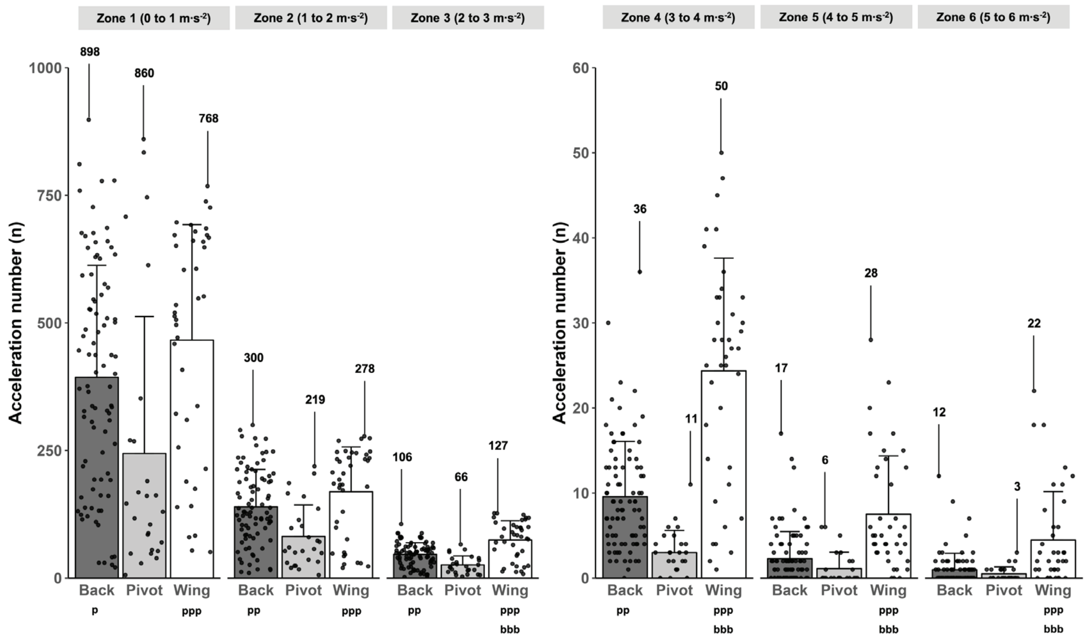

Figure 2. Number of accelerations performed at different intensity zones according to playing positions. Significance level is indicated by the number of symbols: one symbol for $p < 0.05$, two for $p < 0.01$, and three for $p < 0.001$; p significant differences compared to pivots; b significant differences compared to backs.

ly) performed moderately to large more DEC than backs (35.9±18.3; 10.4±6.6; 2.1±2.2; 0.6±1.5, respectively) and pivots (16.0±10.4; 3.1±2.5; 0.6±0.9; 0.3±0.6, respectively) (p<0.01, ES = 0.64-2.00). Additionally, in zones 3, 4 and 5 backs performed moderately more DEC than pivots (p<0.001, ES = 0.45-1.01).

Differences with large effect sizes between playing positions were evident in PL (p<0.001; ηp2 = 0.186). Wings registered moderately more PL (85.0±7.8 a.u.) compared to backs (38.4±19.2 a.u.) and largely more than pivots (25.1±17.7 a.u.) (p<0.001, ES = 0.83; p<0.001, ES = 1.42, respectively). Moreover, backs registered moderately more PL than pivots (p=0.023, ES = 0.59). No significant differences in PL/min between playing positions were found (p=0.86, ε^2 = 0.001).

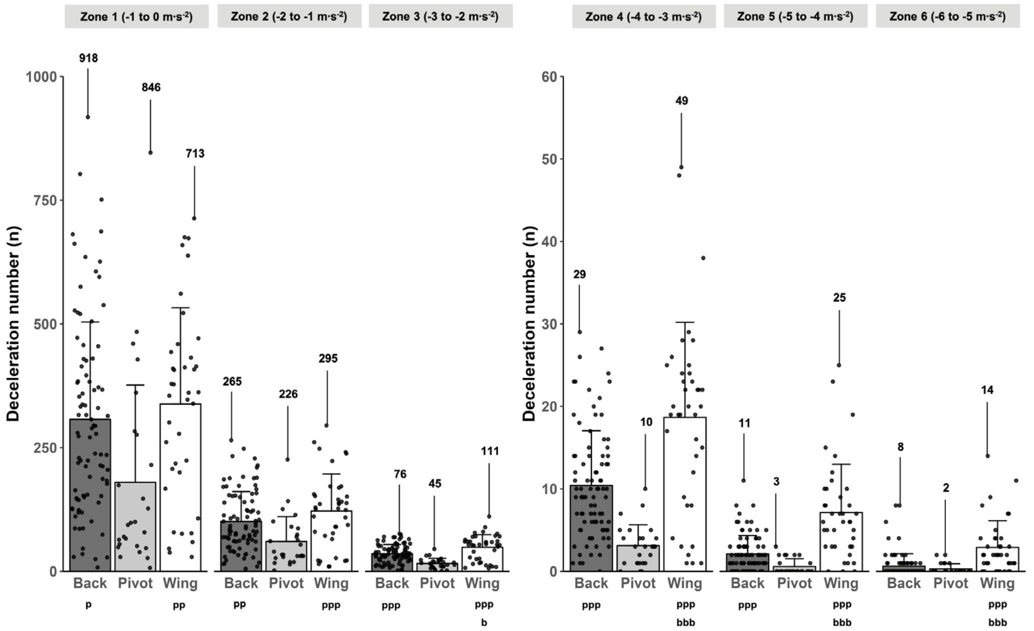

Figure 3. Number of decelerations performed at different intensity zones according to playing positions. Significance level is indicated by the number of symbols: one symbol for $p < 0.05$, two for $p < 0.01$, and three for $p < 0.001$; p significant differences compared to pivots; b significant differences compared to backs.

Discussion

To our knowledge, this is the first study that analyze different external load variables using LPS with IMU technology in semi-professional female handball players during a complete season. Our results confirmed that the external load was significantly different between playing positions, except in PL/minute. Specifically, wings presented the highest external load, while pivots showed the lowest values.

In relation to distance variables, wings covered the highest TDC and TDC/min, while pivots showed the lowest values. Similar results were found in previous studies developed in female players with TMA (Michalsik et al., 2014; Bělka et al., 2016) and in male players with LPS (Font et al., 2021; Font et al., 2023; Cardinale et al, 2017; Manchado et al., 2021). These differences between the pivots and the other playing positions, mainly in total distance covered, could be explained by the unlimited substitutions in handball. Many teams use pivots only in offensive phase for various reasons, such as a lack of defensive ability or load management (Font et al., 2021; Font et al., 2023).

Similarly, previous research has observed that all players covered more distance at low velocities (walking and jogging), either in studies performed with TMA (Manchado et al., 2013; Michalsik et al., 2014) or LPS (Saal et al., 2023; Font et al., 2021; Cardinale et al, 2017; Manchado et al., 2021). Specifically, our results show that during the competition most of the meters were covered at low (6.1–12.0 km·h−1) or very low speed (0–6.0 km·h−1). This fact confirm that handball is an intermittent sport, characterized by periods of long low intensity movements interrupted by short high intensity actions (Karcher and Buchheit, 2014; Manchado et al., 2013). Additionally, wings covered the highest distance in zone 4 and 5, while pivots showed the lowest values. Also, wings covered largely more HSR/minute (12.0±3.5 m·min−1) than the other playing positions. These results are consistent with those of previous studies (Font et al., 2021; Font et al., 2023; Cardinale et al, 2017; Manchado et al., 2020; Manchado et al., 2021) and could be related to the increased participation of wings players in the counter-attack phases (Michalsik et al., 2015). This suggests that wings need different physical training than the other positions, especially emphasizing on-court sprint training (e.g., repeated sprint training or sprint interval training) (Buchheit and Laursen, 2013) and specific strength training to reduce hamstring strain injury (Duhig et al., 2016) and enhance HSR performance (Karcher and Buchheit, 2014; Manchado et al., 2013).

Wings covered largely more HIBD and HIBD/minute than the other playing positions. These differences may be associated with the strong decelerations from a high velocity that they must perform after each counter-attack action. Thus, HIBD are associated with intense eccentric contractions that produce high neuromuscular fatigue and tissue damage, especially if these high braking forces cannot be dissipated and distributed efficiently (Harper et al., 2019; Harper et al., 2022). Also, a reduced deceleration capacity has been identified as a risk factor for non-contact ACL injuries (Boden et al., 2009). Therefore, the technical staff should design optimal training interventions to develop robust musculoskeletal structures that efficiently attenuate high braking eccentric forces and reduce the risk of severe injuries (Harper et al., 2019; Harper et al., 2022; McBurnie et al., 2022).

Regarding accelerometry data, wings performed higher total number of ACC and DEC, followed by backs and pivots. However, when these values were normalized according to the time the players spend on the court (n·min-1), backs performed moderately more ACC and DEC per minute than the other positions. Additionally, wings performed moderately more high-intensity ACC and DEC (>3 m·s−2) than backs and pivots. These results could also be related to the specific technical requirements of each position. Wings perform more counter-attack actions than the other positions, so it seems reasonable to assume that they perform a greater total number of accelerations per game (Michalsik et al., 2015). Backs have a greater deceleration load because they have the main responsibility of building up the positional attack, which is characterized by a constant piston movement. Furthermore, like previous research (Saal et al., 2023), pivots showed the lowest values, because their technical actions are mainly associated with a high isometric force production against the opponent. In contrast, our findings are in opposition with a recent study conducted with elite male players, in which all players present similar values of ACC and DEC (Font et al., 2021). A possible explanation for this difference could reside in the combination of two factors: (1) sample characteristics (male vs. female players) and (2) competition level (elite vs. semi-professional). Therefore, our results indicate that wings and backs should incorporate specific acceleration-deceleration training methods and well-developed muscle strength with two purposes: (1) to ensure these players perform at high-intensity throughout the entire match and (2) to "mechanically protect" players from these damaging consequences of high-intensity decelerations (Harper et al., 2019). Nonetheless, despite the pivots performed lower total number of ACC and DEC compared to backs and wings, they should also be prepared to support these actions during the competition. Thus, they should also incorporate that type of training.

Associated with PlayerLoad variables, wings registered moderately more PL compared to backs and largely more than pivots. Nevertheless, when these values were standardized by playing time (a.u.·min-1) there were no substantial differences according to playing positions. Our results could be explained in part by the higher playing time for wings compared to pivots, due to there is a direct relationship between time on court and external load (in absolute values) accumulated by players. On the other hand, it is difficult to compare our results with other similar studies (Luteberget and Spencer 2017; Wik et al., 2017; Font et al., 2021; Kniubaite et al., 2019), because each trademark uses a different algorithm to calculate this variable (Wik et al., 2017). Only the research conducted by Font et al. (2021), which used the same LPS device as our study, found similar PL/min values for all playing positions. However, their values are slightly lower than ours (≈1.1±0.2 vs. ≈1.9±0.8 a.u.·min-1, respectively). We hypothesised that this difference could be explained by the two factors mentioned above (sample characteristics and competition level). In contrast, Luteberget and Spencer (2017) indicated that backs and pivots showed the highest PL/min values. These results may be due to a different competition level compared to our study. Nonetheless, some caution must be taken when interpreting results of PL, because some researchers indicate that PL calculation methods present many inconsistencies and lack clear and complete information (Wik et al., 2017; Bredt et al., 2020).

Although the current study provides usefulness information for handball coaches and strength and conditioning professionals, some limitations should be mentioned. Firstly, only one female team and only home matches were investigated. Secondly, LPS and IMU may not reflect (tend to underestimate) the real physical demands of pivots, because these players usually perform some high-intensity actions (e.g., blocks and screenings) that not produce a displacement or acceleration. Thirdly, the analysis of specialist players (offensive or defensive) and goalkeepers was not performed. Lastly, differ-

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ent contextual factors could have influenced our results, such as match location, match outcome, score differential, level of the opponent, competition level and player rotation strategy.

In conclusion, the present study indicates that external load experienced by semi-professional female handball players during official competitions are affected by playing positions. Wings registered the highest external load values, followed by backs and by pivots. Additionally, wings are characterized by a high volume of total distance and high-speed running distance (>18 km/h), a higher number of high-intensity ACC and DEC (>3 m·s−2), and a higher PlayerLoad. In contrast, backs are also distinguished by the highest number of ACC and DEC per minute. Therefore, the findings of the present study could provide reference values for technical staff to better prescribe and periodize weekly training load and to design and implement more individualized physical training programs for each playing position (e.g., wings should emphasize repeated sprint training or sprint interval training to enhance HSR performance, backs should develop the capacity of muscles and tendons to attenuate high eccentric forces associated with repeated decelerations and pivots should increase their maximal force to support heavy contacts against the opponents). Furthermore, handball coaches should incorporate different strength training methods (e.g., unilateral and bilateral exercises, single- and multi-joint exercises, eccentric and accentuated eccentric exercises, plyometric exercises, and weightlifting movements and their derivatives) and other training strategies (e.g., single- and double-leg landing stabilisation exercises, pre-planned and unanticipated COD and rapid decelerations from a high velocity) to decelerate efficiently and subsequently reduce injury risk and maximize physical performance. Future studies should investigate the impact of contextual factors on the external load to provide a more comprehensive analysis of the game in female players.

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Conflicts of Interest

The authors declare no conflict of interest.

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REVIEW ARTICLE

Lactate threshold training to improve long-distance running performance: A narrative review

Subbarayalu Arun Vijay[1], Chinnusamy Sivakumar[2], Purushothaman Vinosh Kumar[3], Chittode Krishnasamy Muralidharan[4], Krishnan Vasanthi Rajkumar[3], Karuppaiyan Rajesh Kannan[5], Mani Pradeepa[4], Prabaharan Sivasankar[6], Ameer A Mariam[7,8], Udhaya Kumar Albert Anand[9]

Affiliations: [1]Deanship of Quality and Academic Accreditation, Department of Physical Therapy, Imam Abdulrahman Bin Faisal University, Dammam, Saudi Arabia, [2]PPG college of physiotherapy (Affiliated to the Tamilnadu Dr. MGR Medical University), Coimbatore, India, [3]Faculty of Health & Life Sciences INTI International University, Nilai, Negeri Sembilan, Malaysia, [4]CHETTINAD School of Physiotherapy, Chennai, India, [5]Saveetha College of Physiotherapy, Saveetha Institute of Medical and Technical Sciences, Chennai, India, [6]Deanship of Quality and Academic Accreditation, Imam Abdulrahman Bin Faisal University, Dammam, Saudi Arabia, [7]Department of Physical Therapy and Health Rehabilitation, College of Applied Medical Sciences, Jouf University, Sakaka, Al-Jouf, Saudi Arabia, [8]Department of Biomechanics, Faculty of Physical Therapy, Cairo University, Cairo, Egypt, [9]Mediclinic Al Noor Hospital, Abu Dhabi, United Arab Emirates

Correspondence: Subbarayalu Arun Vijay. E-mail: ausubbarayalu@iau.edu.sa

Abstract

This narrative review revealed the crucial aspects that need to be highlighted when introducing the lactate threshold (LT) training protocol to improve the distance running performance of athletes. The authors searched Google Scholar, Scopus, PubMed and categorized the search results into nine themes. These aspects include the physiology of LT training, the individualization of LT training programs, the effects of the LT training protocol on endurance performance, the practical application of LT training for distance runners, progress monitoring and LT training adaptation, and the role of nutrition and recovery in LT training, the role of artificial intelligence in LT training, possible drawbacks and remedial strategies, and future directions in LT training research. This review suggests improving endurance through improving muscle lactate utilization and highlights the need for individualization of LT training programs, taking physiological variations and psychological factors into account to effectively tailor training. In particular, physiological adaptations such as improved metabolic efficiency and lactate clearance contribute to longer time to exhaustion and longer overall athletic performance. Additionally, the author covers structured training, pacing strategies, and real-world considerations such as terrain and altitude necessary for training long-distance runners. Finally, it is important to monitor progress and adjust LT training protocols based on physiological markers, performance indicators, and environmental factors. Possible disadvantages such as overtraining and injury risks are discussed, as well as strategies to limit damage through regular assessments and biomechanical analysis. This review covers key aspects of LT training and provides insights for athletes and coaches to optimize programs, improve performance, and guide future research.

Keywords: *Anaerobic Threshold, Exercise Training, Distance Running, Artificial Intelligence, Athletes*

@MJSSMontenegro
LACTATE THRESHOLD TRAINING TO IMPROVE DISTANCE RUNNING PERFORMANCE
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Introduction

Distance running is a demanding sport that requires careful training and preparation to achieve peak performance. In particular, long-distance running, including marathons and ultramarathons, pose significant physiological challenges and the ability to effectively manage and utilize lactate is critical (Denadai and Greco, 2022). Lactate threshold (LT) is an important physiological marker of long-distance running performance, and LT training has become a cornerstone of endurance training (Støa et al., 2020). Therefore, the LT protocol has gained considerable attention in the field of endurance training as a potential method to improve distance running performance (Casado et al., 2022). The emphasis is on training at or around lactate threshold, the point at which lactate production exceeds the body's ability to remove it, ultimately leading to improved endurance and faster race times (Stoa et al., 2020). While much remains to be understood about the exact mechanisms behind the LT protocol, numerous studies have demonstrated its effectiveness in improving distance running performance (Casado et al., 2022). During exercise, lactate is constantly produced as a byproduct of glucose metabolism. However, the body has mechanisms to remove lactate from the circulation and use it as an energy source. As exercise intensity increases, lactate production also increases, leading to gradual accumulation in the bloodstream. The LT is the exercise intensity at which lactate production exceeds its clearance capacity, resulting in a significant increase in blood lactate concentration (Goodwin et al., 2007). This phenomenon is closely related to fatigue and loss of performance during prolonged endurance training, which are due to the accumulation of lactic acid (Emhoff and Messonnier., 2023; Yang et al., 2020). In addition, several studies have provided evidence for the concept of lactate threshold, which refers to the exercise intensity at which lactate accumulates faster than it can be cleared from the bloodstream (Goodwin et al., 2007; Ghosh., 2004). These key findings laid the foundation for subsequent research into lactate threshold and its effects on exercise performance and training. (Faude et al., 2009)

Overview of Lactate Threshold Protocol

The LT protocol plays a central role in training and performance optimization for endurance athletes. It represents a crucial physiological marker that describes the transition from aerobic to anaerobic metabolism during exercise (Ghosh., 2004). The LT marks the point at which lactate production exceeds its clearance, contributing to fatigue and a shift toward anaerobic metabolism (Faude et al., 2009). Improved lactate clearance rates during LT training delay the onset of fatigue, especially during longer runs (Nuuttila et al., 2022). Furthermore, LT training leads to adjustments in muscle fiber recruitment patterns, thereby optimizing endurance performance (Bassett & Howley, 2000). In particular, LT training leads to metabolic adaptations, thereby improving the ability to utilize oxygen and sustain high-intensity efforts (Alejandro Lucía et al., 2000). LT is measured using the blood lactate threshold and is one of the most common methods that includes measuring blood lactate levels during incremental exercise tests (Billat, 2001) as well as the use of ventilation parameters such as ventilator equivalent for oxygen (Gouw et al., 2022). By understanding the concept of LT and its influence on distance running performance, athletes and coaches can tailor their training protocols to specifically target and improve this important physiological parameter. Therefore, the authors conduct this narrative review to highlight the critical aspects of LT protocol training and its impact on distance running performance.

Materials and methods

Search Strategy

This study presents a narrative review of the literature on two main objectives: the critical components of the LT protocol and its impact on long distance running performance. Electronic databases such as Google Scholar, PubMed and Scopus. The electronic search was conducted using MeSH (Medical Subject Headings) keywords appropriate to the current topic: "lactate threshold," 'anaerobic threshold," "exercise training," "distance running," "artificial intelligence," "athlete" to broaden and narrow the search.

Data extraction

The authors applied a series of inclusion and exclusion criteria to identify eligible articles and extract relevant data. Original articles, review articles and conceptual papers published

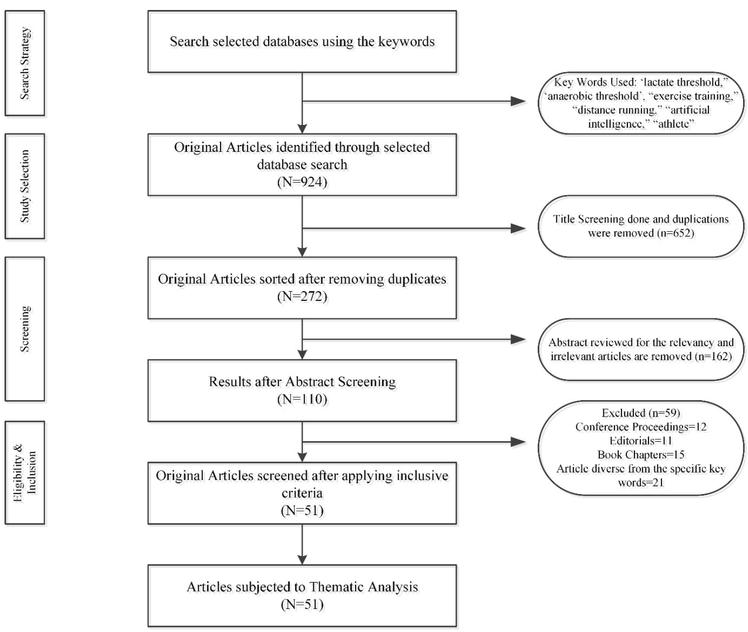

Figure 1. Flowchart showing the article retrieving process

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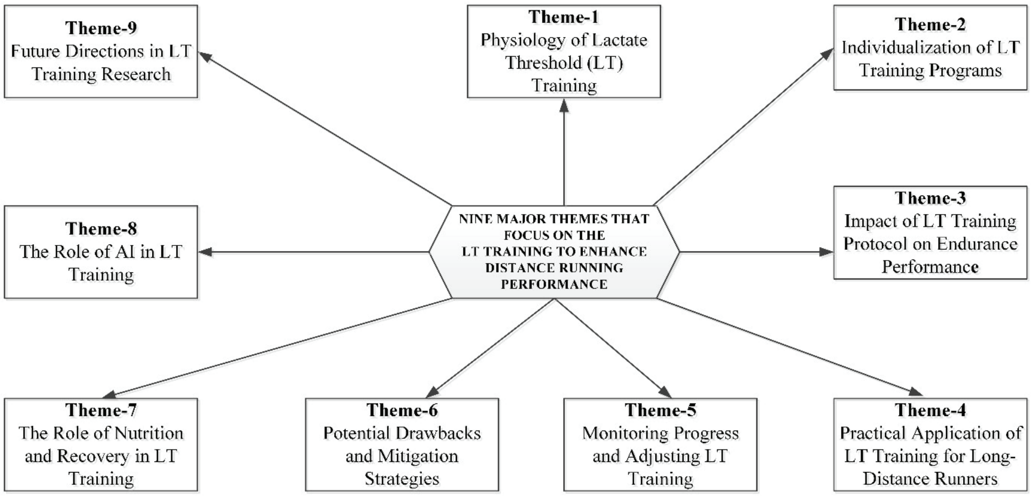

Figure-2: Themes that focus on the LT Training to enhance distance running Performance

between 2007 and July 2023 and written or available in English were included in the thematic analysis. In contrast, abstracts, conference proceedings, editorials, book chapters, and articles that deviated from the specific keywords were excluded. The authors also excluded works that were not available in English and were published before or after the specified time period. After applying these criteria, 924 publications were then retrieved. As a part of the title screening, 272 publications were sorted after removing duplicates. In addition, the abstracts of these selected publications were reviewed for relevance and 162 irrelevant publications were removed, leaving 110 publications. Among them, 59 publications (including abstracts, conference proceedings, editorials, book chapters, and articles deviating from the specific keywords) were excluded. Finally, 51 publications were selected and included in the thematic analysis phase (Figure 1). Specifically, the publications were reviewed in two steps. In the first phase, the authors reviewed the title and abstract of each article and determined whether they were relevant or not. In the second step, only the relevant papers were assessed for their suitability. The authors adopted an inductive approach to organize findings into themes. Accordingly, the principal investigator extracted key texts and potential new lines of inquiry in the form of codes and combined them into nine themes based on the homogeneous information. The principal investigator discussed the emerging themes (n = 9) with other team members with a broader methodological and open disclosure perspective. The research team discussed all articles on each theme to ensure accuracy and eliminate researcher bias. In finalizing the nine themes, the team consciously sought to draw insights from the literature without allowing each member's professional background, experiences and prior assumptions to influence the outcome. The principal author independently reviewed all disputes and consensus was reached. Based on the extracted data following the screening process, nine themes emerged describing the critical aspects of the LT protocol and its impact on distance running performance (Figure 2).

Results

Table 1. Study Characteristics showing key findings mapped under nine themes of LT training.

S.No.	Author	Key Findings	Themes covered
1	Messonnier et al. (2013) ED	Lactate threshold (LT) means the level at which removal of endogenous lactate is restricted, though endurance training augments the volumes for lactate production and removal and clearance for higher absolute and relative workload.	Theme 1
2	Ferraz et al. (2022) OA	Aerobic fitness can be empirically measured in Beagle dogs through velocity corresponding to the visual LT (VLTv) and bi-segmented linear regression model LT (VLTBI).	
3	Goodwin et al. (2007) RA	Elevated blood lactate concentration may be a normal physiological response, though it may be a sign of hypoxemia or ischemia. Clinicians should understand blood lactate concentration responses and their transport, delivery, and analysis.	
4	Theofilidis et al. (2018) RA	Blood lactate dimensions evaluate the input of the anaerobic metabolism to energy expenditure. They also aid in understanding a sportsperson's resistance to fatigue during high-intensity workouts.	
5	Farrell et al. (2021) OA	Training intensity distribution was calculated by evaluating the duration spent in three intensity zones: low, moderate, and high intensity.	
6	MacInnis and Gibala (2017) RA	Interval training is an influential stimulus to provoke progress in mitochondrial content and VO2max.	
7	Hughes et al. (2018) RA	Nutrition and exercise are vital for the adaptations observed in the muscle phenotype with training.	
8	Nuuttila et al. (2022) OA	Individualized endurance training may cause more progress in running performance and upsurge the chance of increased response while reducing the incidence of poor responses to endurance training.	Themes 2, 3, 5, and 6
9	Lievens et al. (2020) OA	An athlete's muscle typology is a crucial performance influential factor in several sports. In humans, muscle fatigue is reliant on the composition of muscle fiber types.	Theme 2

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Table 1. Study Characteristics showing key findings mapped under nine themes of LT training.

S.No.	Author	Key Findings	Themes covered
10	Foster et al. (2017) [RA]	There was more interest in the internal training load, permitting improved titration of training loads in sportspersons of divergent ability given chances of assessment of heart rate, lactate, VO2, and power output.	Themes 2, 3, 4, 5, and 6
11	Hamlin et al. (2019) [OA]	Young elite athletes experiencing University education along with their competition and training loads were susceptible to more stress at specific times of the year, such as examinations and the pre-season and exam period.	Theme 2
12	Casado et al. (2023) [RA]	Lactate-guided threshold interval training enhances the calcium and adenosine monophosphate-activated protein kinase signalling pathways, thereby augmenting mitochondrial proliferation.	Themes 2, 3, 4, 5, 6, and 9
13	Furrer et al. (2023) [RA]	Implementing the training approaches to elite athletes depends on a "trial-and-error" basis, with the athlete and coach's knowledge and practices providing the bedrock for "post hoc" scientific research and investigation.	Themes 3 and 8
14	Stone et al. (2022) [RA]	Specificity has two main facets, i.e., strength-endurance continuum and adherence to principles of dynamic correspondence. Following the dynamic correspondence's values and norms can permit a more significant transfer from training to performance assessments.	Themes 3, 4, 5 and 6
15	Carrier et al. (2023) [OA]	The Garmin Fenix 6® provides precise measurements of VO2 max and LT in athletes and aids in reaching training verdicts.	Themes 3, 4 and 5
16	Mumux Mirani (2022) [RA]	Marathon runners involve training sessions that should be grounded on runners' physiologic dimensions and focused on the improvement of those dimensions.	Theme 4
17	Bossi et al. (2017) [OA]	Fast runners initiate lower relative intensities and show an additional uniform pacing strategy compared to slow runners.	
18	Moisey et al. (2022) [RA]	Intensive care unit survivors described suboptimal nutritional consumption with numerous factors impacting nutritional retrieval.	Theme 7
19	Impey et al. (2018) [CO]	A paradigm named "fuel for the work required' is presented. It is an illustration of a combination of train-low models whereby the obtainability of reduced carbohydrates meets the stresses of future training sessions.	
20	Phillips and Van Loon (2011) [RA]	High protein intake relies on caloric debt, which may be beneficial in stopping the loss of lean mass during energy-constrained times to increase fat loss.	
21	Sawka et al. (2007) [RA]	During exercise, electrolytes and carbohydrate-rich beverages intake can give paybacks greater than water alone at specific conditions. The main focus is to replace any fluid electrolyte deficit following exercise.	
22	Fullagar et al. (2015) [RA]	Deprived sleep quality and quantity could lead to an imbalance of the autonomic nervous system and provoke signs of overtraining syndrome. After sleep loss, rises in pro-inflammatory cytokines could encourage immune system dysfunction.	
23	Ortiz et al. (2018) [SR]	Active recovery sessions can improve physiological recovery through reduced muscular blood lactate levels, enhancing the athlete's performance.	
24	Macdonald et al. (2013) [OA]	Application of an acute session of self-myofascial release for the quadriceps muscle significantly improved the range of motion of the knee joint, deprived of a related discrepancy in muscle performance.	
25	Pickering and Kiely (2019) [RA]	Athletes have to be treated differently despite the potential difficulty of a personalized training process.	Themes 8 and 9
26	Chidambaram et al. (2022) [RA]	Artificial intelligence (AI) methods to process data from sensors can sense patterns in positional and kinematic information and physiological parameters. Thus, AI techniques can indicate how athletes can boost their performance. However, AI adoption in Sports medicine faces numerous challenges, though AI has promising sports-related tools.	Theme 8
27	Dijkhuis et al. (2018) [OA]	Machine learning (ML) is a feasible method to systematize personalized daily physical activity prediction. Coaching can offer accurate and timely data on the participants' physical activity due to the application of ML to the participant's behavior as often and accurately assessed via wearable sensors.	
28	Rahlf et al. (2022) [PLCT]	Runners could respond to augmented risk during routine training using wireless inertial measurement units and ML systems. Thus, they can be dynamically involved in reducing injury during running.	
29	Seshadri et al. (2019) [RA]	Wearable sensors assess posture, movement, injury, and biomechanical forces regarding safety and physical performance. They also evaluate pulse rate, sleep quality, and muscle oxygen saturation.	
30	Hammes et al. (2022) [RA]	Six challenges were recognized concerning applying AI in elite sports. Those include linking AI and elite sports, interpretable AI outcomes, data collection, robust predictive models, closing the "sense-model-plan-act" loop, and having control in the practitioners' hands.	
31	Bodemer (2023) [RA]	Implementing AI in sports training effectively improves training competence, enhances performance results, and supports injury prevention and rehabilitation. AI algorithms, namely computer vision and ML, are used to process data, offer real-time feedback, aid in making judgments, and develop personalized training plans.	

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Table 1. Study Characteristics showing key findings mapped under nine themes of LT training.

S.No.	Author	Key Findings	Themes covered
32	Bouchard et al. (2011) OA	Genomic forecasters of the Vo2max response over regular exercise give fresh targets for reviewing the nature of fitness and its variation to proper exercise.	Theme 9
33	Amann (2011) RA	During exercise under "normal" environments, the regulatory mechanism is effective; however, it might turn into a subsidiary in favor of extreme environmental effects like heat and severe hypoxia.	
34	Van Hoovels et al. (2021) P	Sweat wearable lactate sensors are used for the evaluation of sports physiology. Real-time sweat lactate assessments and other biomarkers permit training periods to be carefully supervised and modified.	
35	Andria Shimi et al. (2022) OA	The improvement in the goalkeeping task performance is equally observed under progressive and fixed-intensity circumstances.	
36	Guest et al. (2019) RA	Personalized nutrition targets to create additional active and inclusive nutritional and supplement recommendations. These recommendations are grounded on fluctuating, interrelating variables in an athlete's sports condition.	
37	Ahmetov and Rogozkin (2009) RA	36 genetic markers are related to athlete status, and 39 might describe a within-group variation of physical performance in retort to strength/endurance training.	
38	McGee and Walder (2018) RA	The critical control spot for gene expression responses is epigenetic regulation of gene expression in retort to ecological provocations.	
39	Urtats Etxegarai et al. (2021) OA	A ML grounded system correlated highly with the empirically observed athletes' LT. This system is an alternative approach to the conventional invasive LT assessments for recreational runners.	
40	Mukhopadhyay (2022) RA	Individualized sports-specific periodization is the foremost concern for demonstrating the best performance in contemporary sports.	Theme 6
41	Lorenz et al. (2010) RA	Periodization regarding strength training is effective in strength and conditioning among untrained and trained athletes with normal health status.	
42	Lorenz and Morrison (2015) CC	Periodization explains the partition of the training process into specific phases. The alteration of the parameters within phases, namely, load, repetitions, sets) are required to produce particular adaptations anticipated during a specific time.	
43	Yang (2019) RA	Cross-training substitutes the kind of exercises involved that decrease fatigue and avoid overuse syndrome.	
44	van der Worp et al. (2015) RA	History of injuries and usage of inserts/orthotics are causative factors for running injuries.	
45	Armstrong et al. (2022) RA	Management of overtraining syndrome persists indefinable as its typical difficulty, definitely individualized phenotype, and inherent determinant connections of several influencing aspects such as severe exercise drill, energy obtainability, and the athlete's genome.	Theme 6
46	Atakan et al. (2021) RA	Several physiological adaptations provoked by high-intensity interval training programs enhance exercise dimensions and metabolic well-being in normal and clinical individuals.	
47	Casado et al. (2022) SR	Highly trained and elite distance runners indicate the benefit of linear periodization models in which "training intensity distribution" and volume exist the same during the preliminary and pre-event duration.	
48	Kreher and Schwartz (2012) RA	Overtraining syndrome results from extreme exercise deprived of enough rest. This condition leads to perturbations of immunologic, neurologic, and endocrinologic systems, along with mood swings.	
49	Doherty et al. (2021) OA	Athletes should own a customized and multidimensional recovery strategy linking hydration, nutrition, sleep, and other mental and physiological features.	
50	Zhang et al. (2023) SR	Exercise programs with specific characteristics are more beneficial in improving mental health than interventions with various types, frequencies, and durations.	
51	Park and Jeon (2023) RA	Psychological skill training comprises positive psychology, mindfulness, and emotions to enhance the quality of life among athletes.	Theme 6

Note: ED-Experimental Design, OA-Original Article, RA-Review Article, CO-Current Opinion, SR-Systematic Review, PLCT-Prospective Longitudinal Cohort Trial, P-Perspective, CC-Clinical Commentary.

Discussion of Major Themes Focusing on the Lactate Threshold (LT) Training to Enhance Long Distance Running Performance

Theme 1: The Physiology of Lactate Threshold (LT) Training:

LT is defined as the exercise intensity at which there is an exponential increase in blood lactate concentration (Messonnier et al., 2013). This increase in blood lactate has traditionally been associated with the onset of fatigue during prolonged exercise, leading to a decline in performance (Ferraz et al., 2022; Goodwin et al., 2007). However, recent research suggests that LT training may increase the capacity of muscles to produce and use lactate as an alternative energy source, thereby delaying the onset of fatigue and improving endurance performance (Theofilidis et al., 2018). LT training involves training for an extended period of time, typically between 30 minutes and 2 hours, at an intensity slightly above the lactate threshold (Farrell et al., 2021). By training at this intensity, athletes can produce physiological adaptations such as increased lactate clearance, improved mitochondrial function and increased oxidative capacity (MacInnis and Gibala., 2017). These adaptations ultimately lead to improved endurance performance by allowing athletes to sustain higher intensities for longer periods of time without experiencing excessive fatigue (Hughes et al., 2018). Therefore, understanding the physiology of LT training is critical for athletes and coaches who want to optimize their training programs and increase their performance.

Theme 2: Individualization of LT Training Programs

Although LT training is widely recognized as a powerful tool for increasing endurance performance in athletes, a one-size-fits-all approach to such training may not realize the full potential of every athlete and must be tailored to the individual athlete with due consideration of the physiological, psychological and performance-related benefits of personalized approaches. (i) Physiological variability: A recent study highlights the significant variation in the metabolic profiles of athletes, which impacts how they respond to LT training (Nuuttila et al., 2022). Athletes with different metabolic characteristics in particular can benefit from different training strategies. The typology of an athlete is underpinned by the composition of muscle fiber types. Fast-twitch fibers are predominantly found in elite sprinters, while slow-twitch fibers are relatively common in elite endurance athletes. Muscle fatigue in humans depends on the composition of the muscle fiber type. Therefore, an athlete's muscle typology is a crucial influencing factor on performance in several sports activities (Lievens et al., 2020). Therefore, training tailored to these differences can optimize performance. (ii) Psychological considerations include: Personalized training programs tailored to an athlete's preferences and motivations improve adherence and long-term success (Foster et al., 2017). A clear understanding of an athlete's psychological profile can serve as the basis for training recommendations. In addition, LT training should be tailored to an athlete's psychological stress, such as competitive anxiety or self-doubt, and can improve mental resilience and performance (Hamlin et al., 2019). Finally, tailored LT training programs can better mimic the demands of an athlete's target race distance, thereby optimizing race day performance (Casado et al., 2023).

Theme 3: Impact of LT Training Protocol on Endurance Performance

Lactate threshold training has profound and diverse effects on the endurance performance of long-distance runners. Several studies have been conducted to determine the influence of LT training protocols on endurance performance in distance runners, considering its physiological, performance and practical dimensions. Physiological adaptations include metabolic efficiency, whereby LT training induces metabolic adaptations, optimizes the body's oxygen utilization and increases energy production from aerobic pathways (Furrer et al., 2023). Secondly, lactate clearance, where athletes undergoing LT training have an improved lactate clearance rate, delaying the onset of fatigue during prolonged efforts (Nuuttila et al., 2022). A recent study has shown that LT training also impacts performance outcomes by increasing time to exhaustion at submaximal intensities and allowing athletes to endure higher workloads (Foster et al., 2017), thereby improving athletic performance is improved across different disciplines and distances (Casado). et al., 2023). From a practical perspective, tailoring LT training programs to individual lactate thresholds and performance goals increases training effectiveness (Stone et al., 2022), and real-time monitoring of lactate levels and performance metrics using wearable technology and apps provides valuable insights for optimizing LT training (Carrier et al., 2023).

Theme 4: Practical Application of LT Training for Long-Distance Runners

Studies have examined the practical applications of LT training for distance runners, with particular emphasis on training methods, pacing strategies, and practice considerations. Training methods focus on two specific elements viz. First, the implementation of structured training such as tempo runs and threshold intervals, which are essential for addressing and improving lactate threshold (Casado et al., 2022). Second, the emphasis on progressive overload, which consists of gradually increasing the intensity and volume of LT training, allows for sustained adaptations without overtraining (Foster et al., 2017). Likewise, pacing strategies focus on two key aspects viz. (i) Race pace, where training at or slightly above race pace during LT sessions helps runners acclimate to the intensity, they will face on race day (Mumux Mirani., 2022; Bossi et al., 2017); (ii) Practicing negative splitting in LT training runs teaches runners to finish races strong by maintaining a consistent pace and then accelerating (Casado et al., 2023). Finally, practical applications of LT training should be applied considering the real-world scenario with special consideration of terrain and altitude, whereby adapting LT training to different terrain and altitude mimics race conditions and prepares runners for different challenges (Carrier et al., 2023). Likewise, proper fueling and hydration strategies are an essential part of successful LT training and race day performance (Stone et al., 2022).

Theme 5: Monitoring Progress and Adjusting LT Training

Effective LT training requires continuous monitoring of progress and the ability to adjust training protocols as needed, taking into account physiological markers, performance indicators, and real-world considerations. Physiological markers include regular lactate threshold testing such as lactate profiling, which allows athletes to determine their individual thresholds and track changes over time (Nuuttila et al., 2022), and heart rate variability (HRV) monitoring provides insights into an athlete's readiness to train and can indicate overtraining or undertraining (Foster et al., 2017). Performance indicator monitoring is all about tracking race performance results and comparing them to training progress. This helps athletes assess the effectiveness of their LT training (Casado et al., 2023) and estimate time to exhaustion to determine how long an athlete can sustain efforts close to LT during training sessions. This is a valuable indicator of progress (Foster et al., 2017). Finally, the influence of environmental factors such as temperature and altitude on LT training progress must be monitored and training adjusted if necessary (Carrier et al 2023). Additionally, regular nutritional assessments and adjustments must be made to support training adaptations (Stone et al., 2022).

Theme 6: Potential Drawbacks and Mitigation Strategies

There are several drawbacks of LT training on long-distance running performance. First, long-distance runners who engage in lactate threshold training are at risk of overtraining, which occurs when they push their bodies to the edge of their lactate threshold. This type of training can be physically and mentally demanding and can increase the risk of injury. Overtraining

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is characterized by excessive training volume or intensity, resulting in reduced performance, mood disturbances, and physiological imbalances (Foster et al., 2017). Early warning signs of overtraining, including persistent fatigue, sleep disturbances, and mood swings, are critical for prevention (Foster et al., 2017). To mitigate overtraining, one of the strategies is periodization, which involves the systematic planning and organization of training to allow for proper recovery and adaptation (Mukhopadhyay., 2022; Lorenz et al., 2010). By dividing the training program into specific phases, such as base, build, and peak phases, athletes can strategically increase the intensity and volume of their training and at the same time incorporate rest and recovery periods (Lorenz and Morrison, 2015). Additionally, cross-training with different types of exercise limits fatigue and prevents overuse syndrome (Yang, 2019).

Second, overtraining and repetitive nature of LT training can lead to muscle imbalances and an increased risk of overuse injuries in runners (Nuuttila et al., 2022). The constant strain on muscles, joints and connective tissue can lead to overuse injuries such as stress fractures, tendonitis and muscle strains (van der Worp et al., 2015). By conducting biomechanical examinations, those problems that contribute to the risk of injury can be identified (Stone et al., 2022). Additionally, overtraining can lead to decreased immune function, hormonal imbalances, and fatigue, further increasing the risk of injury. (Kreher & Schwartz., 2012). To mitigate these risks, it is important for runners to incorporate rest and recovery days into their training plans, eat a balanced and nutritious diet, stay hydrated, and get enough sleep. These factors play a crucial role in preventing overtraining and injury (Doherty et al, 2021). Third, long-distance runners who engage in lactate threshold training may experience a performance plateau where further improvement is limited or impossible. Several factors can contribute to performance plateaus, including overtraining, inadequate recovery, or genetic limitations (Armstrong et al., 2022). Therefore, it is recommended to carefully manage training load, monitor recovery strategies, and use periodization techniques to challenge the body and continually stimulate further adaptation (Lorenz and Morrison, 2015). Additionally, adding variety to training methods, such as high-intensity interval training or strength and conditioning exercises, also help overcome performance plateaus by targeting different physiological systems and promoting overall fitness improvements (Atakan et al, 2021). Furthermore, it is also emphasized that focusing exclusively on lactate threshold training may neglect the development of the aerobic base, which is crucial for long-distance running (Casado et al., 2023). Studies have therefore recommended incorporating balanced aerobic training, such as long, slow distance running, to build a solid foundation and periodizing the training plan to include different phases of intensity and volume (Casado et al, 2022). Finally, depressed mood, central fatigue and burnout are considered major disadvantages of LT training, which arise from constant training at or near the lactate threshold (Kreher & Schwartz, 2012). To overcome this, athletes use a variety of workouts in the training schedule, including intervals, tempo runs, and easy recovery days, which help break up the monotony and keep the workout routine interesting (Zhang et al., 2023). Additionally, incorporating other strategies such as visualization and mindfulness, as well as positive self-talk, helps athletes improve their concentration, reduce stress, and maintain a positive mindset (Park & Jeon, 2023).

Theme 7: The Role of Nutrition and Recovery in LT Training

Multiple lines of evidence supporting the synergy between LT training, nutrition and recovery highlight the role of nutrition and recovery strategies in maximizing the benefits of LT training for runners (Moisey et al., 2022). Nutritional strategies to maximize the benefits of LT training for runners include carbohydrate periodization, protein intake, and hydration. Carbohydrates are the primary energy source for endurance activities and the implementation of carbohydrate periodization, as described by Impey et al. (2018), in which carbohydrate intake is strategically manipulated to optimize training adaptations. Consuming carbohydrates before and during LT training can improve endurance performance. Likewise, protein is essential for muscle repair and adaptation, and adequate protein intake, as suggested by Phillips and Van Loon (2011), supports recovery and muscle protein synthesis after LT training sessions and allows for faster adaptations. Finally, it is important to drink enough fluids before, during and after training. This is crucial for maintaining performance and preventing heat-related problems during exercise (Sawka et al., 2007).

Recovery practices used to maximize the benefits of LT training for runners include getting a good quality sleep, incorporating active recovery sessions, and regularly practicing stretching and foam rolling exercises. Good sleep is paramount for recovery and adaptation. Sleep duration and quality significantly impact performance, as Fullagar et al. emphasized. (2015). Athletes should prioritize sleep to optimize the benefits of LT training. Incorporating active recovery sessions promotes blood flow and helps eliminate metabolic by-products, potentially reducing muscle soreness and fatigue (Ortiz et al., 2018). Regularly practicing stretching and foam rolling exercises as recommended by Macdonald et al. (2013), can improve flexibility and relieve muscle tension, facilitating recovery between LT training sessions.

Theme 8: Role of Artificial Intelligence in LT training

AI systems are capable of analyzing a variety of data, such as physiological parameters, recovery trends, and past performance data of athletes during LT training (Chidambaram et al., 2022). This allows AI technology to analyze historical performance data and predict an athlete's future performance. Based on this, AI can help athletes set reasonable goals and develop training plans to achieve those goals by understanding the relationship between an athlete's lactate threshold and their racing performance (Pickering and Kiely, 2019).

It is noteworthy that machine learning (ML) models create personalized training plans based on a person's strengths, weaknesses, and goals (Dijkhuis et al., 2018). Such ML models can adjust training based on progress, helping long-distance athletes who struggle with fixed schedules (Furrer et al., 2023). This personalized approach is critical for remote athletes who may not have access to coaches for frequent assessments. By understanding an athlete's lactate threshold and its relationship to race performance, AI can help athletes set realistic goals and create training plans to achieve those goals. Additionally, ML algorithms can analyze biomechanical data to identify injury risk patterns. Athletes can receive training/form modification and risk reduction recommendations to improve their running careers (Rahlf et al., 2022).

Another innovative addition is wearable devices and sensors that can continuously monitor an athlete's physiological data, including heart rate, pace, and lactate levels (Seshadri et al., 2019).

Using AI algorithms, this real-time data can be processed to provide the athlete with immediate feedback. This feedback helps the athlete to spontaneously adjust their training intensity and duration, resulting in more effective training (Hammes et al., 2022). Thus, AI and ML can revolutionize lactate threshold training for distance athletes by providing personalized, data-driven approaches to performance optimization. (Bodemer, 2023).

Theme 9: Future Directions in LT Training Research.

Future directions in LT training research with a focus on innovative methodologies, new technologies, personalized approaches, and integration of genetic insights that will pave the way for the future of athletic performance. Innovative methods include multi-omics analysis, which integrates genomics, proteomics and metabolomics and could provide a comprehensive understanding of individualized LT responses (Bouchard et al., 2011). Furthermore, future research could focus on neurobiological insights to examine the role of the central nervous system in LT adaptation, which could open opportunities for targeted training interventions (Amann., 2011). Research into new technologies includes the invention of advanced wearable sensors that can monitor lactate levels in real time during exercise sessions and could revolutionize LT training (Van Hoovels et al., 2021). Additionally, virtual reality (VR) enhanced LT training environments can provide new opportunities to stimulate and challenge athletes (Andria Shimi et al., 2022). Future research could focus on integrating nutritional genomics to create tailored nutritional plans that support LT adjustments (Guest et al., 2019).

Future research could focus on integrating nutritional genomics to create tailored nutritional plans that support LT adaptations (Guest et al., 2019). Research could also focus on integrating genetic insights such as genetic profiling, which identifies genetic markers associated with LT training responses to support personalized training strategies (Ahmetov and Rogozkin., 2009). Furthermore, epigenetic research is needed to examine epigenetic modifications that influence LT adaptations and responses to training (McGee & Walder, 2018).

Additionally, research could focus on comparing the results of personalized, AI-generated training plans with traditional, non-personalized approaches and identifying factors that influence the effectiveness of AI-driven training plans, such as age, gender, and training history (Casado et al., 2023; Urtats Etxegarai et al., 2021). Finally, there is a need to explore how additional biometric data such as genetic information, sleep patterns, and nutritional data can be integrated into AI algorithms to improve the accuracy and individualization of lactate threshold training programs (Pickering & Kiely, 2019).

Limitations

It is crucial to acknowledge the limitations of using the narrative synthesis approach in this study. Efforts to conduct a comprehensive search of electronic databases such as PubMed and Google Scholar may still miss relevant studies due to variations in indexing, availability of full-text articles, or inclusion criteria used. Subjectivity in identifying and categorizing themes in literature reviews can lead to bias. Efforts were made to minimize bias by involving multiple reviewers, but individual interpretations may have influenced the results. Finally, limiting the study to English-language articles may have led to the exclusion of relevant non-English language publications, which would have reduced the scope and generalizability of the results.

Conclusions

The narrative review reveals the critical aspects of LT protocol training and its impact on distance running performance. When describing the effects of the LT protocol on distance running performance, nine themes emerged in this review. These include the physiology of lactate threshold training (LT), the individualization of LT training programs, the effects of the LT training protocol on endurance performance, the practical application of LT training for distance runners, progression and adaptation to LT training, and potential disadvantages and mitigation strategies, the role of nutrition and recovery in LT training, the role of Artificial Intelligence in LT training and future directions in LT training research.

It is concluded that the Lactate Threshold (LT) protocol plays a central role in the training and performance optimization of endurance athletes. Furthermore, it is emphasized that LT training should be tailored to the individual athlete with due consideration of the physiological, psychological and performance benefits of personalized approaches. When providing LT training, special emphasis should be placed on the training methods, pacing strategies and real-world considerations to train athletes on different terrains and altitudes that mimic racing conditions and prepare runners for different challenges. Likewise, LT training requires continuous monitoring of progress using physiological markers such as regular lactate threshold testing and heart rate variability, as well as monitoring and tracking race performance results and comparing them to study training progress. Further, regular nutritional assessments and adjustments must be made to support training adaptations. This study also pointed out the two main disadvantages of LT training, namely overtraining syndrome (OTS) and the repetitive nature of LT training, which can lead to muscle imbalances. Furthermore, it is emphasized that appropriate nutritional strategies must be employed to maximize the benefits of LT training for runners, including carbohydrate periodization, protein intake, and adequate hydration before, during, and after exercise. This study also suggested that recovery exercises can be used to maximize the benefits of LT training for runners, such as good sleep quality, incorporating active recovery sessions, and regularly practicing stretching and foam rolling exercises. Additionally, the authors emphasized that AI systems analyze physiological and performance data to create personalized LT training plans for distance athletes. Wearable devices and sensors monitor the data and AI algorithms process it to provide instant feedback, leading to effective training and personalized performance optimization. Finally, the authors have outlined some future directions for LT training research, focusing on innovative methodologies, new technologies including virtual reality (VR)-assisted LT training environments, personalized approaches, and integration of genetic insights, paving the way for LT training research.

Conflict of interest

The authors declare that there is no conflict of interest

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REVIEW PAPER

Using Gamification in Teaching Physical Education: A survey review

Ricardo Ferraz [1,5], Diogo Ribeiro[1], Ana R. Alves[1,5], José E. Teixeira[3,4,5], Pedro Forte[3,4,5,7], Luís Branquinho[5,6,7]

Affiliations: [1]Department of Sport Sciences, University of Beira Interior, 6201-001 Covilhã, Portugal, [2]Department of Sports, Higher Institute of Educational Sciences of the Douro, 4560-708 Penafiel, Portugal, [3]Department of Sports Sciences, Instituto Politécnico de Bragança, 5300-253 Bragança, Portugal, [4]Polytechnic Institute of Guarda, Guarda, Portugal, [5]Research Center in Sports Sciences, Health Sciences and Human Development, 5001-801 Covilhã, Portugal, [6]Agrarian School of Elvas, Polytechnic Institute of Portalegre, 7350-092 Elvas, Portugal, [7]CI-ISCE, Higher Institute of Educational Sciences of the Douro, 4560-708 Penafiel, Portugal

Correspondence: ricardompferraz@gmail.com; ricardo.ferraz@ubi.pt

Abstract

Nowadays, the determining role that Physical Education (PE) assumes for cognitive, psychomotor and affective development is widely accepted. Even so, several investigations continue to report the difficulty in motivating children to be involved and participate in PE classes through traditional teaching methods. Thus, to combat this scourge, gamification has been suggested as a useful tool to increase students' motivation to practice PE. Based on these considerations, the main objective of this survey review was to critically analyze the potential impact of using gamification in PE classes. The Preferred Reporting Items for Systematic reviews and Meta-Analyses literature search extension (PRISMA-S) guidelines were advised for this survey review. After searching procedures, 68 articles remained for analysis. Traditional teaching models can be applied by using the direct instruction model, and teaching dominated approaches. By contrast, nowadays physical education and sports education have been based on game-based models. From this, gamification strategies seem to be valid and efficient as a contribute to the previous ones, applying game elements, mechanics, and principles to non-game contexts to enhance engagement and intrinsic motivation. Thus, gamification models extend to as fundamental element the theory of self-determination expressed by theory of gamified learning, dynamical model for gamification of learning, goal-access-feedback-challenge-collaboration, gamification, and virtual gamification. This investigation allows us to conclude that the inclusion of gamification in PE classes seems to translate into an increase in motivation in children and youth. For this reason the introduction of technology in classes seems to be a key factor to increase sports participation, regular physical activity and improve motor learning and control.

Keywords: *Sport, Children, Health, Motivation, Learning*

@MJSSMontenegro
GAMIFICATION IN PHYSICAL EDUCATION
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Introduction

Physical Education (PE) plays a key role in cognitive skills, psychomotor and affective development (Ferraz et al., 2023; Silva et al., 2022), while encouraging healthy lifestyles and encourages peer socialization during childhood and adolescence (Sortwell et al., 2022). Also, the PE has a strong focus for developing metacognition, emotional skills and psychosocial enjoyment in the teaching and learning process (Quennerstedt, 2019; Wang et al., 2022). Emphasizing these assumptions, other investigations have shown the benefits of PE for the development of the student's metacognition, motor proficiency in motor performance skills, and emotional physical benefits lifelong physical activity (PA) (Costa et al., 2015; Sortwell et al., 2022; Spanaki et al., 2016). Also, children and youth who have greater motor skills (i.e., such as muscle strength and power), are better prepared to develop motor performance skills that enhance the learning of different sports (Branquinho et al., 2022; Ferraz et al., 2020). It is at early ages that the sensitive phases of development occur (Ozturk Ertem et al., 2019), and the inclusion of PE in the curriculum allows a harmonious multilateral and interdisciplinary development, enabling the development of motor and basic skills (Rus et al., 2019). In this sense, the structured development of children and youth through PE environments is an emerging topic in contemporary society and one that continues to need to be investigated (Branquinho et al., 2022).

In particular, gamification strategies have been gaining prominence in different education environments, given the combination of cutting-edge mobile technology, virtual reality and social networks (Jayanthi et al., 2022). Concretely, gamification can be defined by the integration of game elements and mechanics into PE lessons, aiming to create a more dynamic and interactive learning environment (Arufe-Giráldez et al., 2022). The gamification strategies should be applied in integration with existing teaching models into different educational domains in childhood and adolescence (Santos et al., 2023). These domains are fundamental for the healthy development of children and can be seen as predictors of regular participation in PA and motor development (Bailey et al., 2009; Batista et al., 2019). For these reasons, it is essential that teachers and researchers develop innovative and playful methodologies to motivate students and promote a taste for PA, motor skills and psychosocial engagement (Dichev et al., 2015; Landers, 2015). So far, some approaches have been carried out in this direction (Aktop & Karahan, 2012; Metzler, 2017; Syrmpas et al., 2017), but more research still needed on new practices and methodologies that can be used in the context of PE to promote participation for the structured development of children and youth (Pate et al., 2006; Sallis & McKenzie, 1991; Tappe & Burgeson, 2004). Even so, the literature reports that traditional teaching models continue to prevail in classrooms (Area-Moreira et al., 2016; Harvey et al., 2020). However, the normative charging of PA for all students' children and young has been critically discussed in sport pedagogy (Sortwell et al., 2022; Syrmpas et al., 2017). In this sense, gamification strategies seems to emerge, according to independent factors, such as age, sex and applications contexts (e.g., PE and/or sports games) (Fulton, 2019; Kulkarni et al., 2022; Pozo et al., 2018; Quintas et al., 2020).

Teaching models are characterized as global plans aimed at transmitting a central idea for teaching through a standardized theoretical structure that simplifies the teacher's decision-making of teacher (Metzler, 2017; Pozo et al., 2018). Particularly, gamification strategies in teaching PE involve the use of game elements and game design techniques to enhance the learning experience and engage students in educational activities (Dichev et al., 2015). While gamification is a powerful and engaging teaching strategy, it is often integrated into existing teaching models to enhance the learning experience (Arufe-Giráldez et al., 2022). Gamification strategies allows for the setting of specific objectives in PE classrooms, providing a clear pathway for achievement problem-solving, decision-making, and strategic thinking, which are cognitive skills important in sports practice (Fulton, 2019; Quintas et al., 2020). These strategies leverage the motivational aspects of games to promote active participation, increase student motivation, and foster a deeper understanding of the subject matter. More important, gamification strategies have demonstrated short-term benefits (motivation and engagement in PE classes) and the long-term benefits (lifelong maintenance of PA, exercise and sports concepts) for children and youth (Kulkarni et al., 2022). It is important to note that gamification strategies should be thoughtfully designed, aligning with the learning goals and objectives of the educational context (Fulton, 2019; Kulkarni et al., 2022). When implemented effectively, gamification can enhance student motivation, promote active learning, and create an enjoyable and immersive educational experience (Kulkarni et al., 2022).

Due to the decreasing motivation of students to participate in the discipline of PE, there is an urgent need for pedagogical innovation and formative change in the teaching of PE. In this sense, the gamification of the teaching process has been suggested as an effective and innovative approach for this purpose (Quintas et al., 2020). The potential impact of gamification on the PE teaching process continues to arouse debate and attention in the scientific community (Fernandez-Rio et al., 2020; Pérez-Muñoz et al., 2022). Therefore, it is important to clarify how we can develop PE teaching environments based on gamification strategies. For these reasons, the objective of this survey review was to critically reflect on how gamification can influence the development and involvement of students in the PE discipline.

Materials and Methods

Search Strategy

The Preferred Reporting Items for Systematic reviews and Meta-Analyses literature search extension (PRISMA-S) guidelines were advised for double-check review (Rethlefsen et al., 2021). To carry out this narrative review, the available literature was consulted through searches carried out in the Web of Science, Google Scholar and PubMed databases. Articles published between 2000 to present were considered for analysis. The search strategy was based on the combination of two primary keywords ("gamification" and "physical education"), using a Boolean operator: "gamification" AND "physical education" The inclusion criteria for the articles were: (1) relevant data on gamification in the PE teaching process; (2) experimental studies in students who used gamification as a learning methodology; (3) original papers or books that are fully text accessible in English and published in peer-reviewed Sports Science journals; (4) high-caliber research that complies with CONSORT standards . Studies were excluded if: (1) they did not include data relevant to this study according to the inclusion criteria or studies that address gamification in contexts other than education, specifically

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teaching PE.; (2) others research fields and non-human participants; (3) articles with poor quality in the description of study sample and screening procedures according to CONSORT stands; (4) low level of evidence studies such as reviews, abstracts and papers for conferences, surveys, articles of opinion, commentary, books, magazines, editorials or case studies. The articles were selected based on the evaluation of the title and abstract. All articles or books that did not focus on the investigation were excluded. In total, 105 articles were considered relevant for this review. After this procedure, 68 articles remained for analysis (Figure 1).

Quality Assessment and information handling

Current survey review was based the methodological quality by the CONSORT stands for the Consolidated Standards of Reporting Trial (Cuschieri, 2019). All articles were read in detail and evaluated for relevance and quality by two senior researchers with experience and relevant publications in the field. All articles that did not meet the criteria were excluded. Two independent authors (R.F. and L.B.) conducted the literature search strategy between January and June 2023. A third reviewer (J.ET.) was named in to mediate arguments between the authors about the study's selection.

A survey and narrative interpretation was subsequently carried out to scrutinize the theoretical considerations and future perspectives about gamification in teaching PE. The summary of previous research was compiled in: (a) teaching models in PE; (b) game-based models in PE; (c) gamification in PE; (d) classification of gamification strategies; (e) gamification strategies for teaching PE; (f) the role of gamification in socio-affective and motor development during PE; (g) interdependent factors contributes for gamification strategies. The information were further analyzed using a narrative review methodology (Silva et al., 2022) to expose the explanation of subject matter and theoretical basis, as well as the practical application and suggestions for further research.

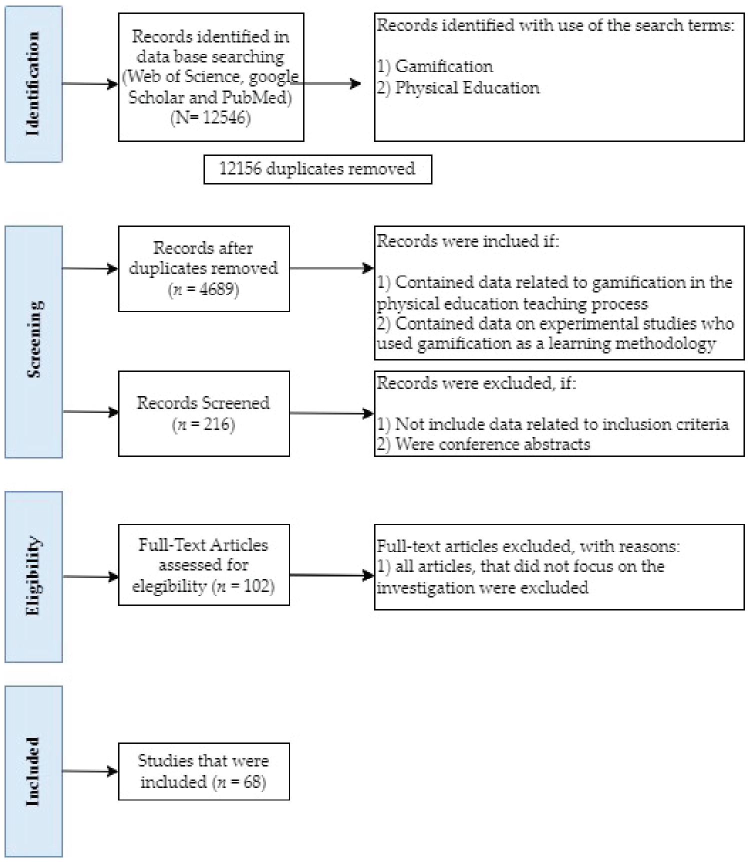

Figure 1. PRISMA Flowchart with included studies

Results

Teaching Models in Physical Education

The teaching of PE is a continuous process, which intrinsically results from new theories alluding to the teaching-learning process, following recent theories that highlight the reorganization of the process of motor development and performance in the school context (Ferraz et al., 2023). In this regard, several teaching models have been promoting innovative processes in the way students learn. Traditionally, the Direct Instruction Model, which directs the teaching-learning process in the teacher, has been the most used in the school context (Dyson et al., 2004). This approach gives the student a passive role, essentially connoted by the reproduction of knowledge transmitted by the teacher. Even so, this teaching model has proved to be unappealing because it ignores the need to solve problems related to the low motivation that students show in the modalities addressed in PE (Siedentop et al., 2011). This model assumes the teacher as a central core in majority of the decision-making regarding the teaching-learning process, particularly in prescribing the pattern of student involvement in learning tasks. In this domain, the teacher delimits the rules and procedures for student management to obtain maximum effectiveness in the teaching-learning activities developed by them (Mesquita et al., 2009). Teacher-centred learning and direct and whole group instruction are also described as lecture-based teaching (i.e. especially teaching of rules, guidelines and key points) (Boling & Robinson, 1999; Esslinger et al., 2016), lecture-based teaching (Dyson & Casey, 2016; Esslinger et al., 2016), skill drills and repetition (i.e., analytic prespective) (Faulkner & Finlay, 2002), and other teaching dominated approaches such as expository teaching, teacher-dominated discussions, whole-class teaching and behaviorist approach (Fernandez-Rio et al., 2020; Rethlefsen et al., 2021). Other relevant model that has been used in PE teaching is the Sport Education Model, which seeks to broaden students' experiences and challenges traditional pedagogical approaches (Siedentop et al., 2011). This model aimed to develop competence, literacy, and enthusiastic sportspersons, being commonly considered as a student-led approach (Hastie & Wallhead, 2016; Wallhead & O'sullivan, 2005). The Sport Education Model is a comprehensive and student-centered approach to PE that aims to enhance the learning experience and overall engagement in sports. It was developed by Daryl Siedentop in the 1980s and has been widely implemented in PE programs around the world (Siedentop et al., 2011). The model seeks to replicate the characteristics of actual sports teams and competitions to provide students with a more authentic and enjoyable sports experience (Hastie & Wallhead, 2016; Wallhead & O'Sullivan, 2005). A learner-based approaches revolutionize PE teaching, with game-based models gaining increasing application and interest in PE, with particular evidence for the teaching games for understanding model (TGfU) (Webb et al., 2006). Overall these models can be classified as learner-centered or student-centered teaching approaches so it is essential to particularise the main premises, objectives and scopes of game-based models in PE.

Game-Based Models in Physical Education

Game-based learning involves using actual games or modified versions of games to teach specific skills, concepts, or knowledge (Mesquita et al., 2012; Rink, 2001). In PE classrooms, this approach may also involve using sports games, mini-games, or game-like activities to teach fundamental movement skills, sports tactics, or fitness concepts (Arufe-Giráldez et al., 2022; Rink, 2001). The TGfU model could be considered as a model reference in the teaching of PE. This model highlights the importance of understanding and reflection in the game, on the part of the student, focusing in this way on their awareness and decision-making tactics according to the context in which they are inserted or through the practice of modified game versions (e.g., simplified games, conditioned games) appropriated to the students' proficiency needs (Webb et al., 2006). Based on TGfU, a second-generation related models reported in the literature such as Game Sense (Thorpe, 1996); Tactical Games Model (Mitchell et al., 2020); Tactical Decision Learning Model (Gréhaigne et al., 2005); Invasion Competency Games Model (Tallir et al., 2003), Games Concept Approach (Rossi et al., 2007); Play with Purpose (Pill, 2007); Ball School (Kröger et al., 1999), Game Insight (Pill, 2007); Inventing Games Model (Butler, 2015). The Non-linear Pedagogy model is also referred which was developed and built on an ecological dynamics approach (Nathan et al., 2017). On the basis of this pedagogical framework is exploratory learning, with an emphasis on encouraging individualized movement solutions for individuals (Chow & Atencio, 2014). In fact, TGfU and derived models use teaching tactics principles and rules, that is, technical skills are built from the context of the game and its understanding (Mesquita et al., 2009; Metzler, 2017). Also, a progression of tasks of increasing complexity is used, without obeying a rigid hierarchy, nor passing through all levels, but with the manipulation of tasks dictated by the particularities of learning (Farias et al., 2018; Mesquita & Graça, 2011). The concept of learning to play follows, in a simpler than formal context, with active instruction from the teacher is also a relevant purpose (Farias et al., 2018; Mesquita et al., 2012).

It is fundamental to mention that no model that is suitable for all learning involvements and therefore a fundamental issues must be taken into account by the teacher to use the teaching models that best suit the needs of students (Rink, 2001). In this context, the constrains-led approach (Chow et al., 2021) has been an effectively applied approach in PE contexts and sports games to enhance student engagement, skill development, and overall enjoyment of sports and physical activities (Ferraz et al., 2023; Silva et al., 2022). For example, small-sided games involving a modify traditional sports games to be played with fewer players and in smaller playing areas (Teixeira et al., 2022), are commonly used in various settings, including schools, recreational programs, and sports clubs. This strategy promotes active participation, teamwork, and the application of skills in a game-like settings (Santos et al., 2023; Santos et al., 2016). It also allows for more opportunities for students to be actively involved compared to traditional large-scale games (Ferraz et al., 2023; Silva et al., 2022).

Different approaches continue to exist for teaching PE, but due to the need to fill gaps and increase the motivation of PE classes, new approaches continue to be required. Following this line of reasoning, in the search for new didactic approaches, gamification emerges that has gained strength in recent years in the educational field (Arufe-Giráldez et al., 2022). This methodology is currently expanding and involves different mechanisms of games in the classroom. The game is considered as the central motivating element in the classroom, while this methodology is considered active, as the student is active in the learning process, making the teaching and learning process more enjoyable, meaningful and effective (González et al., 2020). Faced with this reality, the discipline of PE has been one of the scenarios where multiple experiments were developed to consolidate gamified learning environments (Arufe-Giráldez et al., 2022). For these reasons, it is important to know in more detail the pedagogical proposals and didactic experiences of gamification that have been used in the PE classroom (Ferraz et al., 2023; Silva et al., 2022).

Gamification in Physical Education

Gamification involves applying game elements, mechanics, and principles to non-game contexts to enhance engagement and motivation (Teixeira et al., 2022). In PE, gamification may include the use of points, badges, leaderboards, rewards, challenges, and levels to motivate students and create a more game-like atmosphere (Ferraz et al., 2023; Silva et al., 2022). Indeed, the engament and motivation is considered a fundamental element for the practice of PA, and the theory of self-determination (Ryan & Deci, 2017) is one of the most used structures to understand this phenomenon. In fact, new generations have been considered particularly difficult to motivate when traditional teaching methods are applied (Fernandez-Rio et al., 2020). Although there is a continuous effort through teachers and education professionals to apply new and innovative teaching methodologies, many students

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consider traditional schooling boring and ineffective (Putz et al., 2020). Thus, gamification strategies should be applied into a student-centered teaching model to promote active learning, collaboration, and problem-solving within the constructivist framework. A teaching model provides a framework for structuring lessons, planning curriculum, and facilitating learning. It outlines the overall philosophy, goals, and methods of instruction was typically encompasses by the teaching models (Ferraz et al., 2023; Silva et al., 2022). Gamification has been defined as a pedagogical strategy and/or methodology. Although should not be considered a teaching PE model in itself (Arufe-Giráldez et al., 2022), could be a important methodological tool for its implementation.

The intrinsic technological nature of modern times is inducing continuous changes in the daily actions and behaviors of the population in general and particularly of young people (Maldonado Berea et al., 2019). Curiously in the field of education, technology is reaching a prominent role (Area-Moreira et al., 2016). This fact has led to the emergence of new pathways of teaching and learning content based on innovative perspectives, in which students assume a remarkable role (Li et al., 2019). In this sense, educational agents identified the challenging need to refine teaching methodologies that are efficient in sharing knowledge and that ensure student involvement and motivation (Putz et al., 2020). In this regard, students assume that they prefer engaging and interactive learning activities (Kiili, 2005), which makes playful learning emerge as a potential solution, as it promotes new skills and stimulates increased knowledge (Pereira et al., 2019; Putz et al., 2020). In this sense, a new pedagogical approach called gamification is becoming increasingly popular in educational contexts (Koivisto & Hamari, 2019; Ouariachi et al., 2020; Putz et al., 2020) and particularly in encouraging PA practice in young populations (Fernandez-Rio et al., 2020; Ferriz-Valero et al., 2020; González et al., 2020; González-González et al., 2018; Kostenius et al., 2018; Quintas et al., 2020; Segura-Robles et al., 2020). Gamification has been defined as the use of game design elements in any non-game system context to increase users' intrinsic and extrinsic motivation, helping them to process information, or even help them to better achieve goals and/or help them change their behavior (Hamari et al., 2014; Treiblmaier et al., 2018). Gamification was inserted in education when design elements and game experience were considered in the formulation of learning processes (Dichev & Dicheva, 2017; Dicheva et al., 2015). Previous investigations have shown that gamification can promote intrinsic motivation (Goh et al., 2017; Hamari & Keronen, 2017), convert learning more engaging and attractive (Çakıroğlu et al., 2017; Gatti et al., 2019), and increase student knowledge retention (Arufe-Giráldez et al., 2022; Majuri et al., 2018). Furthermore, another investigation found that students were more involved in gamified environments compared to non-gamified environments (Tsay et al., 2018). Specifically in the case of PE, gamification seems to present itself as an undoubtedly powerful tool for the promotion of healthy lifestyle habits and underlining motivations for the practice of sports in children and adolescents. In fact, gamification strategies contribute to sustained interest and long-term engagement in physical education. Students are more likely to retain knowledge and skills acquired through gamified activities due to the enjoyable and memorable nature of the learning experience (Çakıroğlu et al., 2017; Gatti et al., 2019).

Classification of Gamification strategies

Applying gamification in education has been made from the lowest to the highest educational levels based, leading to various gamification-based models and frameworks: (1) theory of gamified learning or gamification (Landers, 2015); (2) dynamical model for gamification of learning (DMGL) (Kim & Lee, 2015); (3) goal-access-feedback-challenge-collaboration (GAFCC) gamification (Huang & Hew, 2018); (4) model for introduction of gamification into e-learning. Indeed (Urh et al., 2015), gamification (Landers, 2015), gamified learning (Kim & Lee, 2015), intelligent gamification (FIG) (Fulton, 2019) and/or gamefullness (Deterding et al., 2011) has been the terminology applied in recent years in to describe gamification learning. These approaches have been applied to enhance the educational contexts of e-learning, applied sciences (Vries et al., 2006) and working environments. Landers et al. (Landers et al., 2017; Landers, 2014) defends that the game element can strongly influence the learner's attitude and behaviour within an existing instructional content and method, thus effectively altering the learning outcome. Quality and results of instructional design (a moderating process) and/or by directly affecting learning (a mediating process) (Landers, 2014). Kim & Lee (2015) explored the primary self-determination factors (i.e., curiosity, challenge, fantasy and control) for DMGL model underpinned by ARCS model (i.e., attention, relevance, confidence, and satisfaction), MDA framework (i.e., mechanics, dynamics and aesthetics), game design features (GDF) (i.e., game play and balance) and key characteristics of a learning game (KCLG) (i.e., control, contingency, choice, and power contribute. Huang & Hew (2018) developed a theory-driven gamification model for higher education based on motivation needs (i.e., goal, access, feedback, challenge and collaboration), design five-stage gamification procedure: 1st stage (examination): to investigate the precise learning objectives, learner context, and technological affordances of a given online platform, such as a learning management system; 2nd stage (decision-making): to identify the motivational components such as (i.e., goal, access, feedback, challenges, collaboration) that need to be strengthened or added; 3rd stage (match): pick which gamification tactics to use by matching motivational features with game design components and learning activities; 4–5th stages (design implementation and evaluation): implement the design in actual classes and evaluate the design. Consider the implementation outcome once the design has been implemented and look at whether the design need improvement (Huang & Hew, 2018; Kim & Lee, 2015). Deterding et al. (2011) reported a human-computer interaction for serious games, pervasive games, alternate reality games, or playful design.

Game-based environments were developed to emphasized gamification in a broad spectrum where it can be found in: (1) complete and serious games: health games, new games, heavy games, educational games, simulation and training games; (2) game design (gamification itself): game elements, technology, practices (serious games); (3) persuasive and extensible games: live action role-playing (LARP) games, alternate reality games, augmented reality games, location-based games; (4) playful interaction, design and toys. Virtual realities and augmented feedback should be also considered for gamification strategies in education contexts (Silva et al., 2022). Game based learning has also gained interest for PA, exercise and sport, with PE being a major contributor (Erenli, 2013). Another research inferred the effects of an innovative experience, which included a gamification proposal during classes at a sports university (Pérez-López et al., 2017). The results showed that gamification enhanced the development of a good learning climate, and that students and teachers expressed that they felt better with learning experiences through gamified practice. In addition, another study (Hernando et al., 2015) carried out in secondary education, used gamification as a motivating and fun tool to encourage healthy lifestyle habits and specifically to apply adjusted heart rates in different resistance exercises. The results indicated that both students and teachers praised the use of gamification as a motivational strategy to enhance learning. Recently, another investigation (Fernandez-Rio et al., 2020) also reported significant increases in students' intrinsic motivation after experiencing the implementation of gamification. Yet, Ferriz-Valero et al. (2020), showed that the implementation of gamified strategies was beneficial for academic performance, however the results related to motivation did not showed significant changes. In an increasingly globalized, competitive and computerized era, it is imperative that teaching spaces have new technological innovations to obtain advantages and enhance new skills among students and teachers in the teaching, learning and inclusion process (Borg et al., 2011). If students need a differentiated (i.e., gamified) education, teachers need to be able to adequately respond to this need (Erenli, 2013). However, teachers have shown concern about the workload of the new pedagogical approach (Fernandez-Rio et al., 2020). Figure 2 presented the several theoretical approaches, models and frameworks applied in the traditional teaching and gamification approach in teaching PE.

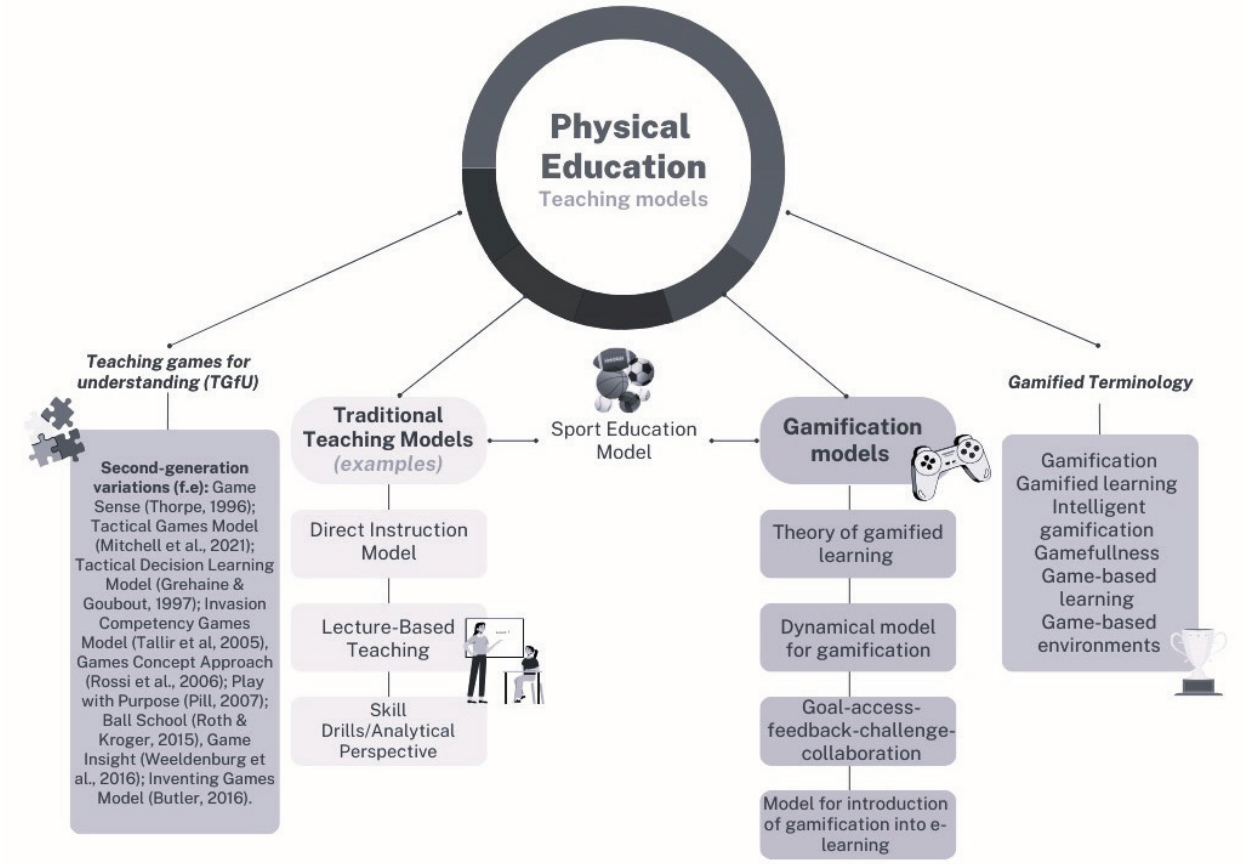

Figure 2. Teaching Physical Education using traditional, game-based and gamification models

Gamification strategies for teaching Physical Education

Literature compiles some common gamification strategies used in PE: (1) classification points, badges, and leaderboards – implementing a system of points, badges, and leaderboards can provide a sense of achievement and healthy competition among students. Points can be awarded for completing tasks or achieving specific learning objectives, while badges recognize milestones or specific accomplishments. Leaderboards display the progress and rankings of students, fostering a sense of achievement and motivation (Plass et al., 2020); (2) quests and missions – structuring educational activities as quests or missions can create a narrative framework that immerses students in a game-like experience. Students may be given a series of challenges or tasks to complete, earning rewards or unlocking new content as they progress. This approach can enhance engagement and provide a clear sense of purpose and progression (Kapp, 2013; Krath et al., 2021); (3) virtual rewards and unlockable content – offering virtual rewards, such as virtual goods or in-game items, can incentivize students to actively participate in learning activities. For example, completing a quiz could unlock additional educational resources, access to exclusive content, or virtual currency that can be used within the learning environment (Orji et al., 2018); (4) progression and leveling up – adopting a leveling system where students can advance through different levels or stages based on their progress can provide a sense of achievement and mastery. As level advance, they may unlock new challenges, content, or privileges, motivating them to continue learning and progressing (Kapp, 2012; Ortega-Sánchez, 2022); (5) collaborative and competitive elements – incorporating collaborative and competitive elements into educational activities can promote teamwork and engagement (Huang & Hew, 2018). Students can

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work together in teams to solve problems or compete against each other in educational games or challenges. This encourages interaction, cooperation, and healthy competition among students; immediate feedback and performance tracking: providing immediate feedback on students' performance can simulate the instant feedback often found in games (Fulton, 2019). This feedback can help students gauge their progress, identify areas for improvement, and adjust their learning strategies accordingly. Performance tracking, such as progress bars or visual representations of achievement, can further motivate students to strive for continuous improvement (Andrade et al., 2016); (6) narrative and storytelling – utilizing storytelling techniques can engage students and create a compelling learning experience. Presenting educational content within a narrative framework or using characters and plotlines can make the learning material more relatable and memorable (Chitra, 2021; Cruz-Campos et al., 2022; Garone & Nesteriuk, 2019).

Also, gamification teaching strategies in PE involve the integration of game elements and game design principles to enhance student engagement, motivation, and skill development (Plass et al., 2020). These strategies leverage the motivational aspects of games to create a more immersive and enjoyable learning experience (Fulton, 2019; Landers et al., 2017). Here are some main gamification teaching strategies in PE. Game-based learning introduce game-based activities where physical movements and skill development are embedded within a game context (Garone & Nesteriuk, 2019; Landers, 2015). This can include modified versions of traditional games, fitness challenges, or cooperative games that require students to apply physical skills while achieving specific objective (Kim & Lee, 2015). Applying digital platforms and mobile apps, or interactive fitness technology to gamify PE (Orji et al., 2018; Silva et al., 2022; Wang et al., 2022). These platforms can offer virtual simulations, interactive challenges, or leaderboards that track students' progress and provide immediate feedback with avatars, rewards, and levels to enhance motivation and engagement (Ortega-Sánchez, 2022). Fitness quests and challenges: design fitness quests or challenges that students can complete individually or in teams. These quests can involve setting personal fitness goals, tracking progress, and unlocking awards or achievements as they reach specific milestones. Incorporate elements like points, badges, or levels to create a sense of achievement and progression (Kapp, 2013; Kim & Lee, 2015). Effective implementation involves aligning gamification strategies with educational objectives to expand pedagogical implications, considering individual differences, and creating an inclusive and enjoyable learning environment (Orji et al., 2018; Silva et al., 2022; Wang et al., 2022).

Gamification allows for the explicit definition of objectives and goals within the game-based model, by using goals provide students with a sense of direction and purpose, and progress tracking allows them to see their advancements, fostering motivation (Wang et al., 2022). Setting specific, achievable goals within the gamified model gives students a clear sense of direction (Prakash & Manchanda, 2021). Goal-oriented learning helps students stay focused, and achieving these goals becomes a source of motivation and satisfaction (Huang & Hew, 2018). Gamification encourages continuous learning by providing an idea of continuous improvement motivates students to explore new concepts and skills, contributing to sustained engagement with an extensive practical application of technology (Cruz-Campos et al., 2022; Huang & Hew, 2018). Other rising field in gamification strategies are the augmented reality (AR) and virtual reality (VR). The teachers can introduce AR or VR technologies to create immersive PE experiences (Silva et al., 2022). Students can engage in virtual simulations that require physical movements, practice skills in virtual environments, or participate in interactive games that blend PA with digital elements (Orji et al., 2018; Silva et al., 2022; Wang et al., 2022). In the same vein the interactive feedback and progress tracking using wearable fitness trackers or sensors that provide real-time feedback on students' performance during physical activities (Teixeira et al., 2021, 2022). These devices can track metrics like heart rate, steps, or movement accuracy, providing immediate feedback and allowing students to monitor their progress over time. Team challenges and tournaments promote teamwork, cooperation, and healthy competition. These can include modified versions of popular sports or game activities where students compete against each other (Andrade et al., 2016; Orji et al., 2018).

Finally, implement leaderboards or point systems to track team rankings and recognize achievements. It is crucial apply personalized learning paths to students' individual abilities, goals, and interests (Kapp, 2012, 2013). Allow students to choose activities or challenges that align with their preferences and skill levels. Offer a variety of options and create opportunities for students to explore different areas of interest within PE (Hakulinen, 2015). The strategies for personalized learning paths can be narrative/storytelling, reflection/goal setting, and group collaboration and /or social interaction. Each of these points has particular characteristics (Hakulinen, 2015; Plass et al., 2020). Create a narrative framework or storyline that connects physical activities and skill development. Incorporate characters, quests, or plotlines to make the learning experience more engaging and immersive. Students can progress through the narrative by completing challenges, unlocking new content, or advancing to higher levels (Landers, 2015). Encourage students to reflect on their PE experiences, set personal goals, and track their progress. Provide opportunities for self-assessment, goal setting, and reflection on achievements. This promotes self-awareness, autonomy, and a sense of ownership over their learning (Cruz-Campos et al., 2022; Huang & Hew, 2018). Collaboration and social interaction among students through gamified activities. Incorporate cooperative games, group challenges, or team-based activities that require students to work together to achieve common goals. Encourage communication, teamwork, and peer support (Prakash & Manchanda, 2021; Urh et al., 2015). By implementing gamification teaching strategies in PE, educators can enhance student engagement, motivation, and skill development. These strategies provide a fun and interactive approach to learning, promoting a lifelong love for PA and overall well-being (Orji et al., 2018). There are other examples of gamification strategies in educational environments such as PE classrooms, such as achievement badges allows to create a system of achievement badges for various accomplishments, such as mastering a specific skill, consistently participating, or achieving fitness goals (Landers, 2015). The badges provide a visual representation of students' accomplishments, encouraging a sense of achievement and motivating them to pursue additional challenges. Developing fitness challenges set up such as step counts, distance covered, or time spent on physical activities (Cruz-Campos et al., 2022). Students can compete individually or in teams using interactive fitness apps or gamified platforms designed for physical education. These can track progress, set goals, and provide challenges (Huang & Hew, 2018). Organize team-based challenges or competitions where students work together to achieve a common goal (Prakash & Manchanda, 2021; Urh et al., 2015). Other strategies was to role-playing games to incentive programs with skills levels and progression where students earn rewards (e.g., extra break time, choosing an activity) based on their level of participation and achievements (Hakulinen, 2015).

The role of gamification in socio-affective and motor development during Physical Education

For these reasons, educational institutions must define attractive and differentiating strategies that allow not only the satisfaction and motivation of their professionals, but also rewarding results in terms of learning on the part of their students (Plowman & Stephen, 2005). Through the nature of the elements of rewards or punishments - characteristic of the gamified pedagogical approach, an important role can be seen in the results regarding the teaching and learning process of PE, since the external regulation seems to increase significantly after the sessions of PE intervention (Ferriz-Valero et al., 2020). Furthermore, the gamification model can be a resource capable of producing positive psychological effects in PE classes (Quintas et al., 2020). The gamification of teaching can therefore be a bridge between the student, learning and the real world (Erenli, 2013), provoking benefits in basic psychological needs, enhancing academic performance, and increasing motivation (Quintas et al., 2020).

Thus, pedagogical success in PE requires, on the part of the teacher, the ability to articulate diagnostic, instructional and management skills, adapting their action and behavior to the particularity of each educational situation. Additionally, the training needs of the students should be also considered to provide better learning conditions. These adjustments can be fundamental to stimulate the participation and motivation of students and teachers during PE classes. It is known that games reflect many of the realities of the real world, so it is important to take advantage of this opportunity for the elaboration and planning of games, according to the objectives listed to work on a certain theme.

Interdependent factors contributes for gamification strategies

Applying gamification strategies could be affected by the following interdependent factors contributors in PE lessons (Kapp, 2012; Landers, 2014; Siedentop et al., 2011): (1) student engagement: the level of student engagement and motivation plays a crucial role in the success of gamification. If students are not interested in the gamified elements or do not find them meaningful, the effectiveness of the strategy may be limited; (2) learning objectives: The alignment between the gamification strategies and the learning objectives in PE is essential. The gamified elements should support and reinforce the intended learning outcomes; (3) game design: the design of the gamified elements, including the choice of game mechanics, rewards, challenges, and feedback mechanisms, can impact how students respond to the gamification strategy; (4) teacher support and guidance: teachers' understanding and implementation of gamification play a vital role in its success. Teachers need to provide clear instructions, feedback, and support to help students navigate the gamified learning environment effectively; (5) individual differences: Students have diverse learning preferences, motivations, and abilities; (6) gamification strategies should consider these individual differences to ensure inclusivity and provide personalized learning experiences; (7) intrinsic and/or extrinsic motivation: The balance between intrinsic motivation (motivation from within, driven by interest and enjoyment) and extrinsic motivation (motivation from external rewards or incentives) should be considered when designing gamified elements; (8) technology and resources: the availability and access to technology and resources can affect the implementation of gamification. The use of digital tools and platforms may require proper infrastructure and support; (9) feedback and progress tracking: providing timely and constructive feedback, as well as opportunities to track progress and achievements, can enhance student motivation and engagement; (10) social interaction: Incorporating social interaction and collaboration among students through gamified elements can promote teamwork and peer support; (11) cultural and contextual considerations may influence students' responses to gamification. It is essential to consider cultural sensitivity and adapt gamification strategies accordingly; (12) time and scheduling: the amount of time allocated to gamification activities within the PE curriculum can impact the depth and frequency of the gamified experiences. Toda et al. (2019) proposed a taxonomy to describe game-based elements and gamification strategies based on five variables: (1) comprehensibility: the "name," which is the standardized idea for the collection of game elements; (2) description: the explanation of the topic; (3) relevance: the element's significance throughout the entire taxonomy; (4) examples: the instances connected to the notion and definition; (5) coverage: the total taxonomy represented. The 21 components in this package accurately depict and cover the game aspects required for instructional applications.

Concretely, gender, age, and the type of sport can significantly greatly influence the application of gamification strategies in PE (Quennerstedt, 2019; Siedentop et al., 2011). Each of these factors contributes to students' preferences, motivations, and learning styles, which need to be considered when designing and implementing gamified learning experiences (Dyson & Casey, 2016; Siedentop et al., 2011) .Gender differences may influence the types of games or sports that students prefer. For example, some girls may feel more comfortable with certain sports, while boys may gravitate toward others (Esslinger et al., 2016). Gamification strategies should be designed to be inclusive and appealing to all genders, taking into account diverse interests and motivations (Deterding et al., 2011; Kapp, 2013). Teachers should avoid reinforcing gender stereotypes in gamified activities and promote equal opportunities for all students to participate and excel. Younger students may respond better to gamification strategies that involve colorful visuals, playful elements, and immediate rewards. Older students may prefer more sophisticated game mechanics and challenges that reflect their maturity level and interests (Siedentop et al., 2011). The complexity and difficulty of gamification elements should be adjusted to align with students' age and cognitive development. Different sports have unique characteristics and skill requirements (Akcaoglu et al., 2021). Gamification strategies should be tailored to suit the specific demands and objectives of each sport. For team sports, gamification can emphasize teamwork, communication, and strategy, whereas individual sports may focus on personal achievement and skill improvement (Quennerstedt, 2019). Sports with a competitive nature

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may benefit from leaderboards and score-tracking, while cooperative sports may encourage collaborative challenges and shared achievements. Also, the students' motivation and interest in specific sports or physical activities can influence their engagement with gamification (Landers, 2015; Landers, 2014).

Practical applications, research limitations and future perspectives

The limitations of the current study should be taken into account when interpreting its conclusions. Methodologically, the reader should consider the narrative approach and the partial application of the PRISMA methodology (Ardern et al., 2022). Theoretically, it should be made clear that there are grey areas in the literature on teaching models, and that these are interconnected for both PE and sports games contexts (Silva et al., 2022). In future research, it is necessary to develop games through scenarios and daily challenges (Erenli, 2013). Most of the studies carried out so far have focused on studying students' motivation during PE classes or on learning subject content, and the results are encouraging in gamified contexts. In fact, the use of rewards or punishments through points (i.e., experience, damage points or health) in the creation of gamified learning environments can have a dual motivational aspect, increasing motivation in some students and not affecting, or even decreasing motivation in others (Van Roy & Zaman, 2019). The use of new methods can bring effectiveness to the autonomy and self-regulation of student learning (Silva et al., 2018), to contribute to the conception of learning spaces or improvements of institutional and professional initiatives in the classroom (Parra-González et al., 2020). Also, it is important to establish programs based on creativity, collaborative behavior and exploration of materials through programs in the student community, the sports system and lifestyles (S. Santos et al., 2023; Santos et al., 2016).

However, the implementation of gamification in physical education comes with various challenges and limitations. Students and teachers may resist the introduction of gamification, especially if they are not familiar with the concept or have a more traditional view of physical education (Ardern et al., 2022). Students with different athletic abilities may have varied levels of participation and success in gamified activities (Van Roy & Zaman, 2019). The technological development can be an barrier because teachers and schools may face technological challenges when implementing gamification strategies that require the use of digital devices improvement (Huang & Hew, 2018; Kim & Lee, 2015). Developing gamified activities that align with educational objectives without losing focus on learning can be challenging and needs a monitoring and control to understand if the gamification strategies can be challenging, especially in terms of their impact on learning (Kim & Lee, 2015). Otherwise, students may become excessively reliant on gamification elements for motivation, which may not be sustainable in the long term. Gamification strategies relying on technology may create disparities in access due to financial, infrastructure limitations and socioaffective factors (Deterding et al., 2011; Kapp, 2013). Without careful design, gamification can become superficial, with students focusing only on rewards rather than genuine learning (Arufe-Giráldez et al., 2022). Developing well-designed gamified activities may require specific design skills that not all teachers possess. Also, competition may lead to inequality if not managed properly, with some students feeling discouraged if they perceive they cannot compete (Quintas et al., 2020). Addressing these challenges and limitations with careful consideration allows educators to maximize the benefits of gamification in physical education, creating an engaging and motivating learning environment for students (Fulton, 2019).

Finally, technology seems to play a key role when combined with gamification strategies to improve motivation for students and teachers using this teaching methodology compared to the use of traditional methods (Akcaoglu et al., 2021; Siedentop et al., 2011). In particular, the next research should try to understand which type of motivation is most improved by gamification-based strategies (whether intrinsic or extrinsic motivation as well as what role it plays in the persistence of practice and behaviours).

Conclusion

This review allows us to conclude on the potential benefit of using gamification for teaching PE. From this, gamification strategies seem to be valid and efficient as contribute to the previous PF models, applying game elements, mechanics, and principles to non-game contexts to enhance engagement and motivation in children and youth, specifically in PE classroom. Gamification models extend to as fundamental element the theory of self-determination expressed by theory of gamified learning, dynamical model for gamification of learning (DMGL), goal-access-feedback-challenge-collaboration (GAFCC) gamification, and virtual gamification. Evidence reports increases in motivation for students and teachers using this teaching methodology compared to the use of traditional methods. In this way, it is possible to expect that with the continuous technological advancement which it has been witnessed in this era, the overlapping of this type of teaching methodologies (i.e., gamification) to the detriment of other approaches may become a reality in the short term. The introduction of technology in the educational context can be the key to success in promoting children's lasting bonds with PE and consequently with sport for their lives. Even so, it is important to note that the pedagogical didactic strategies, the teaching model or the hybrid teaching model chosen by the teacher, must always adapt to the individual characteristics of the students and aim to enhance their sports abilities, regular PA, and motor control.

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ORIGINAL SCIENTIFIC PAPER

Isokinetic profiles of hamstring and quadriceps muscles in the police special force operators

Aleksandar Kukrić[1], Nemanja Zlojutro[1,2], Robin Orr[3], Marko Joksimović[4], Filip Kukić[1]

Affiliations: [1]Biomechanics lab, Faculty of Physical Education and Sports, University of Banja Luka, Banja Luka, Republic of Srpska, Bosnia and Herzegovina, 78000, [2]Faculty of Sport and Physical Education, University of Belgrade, Belgrade, Serbia, 11000, [3]Tactical Research Unit, Bond University, Gold Coast, Queensland, Australia, 4213, [4]Faculty of Sport and Physical Education, University of Montenegro, Montenegro

Correspondence: F. Kukić, Biomechanics lab, Faculty of Physical Education and Sports, University of Banja Luka, Banja Luka, Bosnia and Herzegovina, Bulevar vojvode Petra Bojovića 1A. E-mail: filip.kukic@ffvs.unibl.org

Abstract

Knee injuries are of concern to police. The aims of this study were to determine initial reference values for isokinetic knee extension and flexion in police special force operators to explore the conventional hamstring contraction (Hcon) quadriceps contraction (Qcon) ratio, and to determine the limb symmetry index of the quadriceps and hamstring muscles. Absolute and relative isokinetic torque of quadriceps and hamstrings were assessed in 10 police special force operators using an isokinetic dynamometer Con-Trex. Subjects performed maximal knee extension and flexion at a contraction velocity of 60°/s at 90° of knee flexion. Means, standard deviations, 95% confidence interval values, and effect sizes were calculated. A paired samples t-test was used to test the between-leg differences in absolute and relative torques of quadriceps and hamstring muscles and to test the between-leg difference in Hcon/Qcon ratios as well as strength asymmetries of quadriceps and hamstrings. Descriptive statistics revealed torque values similar to athletes, and paired sample t-tests showed no significant between-leg differences in torque values at a group level. Small effect sizes were observed between legs in both the absolute and relative peak torque of the hamstring muscles. While, on a group level, no Hcon/Qcon ratio disparity between legs or asymmetries were observed, individual results indicated a trend towards greater dispersion for the dominant leg and some individual results indicated an increased asymmetry in isometric strength of hamstrings. The study provides normative data for this unique police population and highlights the need for relative strength work in this population.

Keywords: *knee function, injury prevention, muscle strength, leg extension*

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ISOKINETIC STRENGTH IN POLICE SPECIAL FORCE OPERATORS
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Introduction

Considering the structure, function, and daily workload of the knee joint, injuries to this structure are common for many population groups and occur regardless of gender, age, or type of physical activity being performed (Gage et al., 2012). This is also true for physically demanding occupations such as tactical professions, inclusive of police forces (Lyons et al., 2021). As examples, a large retrospective cohort study of 12,452 lower limb injuries suffered by police officers found that the knee was the most common site of injury (31% of all lower limb injuries) (Lyons et al., 2021) whilst in general duties officers in particular, the knee was been identified as the leading site of

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injury overall (Orr et al., 2023). Of concern, research suggests that, together with firefighters, police officers have more days away from work following a knee injury than other US government workers (Chen et al., 2013). Thus, not only are knee injuries common but they have a notable impact on police officers and their agencies.

Knee injury frequency and their impacts are not surprising given the nature of the law enforcement profession. Police officers respond to a variety of tasks from checking a suspicious person's credentials to attending a domestic dispute and arresting offenders (Orr, Hinton, et al., 2020) all while wearing around 10 kg of personal protective equipment on their bodies (Baran et al., 2018). Thus, officers' tasks can range from general duties deskwork and driving in vehicles, to chasing offenders on foot across various terrains and over obstacles. One means of mitigating injury in police personnel is through physical fitness whereby personnel with higher levels of fitness are generally at a lower risk of injury (Orr et al., 2023) with physical fitness associated with many policing tasks (Lockie et al., 2023). As such, physical fitness is considered a very important pillar of policing (Orr, Robinson, et al., 2022). Noting this requirement for general duties officers, specialist police perform tasks beyond those of general duties police officers, carry loads of 20+ kg, and are required to be fitter than general duties officers (Maupin et al., 2018).

Although various tests are applied in practice to assess risk of the injury (Orr, Lockie, et al., 2022), the isokinetic tests for the strength imbalance index between muscle groups surrounding the knee joint (i.e., hamstring contraction to quadriceps contraction ratio, Hcon/Qcon ratio) is among the few precise measures available (Coombs & Garbutt, 2002). The conventional Hcon/Qcon ratio represents the ratio between the peak torque of the hamstring and the quadriceps muscles and is measured during concentric contractions (Pellicer-Chenoll et al., 2017). Hewett et al. (2008) found a correlation between the conventional Hcon/Qcon ratio and angular velocity of movement in non-athletes, where an increase in angular velocity led to an increase in the Hcon/Qcon ratio. Furthermore, studies have found that low values of a Hcon/Qcon ratio (e.g., Hcon/Qcon < 0.60 at an angular velocity of 60°/sec) increased the risk of knee joint (e.g. anterior cruciate ligament tear) and supporting structure (e.g., hamstring strain) injuries (Coombs & Garbutt, 2002). Thus, diagnosing the Hcon/Qcon ratio could provide an early indication of increased risk of injury to the knee joint and supporting structures.

Analyzing the risk of injury in police officers using standardized laboratory conditions and equipment, such as isokinetic testing, is scarce. Rare opportunities, when the utilization of such tests is possible, should be used to build the scientific body of knowledge and possibility of developing standards for an individual assessment of officer's knee joint injury risk. Considering this, the aim of this study was to determine reference values for isokinetic knee extension (quadriceps muscle) and flexion (hamstring muscle) in specialist police forces. Furthermore, the study aimed to explore the conventional Hcon/Qcon ratio and to determine the limb symmetry index (LSI) in quadriceps and hamstring muscles in this population. At an individual officer level, this information can inform their conditioning, and reconditioning following knee injury, requirements.

Methods

Experimental approach to the problem

This study employed a cross-sectional research design on a specific sample of subjects who served as specialist police officers. The research was conducted at the Faculty of Physical Education and Sports, University of Banja Luka, Bosnia and Herzegovina. Subjects visited the laboratory once. During their visit their anthropometric characteristics were taken following which they warmed up, performed a familiarization trial, and then performed the test of hamstring and quadriceps muscle isokinetic strength. The research was approved by the Ethics Committee of the Faculty of Physical Education and Sports, University of Banja Luka. The research was conducted in accordance with the Helsinki Declaration.

Subjects

Subjects were 10 male (mean age = 26 ± 4.89 years; mean height = 179.90 ± 4.74 cm, mean mass = 89.10 ± 6.33 kg; and mean body mass index (BMI) = 27.5 ± 2.21 kg/m2) members of the special police units of the Republic of Srpska, Bosnia and Herzegovina. All subjects were experienced police officers with a minimum of 3 years of service in the police force. They were all physically active, engaging in at least three weekly organized conditioning training sessions. They were in good physical and mental health, without lower body injuries that could influence the research results, and regularly participated in organized physical activities within their units. Subjects were informed about the purpose and objectives of the research and the measurement protocols, and all voluntarily agreed to participate in the study.

Anthropometrics

Subject body mass was measured using a Tanita BC418a scale (USA) with a precision of 0.1 kg. Body height was measured using a Seca 216 stadiometer (Germany) with an accuracy of 0.5 cm. Of the 10 subjects, 8 reported that they were right leg dominant, with the remaining 2 reporting their left leg to be dominant. No subjects reported being ambipedal.

Quadriceps and hamstring torque

A general warm-up was performed on a stationary bicycle (Monark, Cosmed, Italy). Subjects cycled for 8 minutes and then performed a dynamic warm-up of the lower limbs for 3 min, and dynamic stretching for 2 min. This warm up was self-directed by each subject under the observation and direction of a researcher. The isokinetic test was performed on an isokinetic dynamometer (Con-Trex, Dubendorf, Switzerland). Subjects were seated, with the upper/lower body angle at approximately 85°. Subjects were fully secured with straps over the chest, hips, and distal thighs. The reference point for the axis of rotation was the lateral femoral condyle. The lever arm length was individually determined for each subject, and the range of motion was 90° of knee flexion, whereby 0° corresponded to extended knee (Norkin & White, 2016). The testing protocol on the isokinetic dynamometer involved performing two sets of warm-ups and adaptation for subjects on the machine. In the first set, subjects performed 10 submaximal concentric contractions of flexor and extensor muscles in the knee joint at an angular velocity of 100°/s. After a two-minute break, subjects performed 8 submaximal contractions at an angular velocity of 80°/s. After another at least two-minute rest, subjects proceeded to the final measurement, where they performed four maximal repetitions at an angular velocity of 60°/s. The rest between legs was at least five minutes.

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Statistical analysis

For analysis, the absolute and relative peak torque values of hamstring and quadriceps muscles were used. The absolute results are presented in newton-meter (N/m) and the relative results in newton-meter per kilogram (Nm/kg). The conventional Hcon/Qcon ratio of concentric contraction was determined by dividing the peak torque of hamstring muscles by the peak torque of quadriceps muscles. The LSI was calculated to determine the percentage of the difference in peak torque produced by the same muscle group of dominant and non-dominant leg. The following formula was used to determine LSI: (peak torque of dominant leg – peak torque of non-dominant leg) / peak torque of dominant leg × 100. The size of the of the asymmetry was determined using a general normative value of 15% and using group arbitrary values of ±2 standard deviations (Parkinson et al., 2021).

The testing results were analyzed using JASP (version 0.18.1, Amsterdam). The descriptive analysis determined the mean, standard deviation, and 95% confidence interval for all investigated variables. The normality of distribution was tested using the Shapiro-Wilk test and all variables were normally distributed. Accordingly, parametric statistical tests were used. A paired samples t-test was used to investigate the between-leg differences in absolute and relative torque of quadriceps and hamstring muscles. This test was also used to test the between-leg difference in Hcon/Qcon ratios. Cohen's effect size (d) was used to quantify the differences as d < 0.2 (trivial or no effect), d = 0.2–0.5 (small), d = 0.5–0.8 (moderate), d = 0.8–1.3 (large), or d >1.3 (very large) (Sullivan & Feinn, 2012). As the study employed a sample of convenience, Power*G software was used to determine the required power for the given sample and level of significance and based on this analysis 0.5 was used as the lower bound for a small effect size.

Results

Table 1 presents the mean, standard deviation, and 95% confidence interval of absolute and relative peak torque values for quadriceps and hamstring muscles for both dominant and non-dominant legs. There were no significant between-leg differences in absolute and relative torque obtained by quadriceps and hamstrings muscles. However, observing the distribution of subjects and consulting the effect size analysis (Figure 1), the difference of a small effect size could be observed between legs in both the absolute (TmaxHams) and relative (TrelHams) peak torque of the hamstring muscles.

Table 1. Means, standard deviations, and effect sizes for absolute and relative peak torque values of flexor and extensor in the knee joint dominant and non-dominant leg.

Variables	Dominant leg	Non-dominant leg	Effect sizes
	Mean ± SD 95% Conf. Interval	Mean ± SD 95% Conf. Interval	
TmaxQuad (Nm)	228.45 ± 15.83 217.13–239.77	228.66 ± 24.53 211.11–246.21	Trivial
TmaxHams (Nm)	142.09 ± 26.40 123.21–160.97	134.14 ± 25.13 116.16–152.12	Small
TrelQuad (Nm/kg)	2.57 ± 0.17 2.45–2.70	2.57 ± 0.27 2.38–2.77	Trivial
TrelHams (Nm/kg)	1.59 ± 0.25 1.41–1.78	1.51 ± 0.26 1.32–1.69	Small

Note. SD: standard deviation; TmaxQuad: absolute peak torque of quadriceps muscles; TmaxHams: absolute peak torque of hamstring muscles; TrelQuad: relative peak torque of quadriceps muscles; TrelHams: relative peak torque of hamstring muscles.

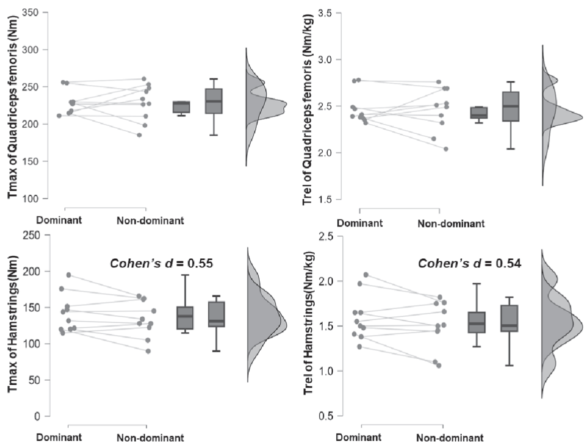

Figure 1. The distribution of absolute and relative torque exerted by Quadriceps and Hamstrings muscles.

Hcon/Qcon ratio

The mean values of the Hcon/Qcon ratio were similar within dominant (Hcon/Qcon = 0.61 ± 0.11) and non-dominant (Hcon/Qcon = 0.58 ± 0.08) legs. In addition, there were no significant between-leg differences in Hcon/Qcon ratios ($p = 0.19$). However, a tendency towards a greater dispersion of absolute Hcon/Qcon ratio could be observed in the dominant leg when compared to the non-dominant leg. It is of note that two subjects had high relative Hcon/Qcon in their dominant leg and that the dispersion of between-leg differences were bigger when the Hcon/Qcon of the dominant leg was larger than in the non-dominant leg (Figure 2).

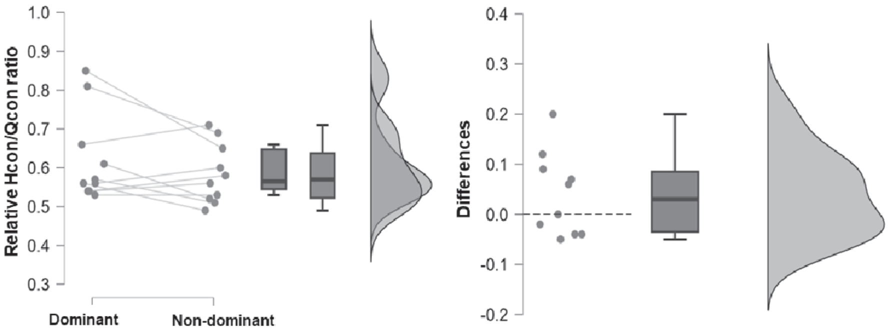

Figure 2. Relative Hcon/Qcon ratio of dominant and non-dominant leg and corresponding between-leg difference.

Between-leg asymmetry

Considering mean values, a small asymmetry could be observed in both quadriceps and hamstring muscles (Figure 3). When both criteria for asymmetry were analyzed, only one subject had quadriceps asymmetry over 15% while two subjects had hamstring asymmetries over 15%. None of the subjects attained the asymmetry larger than ± 2 standard deviations of the group's mean.

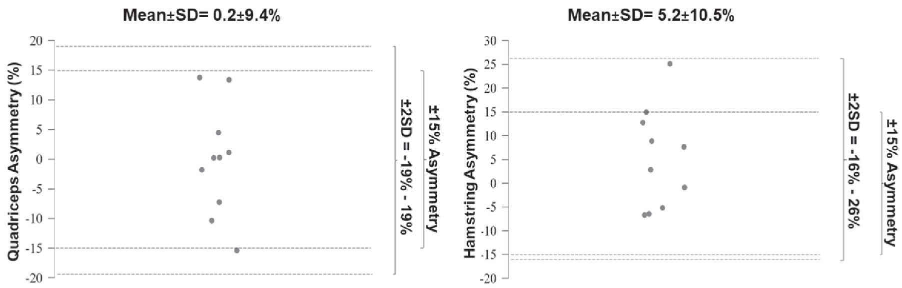

Figure 3. LSI assessed relative to general normative values and relative to sample's mean and data dispersion.

Discussion

This study aimed to establish reference values for isokinetic knee extension and flexion muscles in police special force operators, assess their conventional Hcon/Qcon ratio, and determine leg asymmetry. As will be discussed, descriptive statistics revealed torque values similar to athletes, and paired sample t-tests showed no significant between-leg differences in torque values on a group level. However, when the effect size was calculated and the dispersion of individual results was observed, small differences in hamstrings were noted. Furthermore, while, on a group level, no Hcon/Qcon ratio disparity between legs was observed, individual results indicated a trend towards greater dispersion in the dominant leg. Similarly, asymmetry could not be detected at a group level even though individual results indicated an increased asymmetry in isometric strength of hamstrings. These results suggest that police special force operators belong to higher tiers of individuals in terms of torque produced by quadriceps and hamstring muscles. However, when their quadriceps and hamstring function is tested and analyzed in smaller groups (units) they should be treated both as a group and individually.

Considering that the sample of subjects in this study were presumed to be in excellent physical condition, it could be supposed that they would provide higher outputs of absolute torque when compared to the general population and be similar to those of higher level athletes. This was not necessarily the case however. In a review of the literature Šarabon et al. (2021) considered the mean pooled relative torque of the male adult population to be 2.78 Nm/kg for the quadriceps (knee extension) and 1.25 Nm/kg for the hamstrings (knee flexion). While the data were not divided into dominant and non-dominant leg, their results suggest that the population in this research performed below the adult male population in quadriceps strength (dominant = 2.57 ± 0.17 Nm/kg; non-dominant = 2.57 ± 0.27 Nm/kg) but above the adult male population in hamstring strength (dominant = 1.59 ± 0.25 Nm/kg: non-dominant = 151 ± 0.26 Nm/kg). Considering these differences, the ranges of motion at the knee for the pooled review data ranged from 110 to 180° and the hip angle was generally 90° (94% of studies) but ranged from between 75 and 110°. As such, variations in the positioning of the subject may have impacted performance through alterations to muscle length-tension relationships.

When compared to professional football players in the first division of Belgium (Lehance et al., 2009), similar absolute values of peak torque of the thigh muscles were achieved (quadriceps = 224.2 ± 38.8 Nm / hamstring = 136.8 ± 34.1 Nm) with similar values also found in combat sports athletes (boxing quadriceps = 221.5 ± 48.9 Nm / hamstring = 124.9 ± 28.2 Nm; wrestling quadriceps = 241.0 ± 21.8 Nm / hamstring = 141.1 ± 31.4 Nm; Wushu quadriceps = 250.6 ± 28.6 Nm / hamstring = 142.4 ± 30.22 Nm) (Tatlıcı & Löklüoğlu, 2022). When relativized to body mass, values were higher in football players (quadriceps = 2.98 ± 0.35 Nm/kg and hamstrings = 1.98 ± 0.30 Nm/kg) and the combat sports athletes (boxing = 3.18 ± 0.49 Nm/kg; wrestling = 3.14 ± 0.29 Nm/kg; Wushu = 3.25 ± 0.66 Nm/kg). The reason for the difference in relative values is the significantly higher body mass of the special force

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operators compared to professional football players (89.10 ± 6.33 kg vs. 77.9 ± 6.2 kg) (Lehance et al., 2009) or the combat sports athletes (boxing = 69.30 ± 9.58 kg; wrestling =77.20 ±8.71kg; Wushu = 78.50 ±9.62 kg) (Tatlıcı & Löklüoğlu, 2022). Thus, the relative strength of these athletes' leg muscles may be more effective at handling their body statures and volumes (i.e., body frame and mass accompanied with training load), which is expected given their training history and professional demands.

It is of note, that police special force operators typically carry considerable operational load whilst on duty (Keeler et al., 2022). These loads can average around 20-25kg without additional equipment like door breaching equipment or ballistic shields. This poses additional strain to their legs, thus requiring higher strength levels than those of normal adult population. Furthermore, research suggests that relative strength in particular is crucial for the load carriage ability of police special force officers (Orr, Robinson, et al., 2022). Therefore, to optimize police special force officer capability, strength and conditioning programs meeting the specialized needs of these personnel should be among their training priorities.

The findings of this study fall within the range of professional male football players. A review systematic review by Baroni et al. (2020) of professional male soccer players (totaling 27 studies and 1,274 players) found a Hcon/Qcon ratio ranging from 0.5 to 0.89. Of note in the review, data were drawn from studies whose velocities ranged from 12-600s-1. As such, the wide range and differences in findings may be due to different methodological approaches and resultant impact of force-velocity relationships.

On a group level, identical Hcon/Qcon ratios for both legs calculated from both absolute and relative torque values suggest a potential lack of strength training focused on relative strength (Dawes et al., 2019). Greater dispersion of absolute Hcon/Qcon in the dominant leg suggests that variations in absolute values did not correspond to variations in relative values. Instead, individuals with higher body mass generated larger torque, supporting the supposition of a potential lack of relative strength. This finding underscores the importance of allometric scaling in muscle strength testing (Folland et al., 2008). The between-leg difference in Hcon/Qcon, with positive values indicating a larger ratio in the dominant leg, exhibited a widely dispersed distribution. This suggests greater consistency in the contraction of knee extensors than flexors in the dominant leg. In addition, the approach used for the analysis detected two subjects with high Hcon/Qcon ratio in their dominant legs. Despite Kellis et al.'s (2023) recent systematic review revealing no conclusive link between the Hcon/Qcon ratios and ACL injuries, monitoring this ratio remains essential for assessing the function and effectiveness of knee flexors and extensors (Šarabon et al., 2021).

The LSI results suggest that the differences in muscle strength within the same muscle group in both legs falls within the limit of two standard deviations. In terms of the normative value of 15%, one subject exhibited stronger quadriceps in the non-dominant leg, while two subjects had stronger hamstrings in the dominant leg compared to the non-dominant. The two criteria (i.e., two standard deviations and normative values of 15%) were employed following recent findings in a systematic review by Parkinson et al. (2021) who caution against relying solely on pre-established thresholds (10-15%) for interpreting asymmetry scores, due to a lack of robust evidence. This approach allowed for the comparison of results against external normative values and within the group, both against the group mean and among subjects. It also facilitated the timely identification of individuals with increased imbalances for targeted strength and conditioning programs. Police special force operators, unlike athletes who may develop beneficial sporting asymmetries (Maloney, 2019), require effective movement in diverse scenarios while carrying an occupational load, often under stress and unpredictability. In addition, their professional careers generally last longer and is dependent on their physical health. Thus, detecting and addressing professional asymmetries early would be of benefit in this population.

Several limitations exist in this study. The small sample size necessitates caution in extrapolating findings, highlighting the need for additional subjects in future research. The exclusive inclusion of male operators reflects the current composition of the special force police unit, given the absence of females meeting the physical fitness criteria during the study. Future research should incorporate occupation-specific tests to assess the impact of isokinetic profiles, Hcon/Qcon ratio, and asymmetries on occupational performance.

This study provides preliminary isokinetic strength data for the quadriceps and hamstring muscles among police special force operators. The results reveal absolute torque values comparable to athletes but a lower relative strength, indicating diminished effectiveness of the leg muscles in relation to the officer's body mass. This underscores the importance of implementing strength and conditioning programs that specifically address relative strength. Additionally, the study introduces a methodological framework for the evaluation of data at both group and individual levels, facilitating a comprehensive understanding of how the group compares to normative values specific to this population and identifying individuals necessitating focused attention. This approach allows for meticulous planning of personalized interventions, thereby contributing to enhanced group performance and individual operator health.

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ORIGINAL SCIENTIFIC PAPER

Design and Validation of a New Water Polo Test of Anaerobic Endurance: Preliminary Study of Junior Male Players

Dario Vrdoljak[1], Antonela Karmen Ivišić[1], Ognjen Uljević[1]

Affiliations: [1]Faculty of Kinesiology, University of Split, Split, Croatia

Correspondence: O. Uljević. University of Split, Faculty of Kinesiology, Teslina 6, 21000 Split, Croatia. E-mail: ognjen.uljevic@gmail.com

Abstract

Water polo is a team sport in which anaerobic capacity plays a significant role, but there is a lack of ecologically valid tests of water polo-specific anaerobic capacity. Therefore, the purpose of this study was to design and validate a method for evaluating the anaerobic capacity of water polo players. The sample of participants included 10 male junior water polo players (16.70 ± 1.06 years, 186.11 ± 6.06 cm, 81.18 ± 6.88 kg). Measurements included power output in the Wingate anaerobic test (WAnT) and the newly designed eggbeater kick anaerobic test (EKAT). WAnT included peak power (PP), average power (AP), minimal power (MP), and power drop (PD), and EKAT included the same four parameters as well as anaerobic capacity (AC). The results of this study show a significant correlation between test and retest values of power output (Pearson's correlation: 0.63, 0.87, 0.85, and 0.90 for PP, AP, MP, and AC, respectively). T-test calculation showed no significant differences between test and retest values for EKAT. Correlation analysis between EKAT and WAnT showed no significant correlation between corresponding power outputs. In conclusion, our results suggest that EKAT has proper metric characteristics, indicating the practical applicability of this test for male water polo players. Further studies on older players and female players are warranted.

Keywords: *eggbeater kick, EKAT, WanT, test-retest, reliability*

@MJSSMontenegro
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Introduction

Team sports are characterized as being intermittent activities. The players are required to frequently transition between brief bouts of high-intensity activity and longer periods of low-intensity activity (Milanovic & Vuleta, 2013; Mohr et al., 2003; Reilly, 1976; Varley et al., 2014). Contrary to individual sports such as track and field or swimming, team sports are usually characterized by intense intermittent activity (Meckel et al., 2013). Additionally, team sports players may perform movements such as tackling, blocking, jumping, and directional changes that are integrated with technical skills (Paul et al., 2016; Perazzetti et al., 2023). Thus, due to the constant intensity changes, many team sports can be described as interval sports. Therefore, it has been suggested that success in many sports appears to involve high aerobic and anaerobic capacity (Al'Hazzaa et al., 2001; Hoffman et al., 1996; Smith et al., 1992; Uljevic

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et al., 2014). One of the sports that stands out in terms of the importance of aerobic and anaerobic capacity is water polo.

Water polo is a goal-type ball game played in the water (Kawai, Gonjo, et al., 2023). It is characterized by many complex activities, including swimming and treading water at various intensities, making contact with opponents, passing the ball to teammates, and shooting goals (Botonis et al., 2015; Melchiorri et al., 2010; Platanou, 2004). The difficulty and complexity of water polo can be seen through previously established physiological parameters. Specifically, a high heart rate during the match, with high lactate levels (up to 12 mmol/L-1), suggests that a great deal of energy production originates from anaerobic metabolism (Rodríguez, 1994). Moreover, kinematic analysis of water polo games suggests that there is a great demand on the anaerobic system (Tsekouras et al., 2005). Specifically, sprinting bouts during the game generally do not last longer than 10 s, implying that the major contributor to energy supply during sprinting is the anaerobic system (Bogdanis et al., 1996). To optimise activities while floating in the water, water polo players use a water-treading technique called the eggbeater kick.

The eggbeater kick is primarily used in water polo and artistic (synchronised) swimming (Kawai, Tsunokawa, et al., 2023). The eggbeater kick is used for approximately 45–55% of the total water polo game time (Platanou, 2004; Smith, 1998). During eggbeater kicking, athletes continuously alternate circular movements of their lower limbs to generate an upward propulsive force to elevate the body. The generation of a propulsive force by the eggbeater kick enables players to keep their upper body above the water during passing, shooting, and blocking, and to resist the action of opponents during contact play (McCluskey et al., 2010) (Nakashima et al., 2014; Platanou, 2004; Smith, 1998). Therefore, performing an effective eggbeater kick is important for all water polo players.

Previous brief literature review demonstrates that most of the studies on the eggbeater kick focused mainly on the kinetic and kinematic parameters (Kawai, Gonjo, et al., 2023; Kawai, Tsunokawa, et al., 2023). There are also several studies that developed tests for assessing the eggbeater kick, but in most cases studies implemented test performed in a vertical body position (Melchiorri et al., 2015) or for short intervals of time (Stirn et al., 2014). Therefore, the aim of this study was to construct and validate a new test for determining the anaerobic capacity of water polo players.

Materials and methods

Participants

The sample of participants included 10 male junior water polo players. Their chronological age was 16.70 ± 1.06 years, and they had an average height of 186.11 ± 6.06 cm, body mass of 81.18 ± 6.88, and body fat percentage of 14.14 ± 1.21% (see Table 1). Informed consent was obtained from all subjects involved in the study. The experimental procedures were completed following the Declaration of Helsinki. All athletes participate in water polo training daily; they have a minimum of 5 sessions per week, with matches on weekends during the competitive season. The tested players have extensive experience in sports, with the majority competing in Croatian senior and regional leagues. The water polo technique utilized in this research is commonly practiced during training and matches, thus they had a high level of proficiency. The athletes were aware of the identified minimal risk and voluntarily participated in the study.

Table 1. Descriptive parameters for age, anthropometric parameters, and lactates, in all participants.

Variables	Mean	Minimum	Maximum	SD
Age (years)	16.70	15.00	18.00	1.06
Body height (cm)	186.11	179.00	199.10	6.06
Body mass (kg)	81.18	72.30	92.10	6.88
Body fat percentage (%)	14.14	10.40	19.70	2.78
Lactate pre (mmol/L)	4.15	2.60	4.90	1.21
Lactate post (mmol/L)	9.59	5.80	14.70	2.63

SD, Standard deviation

Variables

The variables in this study included anthropometric indices, lactate levels, and power output from the Wingate anaerobic test (WAnT) and the newly developed eggbeater kick anaerobic test (EKAT).

Anthropometric indices, including body height measured with a measuring tape, body mass, and body height, were assessed by a bioimpedance scale (Tanita BC 418 scale, serial number 15010067, 2015).

To determine blood lactate concentration, blood samples were collected from the fingertip and immediately placed in a portable analyser (Accutrend® Plus, Roche, Lausanne, Switzerland). Blood lactate levels were determined before WAnT and EKAT and immediately after. The assessment was carried out in a sterile environment by an educated professional.

The power outputs of the test were defined using previously established parameters similar to those for the Wingate test (Bar-Or, 1987). The variables included peak power (PP), average power (AP), minimal power (MP), power drop (PD), and anaerobic capacity (AC). PP was calculated as the average for the first 5 seconds of the test. AP was derived as the average during the whole test. MP represents the last 5 seconds of the test. PD was defined as the difference in PP between the first 5 seconds and the last 5 seconds of the test. AC was calculated as the difference between the lowest PP and the highest PP, divided by the highest PP, then multiplied by 100. All power outputs were used as relative values with the body mass of the participants.

PP and MP equation:

$$PP = \frac{Average\ force\ in\ 5\ seconds\ (N)}{Time\ (s)}$$

PD equation:

$$PD = \text{First PP} - \text{Last PP}$$

AC equation:

$$PP = \frac{(High\ PP - Low\ PP)}{High\ PP} x\ 100$$

The variables used for WAnT were peak power (PP), as an indicator of the highest produced power, and average power (AP), as an indicator of anaerobic capacity. They were calculated as relative measurements according to the participant's body mass as W/kg.

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Testing procedure

The testing procedure included 2 anaerobic tests: the Wingate anaerobic test (WAnT), and the newly developed eggbeater kick anaerobic test (EKAT).

Before each EKAT session in the water, all participants executed a 10-to-15-minute warm-up consisting of various styles and intensities of swimming in the pool with appropriate technical elements, such as jumps, turns, water polo scissors, ball handling drills, etc. The warm-up was led and supervised by their coach, who utilized a standard warm-up procedure. Each participant was familiarized in advance with the manner and details of how to perform each test. Between each attempt within the test, participants had a rest period of 3-5 minutes, and there was a 15-minute break between tests. To avoid daily fluctuations in results, all testing sessions were conducted in the morning from 10 to 12 noon, and the testing was carried out in August 2023.

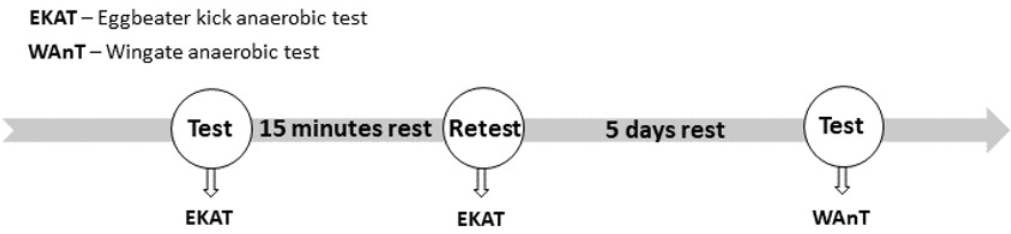

Figure 1. Testing procedure timeline for EKAT test/retest and WAnT.

During the test, participants were connected with a non-elastic rope to a belt tied around their waist. On the other end of the line, the PCE dynamometer (model FB2K, PCE Instruments, Meschede, Germany) was connected and secured so the participants could maintain force throughout the test without the movement of the apparatus. Before the start of the test, all participants were familiarized with the procedure. The participants were instructed to pull the rope as strongly as possible for 30 seconds. In the starting position of the test, the participant elongated the cord as far as possible, then on the mark, "Start!" they started the test. To determine the reliability of the test, the procedure was repeated two times with 15 minute rest between measurements (see Figure 2).

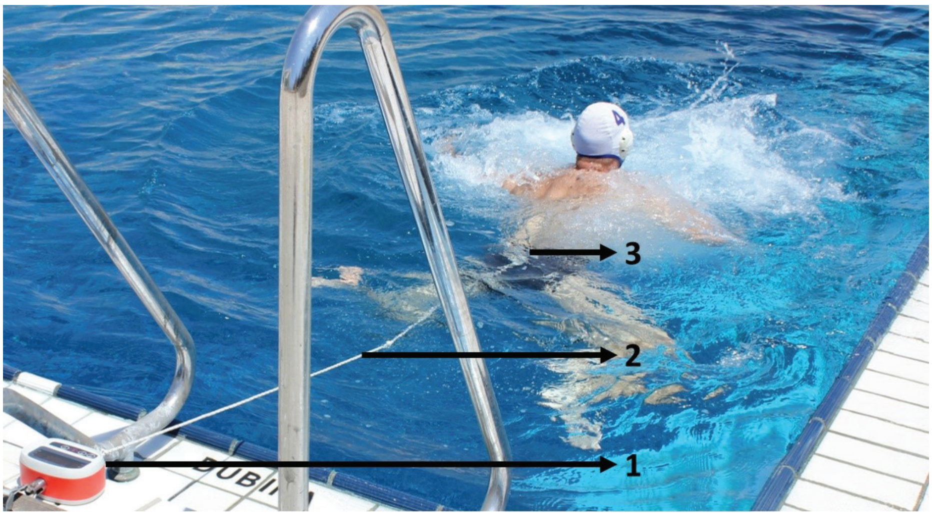

Figure 2. Graphical representation of the EKAT; (1) PCE dynamometer device, (2) cord connecting athlete and device, (3) the waist belt.

The data were derived by using the software for data extraction of the dynamometer during the whole testing procedure. The data are shown as the force value in Newtons (N) during the 30 seconds (see Figure 3). After the test, all data were processed in MATLAB software (MathWorks Inc., Natick, MA, USA).

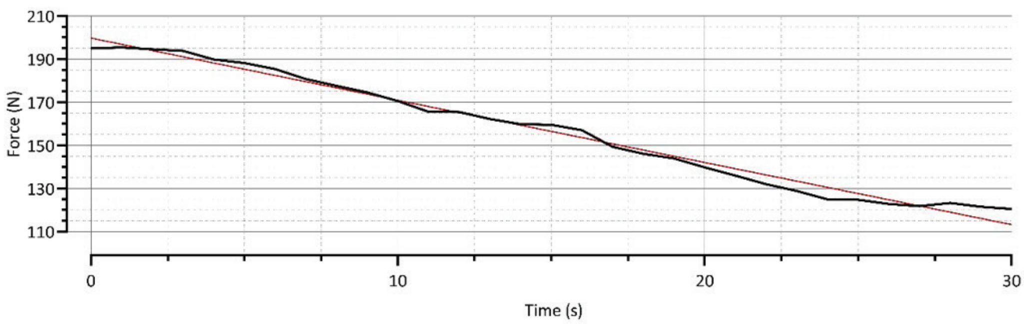

Figure 3. Graphical representation of the force output on the newly designed anaerobic test (EKAT)

WAnT was performed using a Monark 874E cycle ergometer (Monark Exercise AB, Vansbro, Sweden). Before the testing session, all participants executed a 10-to-15-minute warm-up consisting of moderate intensity rowing on an ergometer and self-preparatory exercises. Each athlete performed a 30 s test with the load individually adjusted to their body weight (7.5% of body mass). The task was to produce the highest possible cadence after the "Start!" command and maintain it as high as possible for the duration of the test. The participants were instructed not to raise their hips from the saddle but to always make their best effort to pedal during the Wingate test (Bar-Or, 1987).

Statistical analysis

Statistical analysis included descriptive measurements of all variables, skewness, kurtosis, and Kolmogorov-Smirnov test for determination of sensitivity and homogeneity. To determine the reliability level between variables, Pearson's r correlation coefficient was used. T-test was used to compare the results between test and retest variables, in order to exclude possible bias that may have occurred, due to learning, fatigue, and/or as a consequence of extensive time between measurements. Validity was checked with factor analysis (??? Any rotation???).

All analyses were done in the statistical package Statistica v. 13.5 (Tibco Inc., Palo Alto, CA, USA), with a p-value of 0.05

Results

The obtained results show that the test has good homogeneity and sensitivity according to the K-S test, as the data present normal distribution (K-S p > 0.20) (see Table 2). The reliability values are shown in Figure 4. Pearson's r correlation between test and retest values of power outputs demonstrates a significant relation between PP (0.63), AP (0.87), MP (0.85), and AC (0.90) outputs. On the other hand, there is a small connection between measurements for PD (0.04).

Table 2. Descriptive statistics and test sensitivity parameters for variables of EKAT, in both test and retest measurement.

Variables	Mean	Min	Max	SD	Skewness	Kurtosis	Max D	K-S p
	Test							
Peak Power (N/kg)	2.67	2.22	3.31	0.36	0.68	-0.38	0.16	p > .20
Average Power (N/kg)	2.10	1.72	2.57	0.29	0.21	-1.24	0.13	p > .20
Minimal Power (N/kg)	1.73	1.29	2.14	0.35	-0.07	-1.99	0.23	p > .20
Power Drop (N/kg)	0.93	0.27	1.44	0.36	-0.18	-0.03	0.16	p > .20
Anaerobic Capacity (N/kg)	12.64	10.33	15.41	1.74	0.20	-1.26	0.14	p > .20
	Retest							
Peak Power (N/kg)	2.46	1.76	3.01	0.46	-0.28	-1.67	0.21	p > .20
Average Power (N/kg)	1.96	1.42	2.35	0.34	-0.40	-1.28	0.19	p > .20
Minimal Power (N/kg)	1.69	1.15	2.07	0.32	-0.47	-1.06	0.16	p > .20
Power Drop (N/kg)	0.76	0.31	1.10	0.25	-0.76	-0.20	0.24	p > .20
Anaerobic Capacity (N/kg)	11.83	8.53	14.14	2.07	-0.40	-1.29	0.19	p > .20

Min, minimal result; Max, maximal result; Max D, test value of Kolmogorov-Smirnov test; K-S p, level of significance of Kolmogorov-Smirnov test

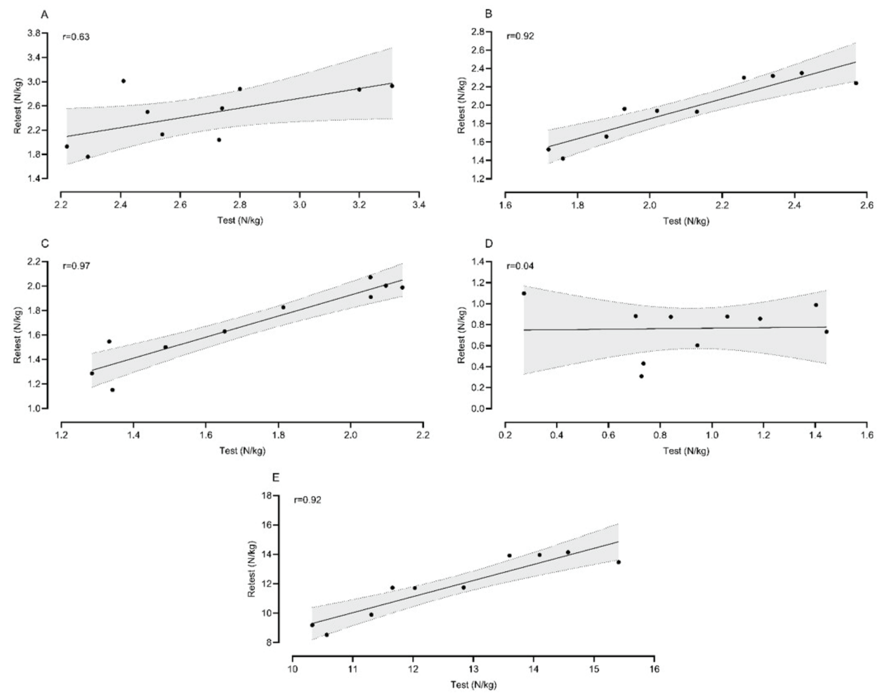

Figure 4. Pearson's r correlation for EKAT power outputs between test and retest measurement: (A) Peak Power; (B) Average Power; (C) Minimal Power; (D) Power Drop; (E) Anaerobic Capacity.

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T-test calculation demonstrates no significant differences between test and retest values of EKAT. Specifically, PP test values (2.67 ± 0.36) do not differ significantly from retest values (2.46 ± 0.46), with p = 0.34. A similar p-value was found for PD (0.93 ± 0.36 and 0.76 ± 0.25, respectively). For AP (test, 2.10 ± 0.29; retest, 1.96 ± 0.34) and AC (test, 12.64 ± 1.74; retest, 11.83 ± 2.07), the significance level is p = 0.11. The highest similarity between test (1.73 ± 0.35) and retest (1.69 ± 0.32) values was found for MP (p = 0.75) (see Table 3). Therefore, all derived power outputs are similar between the two measurements and show that all possible influences between tests were excluded.

Table 3. T-test for dependent samples between test and retest power outputs, of EKAT.

Variables	Test		Retest		t	p
	Mean	SD	Mean	SD		
Peak Power (N/kg)	2.67	0.36	2.46	0.46	1.14	0.27
Average Power (N/kg)	2.10	0.29	1.96	0.34	0.99	0.34
Minimal Power (N/kg)	1.73	0.35	1.69	0.32	0.23	0.82
Power Drop (N/kg)	0.93	0.36	0.76	0.25	1.22	0.24
Anaerobic Capacity (N/kg)	12.64	1.74	11.83	2.07	0.95	0.35

SD, Standard deviation; t, test value of T-test; p, level of significance set at p<0.05

Factor analysis extracted two significant factors. Factor one was correlated significantly with the PP (0.70), AP (0.99), MP (0.96), and AC (0.99) of the test measurement, with explained variance of 3.45 and a total proportion of 0.69. PD of the test measurement was included in factor two (-0.96) (see Table 4).

Correlation analysis between EKAT and WAnT showed no significant correlation between any of the measured power outputs. The only significant correlation was found between lactate levels measured before WAnT and after EKAT (r = -0.64) (see Table 5).

Table 4. Factor analysis for test and retest power outputs, of EKAT.

Variables	Factor (1)	Factor (2)
	Test	
Peak Power (N/kg)	0.70	-
Average Power (N/kg)	0.99	-
Minimal Power (N/kg)	0.96	-
Power Drop (N/kg)	-	-0.96
Anaerobic Capacity (N/kg)	0.99	-
EV	3.45	1.47
PT	0.69	0.29

EV, explained variance of factors; PT, Total proportion of factors

Table 5. Correlation between WAnT power outputs and EKAT.

Variables	Peak Power (W/kg)	Average Power (W/kg)	Minimal Power (W/kg)	Power Drop (W/kg)	Lactates WAnT pre (mmol/L)	Lactates WAnT post (mmol/L)
Peak Power (N/kg)	-0.49	-0.52	-0.41	-0.34	-0.25	-0.04
Average Power (N/kg)	-0.05	-0.07	-0.13	0.12	-0.08	0.21
Minimal Power (N/kg)	-0.10	-0.11	-0.19	0.10	-0.11	0.17
Power Drop (N/kg)	-0.35	-0.37	-0.17	-0.45	-0.14	-0.20
Anaerobic Capacity (N/kg)	-0.06	-0.07	-0.14	0.12	-0.08	0.20
Lactates pre (mmol/L)	-0.21	-0.26	-0.29	0.05	0.32	-0.24
Lactates post (mmol/L)	0.10	0.06	0.02	0.18	-0.64*	-0.38

*, significant correlations

Discussion

Water polo is considered to be an aerobic–anaerobic sport. Previous studies defined the aerobic capacity of water polo players using different sport-specific tests (e.g., swimming tests, VO2max analysis) (Galy et al., 2014; Meckel et al., 2013). However, an assessment of the anaerobic characteristics of players is lacking. Therefore, this study aimed to determine the validity and reliability of the newly developed eggbeater anaerobic test (EKAT) for water polo. Based on our results, we can highlight several important findings. First, the newly developed EKAT showed good reliability parameters. Second, retest measurement demonstrated consistency in the results for measured power outputs. Third, EKAT and WAnT showed no significant correlation between corresponding variables.

The results of this study demonstrate a high correlation between test and retest measurements. Specifically, average power, minimal power, and anaerobic capacity had high test–retest correlation coefficients (0.92, 0.97, and 0.92, respectively), whereas peak power showed a moderate effect (0.63). On the other hand, PD showed no significant correlation, with low reliability. Such results can be explained in two ways. First, retesting was done with 15 minutes of rest. Hence, the lack of rest for participants may be an influencing factor on the PD output, since it is a indicator of fatigue during the test (Ozkaya et al., 2018). This can be clearly seen in the PD results, where the test measurement (0.93 ± 0.36) is higher than the retest value (0.76 ± 0.25). Second, factor analysis of the test procedure extracted two significant factors, with the first one collecting all variables except PD in test measurement. Consequently, it can be noted that PD is a variable that indicates different capacity than the other power outputs. This result corroborates with previous findings, in which new variables for fatigue were considered rather than PD (Ozkaya et al., 2018; Pekünlü et al., 2016). Altogether, the results imply that the newly developed test is properly reliable when considering all variables except for PD.

The analysis of differences between test and retest measurements showed no significant difference between the two. This result implies that the measurement procedure is good, and excludes the effects of mastering the technique, becoming fatigued, or having too much time between measurements (influence of training, improved anaerobic capacity). Furthermore, this is a clear indicator of test stability through repeated measurements. Additionally, the power outputs of EKAT follow the traditional pattern of WAnT variables (PP, AP, MP, and PD) (Bar-Or, 1987). Therefore, the lack of differences can be compared to the results of previous studies examining WanT power outputs (Ozkaya et al., 2018; Pekünlü et al., 2016). The authors of these studies reported similar results for all derived parameters/variables in repeated WanT testing. Also, the descriptive parameters of EKAT indicate a slight decrease in force produced during the retest. This result is logical, since two measurements were made with a short rest in between. Nevertheless, the results indicate that the power output of EKAT could be used as an indicator of anaerobic work in sport-specific environments.

Descriptive statistics indicate that lactate levels ranged from 4.15 ± 1.21 mmol/L-1 before the test to 9.59 ± 2.63 mmol/L-1 after the test. Similar results for lactate levels have been seen in water polo players after a match. Specifically, according to Rodríguez (1994), these levels can increase up to 12.00 mmol/L-1. This similarity in lactate accumulation during EKAT and matches shows that the intensity of the test is appropriate for assessing water polo players. This can also be seen at water polo matches, where athletes perform high intensity intervals of anaerobic work during periods of attack and defence (Botonis et al., 2015). Additionally, EKAT is executed during a specific water polo movement, the eggbeater kick, which is a locomotor form used in 45–55% of the total game time (Platanou, 2004; Smith, 1998). Therefore, the similarity of our results to those of previous studies indicates that the newly developed test can measure the sport-specific anaerobic capacity of water polo players.

However, the correlation analysis between the Wingate anaerobic test and both measurements of the newly developed test showed no significant correlation between corresponding variables. Although such results could be interpreted as a certain lack of validity of the newly developed test, the authors believe that the low correlation between the sport-specific EKAT and the generic WAnT can be explained in terms of the differences in locomotor forms and the corresponding influence of anthropometric indices on text execution. Specifically, WAnT is performed on a bicycle ergometer, on which participants have to endure resistance (7.5% of body mass) for 30 seconds. Even though WAnT results are reported relative to body mass, it is an important factor of performance in this test (Galán-Rioja et al., 2020). On the other hand, in EKAT, tested athletes perform the specific water polo eggbeater kick with their legs while executing the rapid circulating manoeuvre with their hands, trying to generate the highest possible force. Contrary to WAnT, during EKAT body mass is not important in test execution because of the medium in which it is performed (i.e., water).

Supporting these results, previous studies reported similar results when comparing the Wingate test with other sport-specific tests (Bampouras & Marrin, 2009; Hoffman et al., 2000). Specifically, Hoffman et al. (2000) compared the Wingate test to a basketball-specific test (anaerobic sprint test, or line drill) and found no correlation between the fatigue indices. Moreover, Bampouras and Marrin (2009) examined the correlation between the Wingate test and sport-specific in-water tests for water polo players. The authors reported a lack of correlation between the Wingate test and water polo-specific tests for anaerobic power. They also suggested that the Wingate test is not a good indicator of decreased anaerobic performance in sports with an intermittent nature. Their results also suggest that the Wingate test cannot be used as an evaluation tool for the sport-specific parameters examined.

Limitations and strengths

One of the main limitations of this study is the relatively small sample size, Therefore, the results of the study should be considered as preliminary. Furthermore, this study is lacking important information on the performance level of study participants. Therefore, we could not correlate test achievement with objective parameters of success in sport. On the other hand, one of the strengths is that the players perform in one of the strongest leagues and most of them compete in senior championships as well. Also, the literature review showed a lack of investigation of sport-specific anaerobic capacity in water polo players. Therefore, this study is the first to develop such a test, which may be helpful for evaluating and assessing players' capacities.

Conclusion

A newly developed anaerobic water polo test, EKAT, has proper metric characteristics. This is demonstrated by the good sensitivity, homogeneity, reliability, and consistency of the measured power outputs. Since the test consists of the eggbeater kick, a technique that is used frequently in water polo, our results indicate that this test is applicable to water polo players. The results suggest that EKAT can measure the sport-specific anaerobic capacity of water polo players. This is supported by the lactate levels that players reached during the test, which were similar to those measured after a water polo match.

The most important advantage of this test is its non-invasiveness. In addition, the test incorporates several parameters applicable to the analysis of anaerobic endurance and strength capacity in water polo. However, a correlation between the generic and specific anaerobic tests was not found since they differ in specificity according to the athletes who perform in a specific medium. Therefore, EKAT should only be used to specifically assess anaerobic capacity in water polo. It is also possible to use the test for the selection of players during the training process.

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ORIGINAL SCIENTIFIC PAPER

Validity and reliability of a single-beam sensor for assessment of jump performance

Jeffrey Cayaban Pagaduan[1], Jan Charousek[2], Jan Dygrýn[1], Lukáš Rubín[1,2]

Affiliations: [1]Faculty of Physical Culture, Palacký University Olomouc, Czech Republic, [2]Faculty of Science, Humanities and Education, Technical University of Liberec, Czech Republic

Correspondence: Jeffrey Cayaban Pagaduan. Faculty of Physical Culture, Palacký University Olomouc, Czech Republic. E-mail: jcpagaduan@gmail.com

Abstract

This study aimed to establish the validity and reliability of a single-beam sensor for assessment of jump performance. Thirty-four male and female university students (age: 21.47 ± 0.98 years; height: 173.97 ± 9.32 cm; weight: 70.03 ± 10.63 kg) executed three trials of countermovement jump (CMJ) and three trials of squat jump (SJ), respectively. CMJ and SJ were simultaneously recorded using a force platform (reference) and single-beam jump sensor (Jump Pro). The flight time (FT) and jump height (JH) for both jumps were utilized for analyses. Results revealed the following for FT in CMJ performance: 1) Pearson's correlation coefficient (r) with lower limit (LL) and upper limit (UL) = 0.90 (0.82, 0.94); 2) Typical error of estimate (TEE) with LL and UL = 0.03 (0.01, 0.02); 3) Bland-Altman estimate = 0.05; and 4) Intraclass correlation coefficient (ICC) = 0.80. On the other hand, JH in CMJ posted: 1) r = 0.96 (0.94, 0.98); 2) TEE = 2.07 (1.73, 2.62); 3) Bland-Altman estimate = 4.00; and 4) ICC = 0.71. In regards to FT in SJ, r = 0.96 (0.94, 0.98), TEE = 0.02 (0.01, 0.02), Bland-Altman estimate = 0.03, and, ICC = 0.88. Further, JH in SJ exhibited r = 0.96 (0.94 – 0.98), TEE = 1.84 (1.53, 2.32), Bland-Altman estimate = 3.55, and ICC = 0.86. These findings support Jump Pro as a valid and reliable tool for measurement of CMJ and SJ performances.

Keywords: *testing equipment, fitness assessment, anaerobic power, stretch-shortening cycle*

@MJSSMontenegro
SINGLE-BEAM SENSOR FOR ASSESSMENT OF JUMP PERFORMANCE
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Introduction

Vertical jump (VJ) tests are common for assessment of the stretch-shortening cycle (SSC) capability, playing a crucial role in athletic performance (Secomb et al., 2015; Sheppard et al., 2008). The SSC is a natural muscle function wherein concentric action of a muscle is preceded by eccentric contraction (Nicol, Avela, & Komi, 2006). An efficient SSC demonstrates powerful propulsive force from concentric action (Flanagan & Comyns, 2008). Researchers identified VJ as a discriminating factor among elite vs. non-elite athletes (Trecroci, Milanović, Frontini, Iaia, & Alberti, 2018), starters vs. non-starters (Magrini et al., 2018; Sell et al., 2018), sprint vs. endurance athletes (Lewis, Young, Knapstein, Lavender, & Talpey, 2022), and fast vs. slow sprinters (Washif and Kok, 2022). Additionally, the utility of VJ has been extended to monitoring fatigue (Gathercole, Stellingwerff, & Sporer, 2015; Watkins et al., 2017) and training adaptations (Pagaduan, Schoenfeld, & Pojskić, 2019). The countermove-

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ment jump (CMJ) and squat jump (SJ) are usual tests for VJ. The CMJ measures the slow component of SSC (Laffaye & Wagner, 2013), while the SJ quantifies concentric-only muscle contraction (McBride, Kirby, Haines, & Skinner, 2010). The CMJ produces greater vertical jump compared to SJ due to the utilization SSC, contributing to greater work output (Bobbert & Cassius, 2005; Flanagan & Comyns, 2008). The ratio between CMJ and SJ referred to as eccentric utilization ratiois a practical insight of slow SSC ability (McGuigan et al., 2006).

Different tools are used to measure VJ. The force platform (FP) is considered as the gold standard for measurement of VJ. However, the FP is costly, requires technical expertise, and burdensome to transport. In the recent decade, there has been an emergence of low-cost tools for assessment of jump performance. Some of these include accelerometers (Choukou, Laffaye, & Taiar, 2014; Lake et al., 2018), contact mats (Leard et al., 2007; Pueo, Lipinska, Jiménez-Olmedo, Zmijewski, & Hopkins, 2017), optical timing systems (Bosquet, Berryman, & Dupuy, 2009; Castagna et al., 2013) and video-based mobile applications (Balsalobre-Fernández, Glaister, & Lockey, 2015; Haynes, Bishop, Antrobus, & Brazier, 2019; Montalvo, Gonzalez, Dietze-Hermosa, Eggleston, & Dorgo, 2021; Stanton, Wintour, & Kean, 2017). The availability of these technologies has increased the convenience of measuring jump performance, useful for making informed decisions in physical preparation.

In addition to the aforementioned multi-beam optical systems for jump measurement, a tool using a single-beam sensor (Jump Pro, Mobi Pro, Philippines) has been developed. However, there is no available study in terms of validity and reliability of such device. Such information may increase the confidence of practitioners for using the single-beam sensor. Therefore, this study aimed to identify the validity and reliability of a single-beam sensor in measurement of jump performance.

Methods

Experimental Approach

In this study, the researchers examined the validity, agreement, and reliability of flight time (FT) and jump height (JH) from the CMJ and SJ performances using a single-beam sensor (Jump Pro). Participants were asked to perform CMJ and SJ on a force platform (gold standard), while simultaneously measured from the Jump Pro. The Jump Pro displays FT and JH values via a developed mobile application. On the other hand, the FT from the force platform was used to estimate JH. Data from both equipment were examined using the Hopkins' validity and reliability spreadsheets (Hopkins, 2014, 2015).

Subjects

Thirty-four healthy male and female university students (age: 21.47 ± 0.98 years; height: 173.97 ± 9.32 cm; weight: 70.03 ± 10.63 kg) volunteered to participate in this study. Participants have no physical limitations or any injury that affected their ability to perform the jump trials. A signed consent form was obtained prior to further participation. The participants were asked to refrain from any strenuous activity 24 hrs before experimentation and maintain regular dietary habits. The study was approved by the Faculty of Physical Culture Ethics Committee of Palacký University Olomouc (reference number: 21/2023). The study was conducted in accordance with the Ethical principles of the 1964 Declaration of Helsinki and its later amendments.

Procedures

The study involved a single experimentation session between 1000 am – 1200 pm at a fitness room in the Technical University of Liberec. Upon arrival, measurement of height (Leicester Height Measure Mk II) and weight (Xiaomi Mi Body Composition Scale 2) were administered. Then, participants performed a standardized warm-up that consisted of light jogging (5 minutes), dynamic stretching exercises (squat, lunge and reach, reverse lunge and twist, leg swing to toe touch, and knee hug to quadstretch) for 2 sets of 5 repetitions, and 20 jumping jacks. This was followed by a 3-minute active rest (walking/moving to the next activity). After, participants proceeded with CMJ and SJ testing. Twenty-four hours before the testing session, the protocol of the study was explained to the participants, followed by familiarization of CMJ and SJ tests.

Measures

Countermovement Jump. Participants assumed a static position with hands on waist and feet shoulder-width apart. After, participants executed a countermovement, succeeded by vertical jump. Three trials were administered, with intratrial rest of 30 seconds. However, the tester administered additional trial/s upon assessment of faulty jump execution. The FT and JH of the best trial were utilized for validity analysis. A three-minute rest ensued after CMJ testing.

Squat Jump. Participants assumed a similar starting position with CMJ. Then, participants positioned the knees at approximately 90-degrees for 3 seconds. This was followed by a vertical jump, with hands kept on the waist in the entire duration of the jump. The trial with highest FT and JH was used for analysis.

Equipment

Jump Pro. The Jump Pro (Mobi Pro, Philippines) is portable jump measurement tool that utilize a single-beam laser to detect flight time. The emitter (E3F12-30DN1-5V M12 30m sensing DC 5V NPN NO laser, Finglai Electric, China) and receiver (controller: nRF5282, Nordic Semiconductor ASA, Norway)were set at 1 m apart, powered by a portable charger. To minimize error, participants were asked to jump/land on a designated marker, wherein the fifth hallux approximately in line with the laser beam (6). After each jump trial, the FT and JH are displayed on a mobile application developed for Jump Pro. The JH was estimated using the flight time formula (H = 0.5g x t2), where H refers to height of the jump, g is the acceleration due to gravity, and t as the time from take-off to peak of the jump (Bosco, Luhtanen, & Komi, 1983; Moir, 2008)

Force platform. A commercial force platform Quattro Jump (Kistler, Switzerland) was used as the reference criterion. The force platform was connected to a software (Quattro Jump Software, Kistler, Switzerland) at a sampling rate of 1000 Hz. The raw data was extracted to an excel spreadsheet, and used to determine FT, wherein start and stop of FT was computed immediately after zero force and resumption of force measurement, respectively. Then, estimation of JH was performed using similar formula employed in Jump Pro. Figure 2 exhibits the equipment set-up for this study.

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Figure 1. Jump Pro Device.

Statistical Analysis

Descriptive statistics are presented as mean ± standard deviation. Criterion validity was investigated using the Pearson's correlation coefficient (r) interpreted as very weak (<.20), weak (.20-.40), moderate (.40-.70), strong (.70-.90), and very strong (>.90) (Learner and Goodman, 1996). Also, the typical error of estimate (TEE) was used to determine the threshold of disagreement, interpreted as trivial (0.00–0.10), small (0.11–0.30), moderate (0.31–0.60), large (0.61–1.00), very large (1.01–2.00), or impractical (>2.00). The Bland-Altman estimate was also utilised to establish the agreement between the force platform and Jump Pro (Bland and Altman, 1986). The intraclass correlation coefficient (ICC) was utilized to determine intratrial reliability, with ICC values referred as trivial (<0.10), small (0.10–0.30), moderate (0.30–0.50), high (0.5–0.70), very high (0.70–0.90), and practically perfect (>0.90) (Banyard, Banyard, Nosaka, & Haff, 2017). The Hopkins' validity and reliability spreadsheets were utilized in this study (Hopkins, 2014, 2015).

Figure 2. Equipment Set-up.

Results

Table 1 displays the validity and reliability values of CMJ and SJ using the single-beam sensor.

Results revealed that the FT of CMJ in Jump Pro demonstrated r = 0.90 (0.82, 0.94), TEE = 0.03 (0.01, 0.02), and Bland-Altman estimate of 0.05. The ICC of jump trials for FT of CMJ in Jump Pro was 0.80. In regards to JH of CMJ, the r = 0.96 (0.94, 0.98), TEE = 2.07 (1.73, 2.62), and Bland-Altman estimate = 4.00, with ICC = 0.71.

The FT for SJ posted the following: 1) r = 0.96 (0.94, 0.98); 2) TEE = 0.02 (0.01, 0.02), 3) Bland-Altman estimate = 0.03; and, 4) ICC = 0.88. On the other hand, JH of SJ showed: 1) r = 0.96 (0.94 – 0.98); 2) TEE = 1.84 (1.53, 2.32), Bland-Altman estimate = 3.55; and 4) ICC = 0.86.

Table 1. Validity and reliability of CMJ and SJ indices in Jump Pro.

	Flight Time					Jump Height				
	Time (ms)	ICC	*r* (LL, UL)	TEE (LL, UL)	Bland-Altman Estimate	Height (cm)	ICC	*r* (LL, UL)	TEE (LL, UL)	Bland-Altman Estimate
CMJ										
Jump Pro	0.521 ± 0.054	0.80	0.90 (0.82, 0.94)	0.03 (0.01, 0.02)	0.05	33.09 ± 7.50	0.71	0.96 (0.94, 0.98)	2.07 (1.73, 2.62)	4.00
Force Platform	0.501 ± 0.062	0.97				31.26 ± 7.72	0.92			
SJ										
Jump Pro	0.494 ± 0.055	0.88	0.96 (0.94, 0.98)	0.02 (0.01, 0.02)	0.03	30.13 ± 6.61	0.86	0.96 (0.94, 0.98)	1.84 (1.53, 2.32)	3.55
Force Platform	0.482 ± 0.057	0.92				28.84 ± 6.77	0.92			

-ICC – intraclass correlation coefficient; LL – lower limit; UP – upper limit; TEE – typical error of estimate

Discussion

This study aimed to establish the validity and reliability of a single-beam sensor for measuring CMJ and SJ jump performances. Results revealed that Jump Pro demonstrated valid FT and JH values in CMJ and SJ. Additionally, the reliability for both the FT and JH from the CMJ and SJ in Jump Pro were acceptable.

Indeed, the CMJ and SJ indices from Jump Pro demonstrated valid outcomes. These results are in line with previous studies that measured CMJ and SJ using optical timing systems (Lewis et al., 2022; Leard et al., 2007). Further, the Bland-Altman estimates and TEE values of all CMJ and SJ indices posted in acceptable agreement between Jump Pro and force platform. On the other hand, the results of the JH of CMJ in Jump Pro contrasted the findings from JH of CMJ (Parmar, Keenan, & Barry, 2021; Watkins, Maunder, van den Tillaar, & Oranchuk, 2020) and JH of SJ (Watkins et al., 2020) from a similar technology using a single-beam sensor. The overestimation from the previous technology may be due to forward displacement during landing and/or sensor position. The validity results of Jump Pro suggest the practicality of such a tool as an alternative equipment to a force platform.

In this study, the FT and JH values in CMJ and SJ in Jump Pro exhibited acceptable reliability. The reliability of JH values from CMJ and SJ in Jump Pro are in accordance with the results posted by Watkins et al., 2020. Therefore, CMJ and SJ can be measured consistently in Jump Pro.

Limitations of this current study are acknowledged. First, only CMJ and SJ tests were used in this study, restricting utility for assessment of SSC function. Future studies should employ jump tests (e.g. drop jump) that may help elucidate information on other lower body contractile properties. Second, the hands-on-waist procedure was administered in this study to reduce the influence of arm swing on performance (Lees, Vanrenterghem, & De Clercq, 2004). Establishing the validity of other protocols that facilitate maximal jumps, providing more value for practical inference should be warranted. Lastly, only intraday reliability was assessed in this study. Conducting additional test-retest reliability studies with Jump Pro may help identify potential systematic bias or random error of such equipment (Atkinson and Nevill, 1998).

Conclusion

In summary, the results in this study suggest that Jump Pro is a valid and reliable tool for measuring FT and JH in both CMJ and SJ tests. With this, the Jump Pro can be used interchangeably with the force platform for acquisition of similar indices.

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Conflicts of Interest

The first author of the article is the co-developer of the single-beam sensor and co-designer of the mobile application.

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ORIGINAL SCIENTIFIC PAPER

The effects of single and combined jump exercises utilizing fast and slow stretch-shortening cycle on physical fitness measures in healthy adult males: A randomized controlled trial

Rohit K. Thapa[1], Utsav Chaware[2], Bhargav Sarmah[2], José Afonso[3], Jason Moran[4], Helmi Chaabene[5,6], Rodrigo Ramirez-Campillo[7]

Affiliations: [1]Symbiosis School of Sports Sciences, Symbiosis International (Deemed University), 412115 Pune, India, [2]School of Physical Education and Sports, Rashtriya Raksha University, Gandhinagar 382305, India, [3]Centre for Research, Education, Innovation, and Intervention in Sport (CIFI2D), Faculty of Sport of the University of Porto, Rua Dr. Plácido Costa, 91, 4200-450 Porto, Portugal, [4]School of Sport, Rehabilitation and Exercise Sciences, University of Essex, Colchester, Essex CO43SQ, United Kingdom, [5]Division of Training and Movement Sciences, Research Focus Cognition Sciences, University of Potsdam, Am Neuen Palais 10, Building 12, 14469 Potsdam, Germany, [6]High Institute of Sports and Physical Education of Kef, University of Jendouba, Kef 7100. Tunisia, [7]Exercise and Rehabilitation Sciences Institute, School of Physical Therapy, Faculty of Rehabilitation Sciences, Universidad Andres Bello, Santiago 7591538 Chile

Correspondence: Dr. Rohit K. Thapa. Symbiosis School of Sports Sciences, Symbiosis International (Deemed University), 412115 Pune, India. E-mail: rohit.thapa@ssss.edu.in

Abstract

This study aimed to compare the effects of six-week volume-equated jump training using drop jump (DJ), countermovement jump (CMJ), or a combination of both (COMB) on the physical fitness of adult males. Participants were randomly assigned to DJ (n=10), CMJ (n=9), or COMB (n=10) training groups or an active control group (n=7). Performance data were collected for 10-m and 30-m sprint, DJ, CMJ, standing long jump (SLJ), triple-hop jump, change of direction speed (CODS), and maximal isometric strength. The DJ demonstrated improvements in the 10-m sprint, CMJ, and SLJ (g=0.62–1.13, %Δ=3.0–10.8). The CMJ group improved in the 10-m and 30-m sprints, CODS, CMJ and SLJ (g=0.34–1.17, %Δ=3.4–10.5). The COMB group displayed progress in CMJ and SLJ (g=0.46–0.61, %Δ=6.4–8.6). In comparison to the control and COMB groups, the DJ and CMJ groups improved the 10-m sprint (p=0.008, ηp2=0.311), and in comparison to the control group, the CMJ group improved SLJ (p=0.037, ηp2=0.220). To conclude, the findings presented here deviate from the training principle of specificity, particularly in relation to ground contact time. This suggests that the classification of jump exercises into fast- and slow-SSC categories based solely on ground contact time might oversimplify a more intricate phenomenon.

Keywords: *Plyometric exercise; human physical conditioning; resistance training; muscle strength; athletic performance*

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Conflict of interest: None declared.

Introduction

Jump training (JT) is a training method that usually involves using an individual's own body mass as resistance to induce distinct physical and physiological adaptations (Ramirez-Campillo, Moran, et al., 2020). JT serves as a cost-effective training approach, providing numerous physical fitness benefits across diverse populations, including physically active adults (Singh, Kushwah, Singh, Thapa, et al., 2022). The essence of JT lies in the utilization of the "stretch-shortening cycle" (SSC), encompassing three consecutive phases during movement. These are the eccentric, the amortization, and the concentric phases (Seiberl et al., 2021). The SSC action allows the muscles and tendons to store and utilize elastic energy during a pre-stretch movement (i.e., eccentric phase) with the resultant energy being released when the muscle is shortened (i.e., concentric phase) (Bobbert et al., 1996). Furthermore, JT exercises are typically categorized as fast-SSC (<250 ms) or slow-SSC (>250 ms), based on the duration of the ground contact time of a given jump (Duda, 1988). For example, the bounce drop jump (DJ) exercise is often categorized as a fast-SSC exercise as the feet are in contact with the ground for less than 250 ms during the eccentric pre-stretch phase of the movement (Pedley et al., 2017) as are any subsequent jumps carried out in series. The countermovement jump (CMJ), on the other hand, is categorized as a slow-SSC exercise because the feet have a ground contact time of more than 250 ms during movement (McMahon et al., 2018).

Further to the above, the DJ involves jumping or dropping from a raised platform (e.g., plyometric box) and immediately performing a vertical jump upon landing (Pedley et al., 2017) so as to minimize ground contact time whilst maximizing jump height (Pedley et al., 2017). This facilitates a larger magnitude of eccentric loading and therefore training with such an exercise improves the elastic capacity of the lower limbs by increasing the stiffness of the Achilles tendon (Laurent et al., 2020). In contrast, the CMJ exercise requires an individual to be in a standing position after which a pre-stretch (i.e. downward phase of a jump) is initiated prior to a vertical jump (Asmussen & Bonde-Petersen, 1974).

When formulating specific JT interventions, coaches can prescribe a combination of jump-type exercises, such as the DJ and the CMJ, to target a broad segment of the force-velocity curve so as to enhance a wide variety of physical fitness metrics (Ramírez-Campillo, Burgos, et al., 2015; Ramírez-Campillo, Gallardo, et al., 2015; Ramirez-Campillo et al., 2022). Improvements that are obtained through the execution of JT can be partially attributed to the task-specific similarity of the selected jump and the athletic movement it is being used to improve. For example, sprinting requires utilization of the fast-SSC (~150 ms ground contact time) (Ammann et al., 2016) while change of direction (COD) movements require utilization of both fast (i.e., during straight sprinting) and slow (~500 ms ground contact time during turning movement) SSC (Dos'Santos et al., 2020). Accordingly, utilizing jumps with specific SSC-orientated characteristics may induce improvements that are closely related to those exhibited during execution of the athletic task (e.g., fast-SSC for linear sprinting; slow-SSC for turning movement in COD).

Despite the above, there are few JT studies that compare the effects of isolated JT exercises, such as the DJ (i.e., fast SSC) and CMJ (i.e., slow SSC) on physical fitness (Ruffieux et al., 2020; Thomas et al., 2009). In one study that did, Thomas & colleagues (Thomas et al., 2009) failed to report the ground contact time of the DJ exercises during executed training sessions and did not assess DJ performance as an outcome measure (e.g., jump ground contact time, height, and reactive strength index [RSI]). In addition, Ruffieux & colleagues (Ruffieux et al., 2020) used the 'countermovement' DJ and not the 'bounce' DJ in an intervention which compared DJ to CMJ over a six week period. Furthermore, previous research that focused on isolated forms of JT compared only unilateral and bilateral jumps (Bogdanis et al., 2019; Ramírez-Campillo, Burgos, et al., 2015) or horizontal and vertical jumps (Loturco et al., 2015; Ramírez-Campillo, Gallardo, et al., 2015; Talukdar et al., 2022). Moreover, previous studies compared isolated forms of JT that utilized the slow SSC exercise category alone (e.g., CMJ versus horizontal jumps) (Loturco et al., 2015) or compared JT exercises utilizing the slow SSC (e.g., horizontal jumps) versus fast combined with slow SSC (e.g., DJ combined with CMJ) (Talukdar et al., 2022).

Due the above-mentioned limitations within the existing body of literature, which might restrict practitioners' comprehension of the distinct effects of jumps utilizing fast or slow SSCs, this study was designed to assess and compare the outcomes of a six-week of JT using DJ (representing fast-SSC), CMJ (representing slow-SSC), or a combined approach (COMB), on selected measures of physical fitness in healthy adult males. Considering the common ground contact time continuum (e.g., ≤250 to >250 ms) usually observed in sprinting, jumping, and CODS exercises-tests, and the potential relevance of ground contact time during JT exercises to induce adaptations, based on the principle of training specificity (e.g., specific adaptation to imposed demands) (Ammann et al., 2016; Davies et al., 2015; Dos'Santos et al., 2020; Duda, 1988; McMahon et al., 2018; Pedley et al., 2017) we hypothesized that there would be i) greater improvements in sprinting and DJ performance after DJ training, ii) greater improvements in CMJ, SLJ, and triple hop test performance after CMJ training, and iii) greater CODS improvements after COMB training.

Methods

Experimental design

The study was designed taking into consideration international guidelines for quality-based randomized controlled trials (e.g., CONSORT). A two (within-subject; pre-post) by four (between-subject; DJ group, CMJ group, COMB group, control group) randomized controlled study design was conducted to compare the effects of the three different JT interventions on various measures of physical fitness. Baseline and post-intervention assessments were performed at similar times during the day with at least 48 hours of rest after the most recent training session. The sequence of the testing order was the same for all the participants and tests. For outdoor assessments during the pre- and post-intervention testing sessions, the temperature, humidity, and wind velocity were 31.8 – 33.1° C, 40 – 57 %, 3.8 – 6 km/h, respectively.

A total of five familiarization sessions (20 – 30 min duration each) were conducted for the DJ and CMJ exercises'

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technical execution before the intervention and group allocations were conducted. The first, second, and third sessions were focused on the correct technical execution of jumping and landing. During the same sessions, instructions related to the ground contact time were given. The focus was placed on a few important cues such as (i) [keeping] the spine erect and shoulders back, (ii) [positioning the] chest over knees, (iii) jumping straight up with no excessive side-to-side or forward-backward movement, (iv) [execute a] soft landing including toe-to-heel motion and bending of the knees and (v) [jumping as quick as possible] minimal ground contact for the concentric part of the jump (for the DJ). The fourth and fifth sessions were focused on the familiarization of a typical DJ and CMJ session (50 jumps in total were performed in each session; from low to near-maximal or maximal intensity effort) to be used during the intervention. Only participants with the ability to perform both DJ and CMJ with the correct techniques (i.e., ability to adhere to the five cues mentioned above) were finally recruited for the study. Demographic and anthropometric data were collected, and the testing procedures were also explained during the familiarization sessions. In addition, the proper use of a visual analogue scale and session rating of perceived exertion (sRPE) were explained and practiced during the familiarization sessions. Participants were asked to i) refrain from strenuous activity 24 hours before testing and ii) eat (up to 3 hours before testing) and drink habitually. The CONSORT flow diagram is provided in Figure 1.

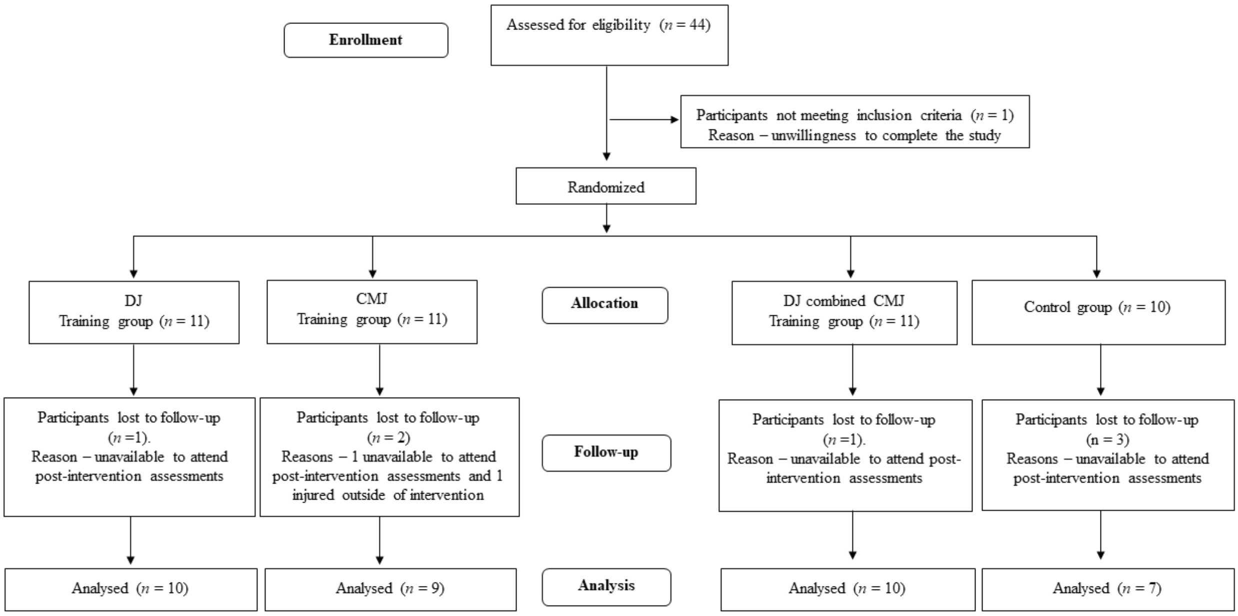

Figure 1. CONSORT flow diagram

Participants

The required sample size was estimated using statistical software (G*power; University of Düsseldorf, Düsseldorf, Germany). The following variables were included in the a priori power analysis: study design, four groups; two measurements; alpha error <0.05; nonsphericity correction =1; correlation between repeated measures = 0.7; desired power (1-ß error) = 0.80; and effect size (f) of 0.33 (i.e., large effect [Cohen d value of 0.66 reported for CMJ converted to Cohen f]), based on prior research investigating the effects of eight-weeks JT with similar study design (i.e., three experimental and one control group) in physically active young males (Ramirez-Campillo et al., 2021).

The results of the a priori power analysis indicated that a minimum of five participants would be required for each group to achieve statistical significance for the main outcome of the study (i.e., CMJ). However, due to the potential for participant attrition in such a trial, we attempted to maximize participant recruitment (n=44). Thereafter, each participant was assessed for eligibility based on the inclusion criteria that required them to be: i) physically active adults who undertook 150 – 300 minutes of moderate-intensity physical activity a week or 75 – 150 minutes of vigorous-intensity physical activity per week; ii) free from any major lower limb injury in the past six months; iii) able to perform both DJ and CMJ with correct technique (detailed information available in the experimental design section) and free from major discomfort or pain; iv) willingness to undergo twelve intervention training sessions as well as fitness tests before and after the intervention. Participants

Table 1. Demographics of the participants in the experimental and control group

	DJ	CMJ	COMB	Control	P – value*
Age	19.9 ± 1.2	20.9 ± 2.3	19.8 ± 1.2	20.4±1.4	0.435
Height	171.5 ± 6.2	176.6±10.6	174.0±6.1	177.0±6.7	0.474
Body mass	62.3 ± 8.6	63.2 ± 9.8	60.8 ± 12.1	61.7±12.5	0.968

Note: CMJ – countermovement jump training group, COMB – drop jump combined countermovement jump training group, DJ – drop jump training group. *one-way analysis of variance were not excluded based on JT compliance although attendance analysis based on categorizations were performed to explore potential effects on pre- to post-test changes. The eligible participants were randomly assigned (using an online randomization tool; www.randomizer.org) to either the DJ training group, the CMJ training group, the COMB training group, or the control group, using a 1:1:1:1 allocation ratio. The allocation sequence was concealed from those implementing the intervention. § The descriptive information of the participants in each group is presented in Table 1. The potential risks and benefits of this study were explained to the participants before they took part. Thereafter, informed consent forms were signed by the participants. The Internal Review Board of   provided ethical approval to conduct the study (approval no.) following which the research protocol was prospectively registered on the OSF platform on 13/04/2023 with the doi . The study was conducted according to the guidelines of Declaration of Helsinki.

Training intervention

The experimental groups followed the JT training protocol for six weeks duration which is sufficient to assess the induced effects in a non-athlete population (Markovic & Mikulic, 2010). A weekly frequency of two sessions was selected based on previous indications that such a JT frequency is likely sufficient to induce positive adaptations (Ramirez-Campillo et al., 2018). A total of 12 sessions were completed by each experimental group. The control group did not perform any form of JT during the six-week period but did continue their normal physical activity routine of 150-300 minutes of moderate or 75-150 minutes of vigorous physical activity, as did the experimental groups. The JT exercises replaced part of the regular physical activity time. Specific instructions were given to the participants while performing DJ and CMJ. During DJ, the participants were instructed to jump as high and fast as possible while minimizing the ground contact time, and during CMJ to jump as high as possible. The participants were instructed to wear the same type of shoes during the training interventions. A soft surface (i.e., natural grass football pitch) was used in weeks 1 and 2 and, thereafter, a hard surface (i.e., concrete) in the remaining weeks to gradually increase the load on the Achillis tendons (Ramirez-Campillo, Álvarez, et al., 2020). Detailed information regarding the weekly training load and progression used is provided in Table 2. In addition, a minimum of three participants from the DJ group and COMB group were asked (at random) to perform DJ repetitions during training sessions using contact time jump platforms (Chronojump Boscosystem, Barcelona, Spain) to check jump ground contact time (i.e., <250 ms) in weeks 2, 4, and 6.

Table 2. Training load for drop jump (DJ), countermovement jump (CMJ), and DJ combined CMJ training (COMB).

	DJ group	CMJ group	COMB‡
	Repetitions × block × series		
Week 1 – 2	10 × 3 × 3	10 × 3 × 3	10 × 3 × 3
Week 3 – 4	12 × 3 × 3	12 × 3 × 3	12 × 3 × 3
Week 5 – 6	14 × 3 × 3	14 × 3 × 3	14 × 3 × 3

* Rest between repetitions, blocks, and series: 3 – 5 s, 60 s, and 180 s, respectively; ‡ The three groups completed a total of 1,296 jumps during intervention. The combined group completed 648 drop jumps and 648 countermovement jumps.

Physical fitness tests

The physical fitness tests were conducted on two separate days, with 30 m linear sprints and CODS performed on day one (i.e., outdoor assessments) and lower body power (i.e., all jump assessments) and isometric maximal strength test performed on day two (i.e., laboratory assessments) (Thapa et al., 2024). All the tests were conducted by the same research assistants who were blinded to the participants' group allocation. Prior to the tests, the participants underwent a general warm-up of ~10 minutes consisting of running at a self-selected speed and involving change of direction actions, followed by short sprints, and dynamic stretching. Thereafter, specific warm-ups were performed according to the test to be performed.

Sprint Speed

A 30 m linear sprint test was conducted with a 10m split time using a reliable dual-beam timing system (Chronojump Boscosystem, Barcelona, Spain) (Thapa, Sarmah, et al., 2023). The testing protocol was conducted on a natural grass surface. Three trials were conducted with a rest of one minute between trials. The best trial was selected for the analysis. The interclass correlation coefficient (ICC) with 95% confidence interval (CI) was 0.86 (0.80 – 0.91) and 0.89 (0.84 – 0.93) for 10 m and 30 m, respectively.

Lower body jump-related performance

Lower body jump-related performance was assessed using the CMJ, DJ, ground contact time and RSI measured from a 20 cm box, SLJ and triple hop jump test (double leg) for distance. A portable contact mat (Chronojump Boscosystem, Barcelona, Spain) was used to analyze the CMJ and DJ. The SLJ and triple hop test were conducted inside a laboratory as described in a previous study (Singh, Kushwah, Singh, Ramírez-Campillo, et al., 2022) and was measured using a tape. Three trials were conducted for all jump tests and the best trial was selected for the analysis. The ICC with 95% CI were 0.92 (0.88 – 0.94) for CMJ height, 0.93 (0.90 – 0.95) for DJ height, 0.79 (0.71 – 0.86) for DJ contact time, 0.82 (0.75 – 0.86) for DJ RSI, 0.79 (0.71 – 0.85) for SLJ distance, and 0.86 (0.78 – 0.91) for triple hop distance.

Change of direction speed

Change of direction speed was assessed using the modified T-test and was conducted with methods outlined in a previous study (Thapa, Clemente, et al., 2023). One pair of dual beam photocell timing gates (Chronojump Boscosystem, Barcelona, Spain) was used to record the time in seconds (Thapa, Sarmah, et al., 2023). Three trials were conducted, and the best trial was selected for analysis. The ICC with 95% CI for CODS time was 0.85 (0.78 – 0.90).

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Isometric maximal strength

Isometric maximal strength (i.e., isometric mid-thigh pull) was measured with a portable strain gauge (Chronojump Boscosystem, Barcelona, Spain) attached to a leg dynamometer. Briefly, the participants were asked to stand upright on the base of the dynamometer with their feet shoulder-width apart. Participants were instructed to hang their arms straight down to hold the bar at the centre with both hands, with palms facing towards the body. Flexion of knees were allowed at approximately 110 degrees, thereafter the chain was adjusted. The subjects were then asked to pull as hard as possible for a duration of ~ 5 seconds and asked to straighten the legs without bending the back. Peak and average force were recorded for each participant. Three trials were conducted with rest of three minutes between trials and the best trial was selected for analysis. The ICC with 95% CI were 0.89 (0.94 – 0.93) and 0.88 (0.81 – 0.92) for peak force and average force, respectively.

Pain analogue scale

A visual analogue scale (0 to 10 point scale) was used to assess acute pain due to the intervention training (Bijur et al., 2001). Each participant was asked to rate pain in lower limb muscles with scores ranging from 0 (i.e., no pain) to 10 (i.e., worst possible pain). The data were recorded immediately, 24 hours, and 48 hours after the first (i.e., at week 1) and last (i.e., at week 6) training session.

Statistical analyses

The normal distribution of the data was tested using the Shapiro-Wilk test. The normality assumptions were violated for DJ contact time, DJ RSI, and SLJ for CMJ group and for 30 m linear sprint time in the control group. Following the visual inspection of the histogram (i.e., data were skewed), a two-step approach method was used for the transformation of the non-normal data (to normal) to perform the parametric tests. Normally distributed data were presented as mean and standard deviation, while non-normally distributed data were presented as median and interquartile range. One-way analysis of variance and Kruskal-Wallis test were used to analyze the demographic and pain analogue data. Two (pre-post) by four (DJ, CMJ, COMB, control) mixed design analysis of variance (ANOVA) was used to find the interaction effects. Further, analysis of covariance (ANCOVA), using the baseline as a covariate was employed to detect possible between-group differences after training. Partial eta squared ($\eta p2$) derived from the ANCOVA output were used as effect size scores. Post-hoc tests using Bonferroni corrections were conducted to detect the exact location of differences between groups. Further, paired t-test were conducted to assess within-group changes. Hedges' g (t-test effect sizes) was calculated to assess the magnitude of improvement from pre- to post-intervention in all groups. Percentage change scores were also calculated for each variable in each group using the equation in Microsoft Excel sheet: [(meanpost – meanpre)/meanpre] × 100. The magnitude of effects for $\eta p2$ was interpreted as small (<0.06), moderate (≥0.06-0.13), and large (≥0.14) (Cohen, 1988), while Hedge's g was interpreted as trivial (<0.2), small (0.2-0.6), moderate (>0.6-1.2), or large (>1.2-2.0) (Hopkins et al., 2009). In addition, the reliability of the testing procedures was assessed using the ICC between trials and was interpreted as poor (<0.5), moderate (0.5-0.75), good (0.75-0.9), and excellent (>0.9) reliability based on the lower bound of the 95% CI (Koo & Li, 2016). Statistical significance was set at $p \leq 0.05$.

Results

Deviation from registered protocol

There were a few deviations in the current study from the original protocol published in the OSF platform with doi on 13/04/2023. Firstly, the session rating of perceived exertion (sRPE) for each training session were not included in this article. The reason for this decision was an insufficient number of sRPE data reported in each of the groups in the study. Since sRPE data collection was conducted using google forms after 30 minutes of completion of the experimental session, the researchers involved did not have control over this element of the data collection process making compliance amongst the participants less likely. Secondly, due to logistical reasons, the data for body composition could not be retrieved for all of the participants. Thirdly, the data for the rate of force development and impulse during the IMTP tests were not reliable, hence we removed this data from the current study. Lastly, the analysis of inter-individual responses to training was considered too lengthy and difficult to accommodate in this paper. To provide adequate context, a comprehensive analysis, and insightful interpretation, the results of inter-individual responses are considered for a secondary analysis manuscript.

Adverse effects

No participants were injured during the interventions. However, dropouts were observed in the experimental groups (n = 3) and control group (n = 3) due to participants' unavailability for post-test data collection. One participant in CMJ group sustained injuries outside of the intervention and couldn't complete the study.

Pain analogue scale

There were no significant differences between the experimental groups in pain analogue score immediately, 24 hours, and 48 hours after the first training session (Kruskal-Wallis p = 0.390 – 0.750). However, a significant difference between groups was observed 24 hours (Kruskal-Wallis p = 0.020) after the last training session of the intervention, with greater pain perceived with COMB compared to CMJ training (p = 0.027). No other between-group differences were observed immediately or after 48 hours (Kruskal-Wallis p = 0.552 – 0.880) of the last training session of the intervention.

Within-group changes

Outcome measures at pre- and post-intervention are presented in Table 3, and Hedges g data are presented in Table 4. Pre- to post-improvements (all p<0.05) were observed in the DJ group in 10 m sprint (g = 1.13, %Δ = 6.1), CODS (g = 0.84, %Δ = 3.0), CMJ height (g = 0.85, %Δ = 10.8), and SLJ distance (g = 0.62, %Δ = 5.1). Similarly, the CMJ group improved (all p<0.05) 10 m sprint (g = 0.89, %Δ = 5.4), 30 m sprint (g = 0.67, %Δ = 3.4), CODS (g = 0.34, %Δ = 2.1), CMJ height (g = 1.12, %Δ = 10.5), and SLJ distance (g = 0.97, %Δ = 8.9). The COMB group improved (all p<0.05) CMJ height (g = 0.46, %Δ = 8.6), and SLJ distance (g = 0.56, %Δ = 6.4). No significant within-group improvements were noted in the control group. A graphical representation of pre- to post-intervention percentage change is presented in Figure 2.

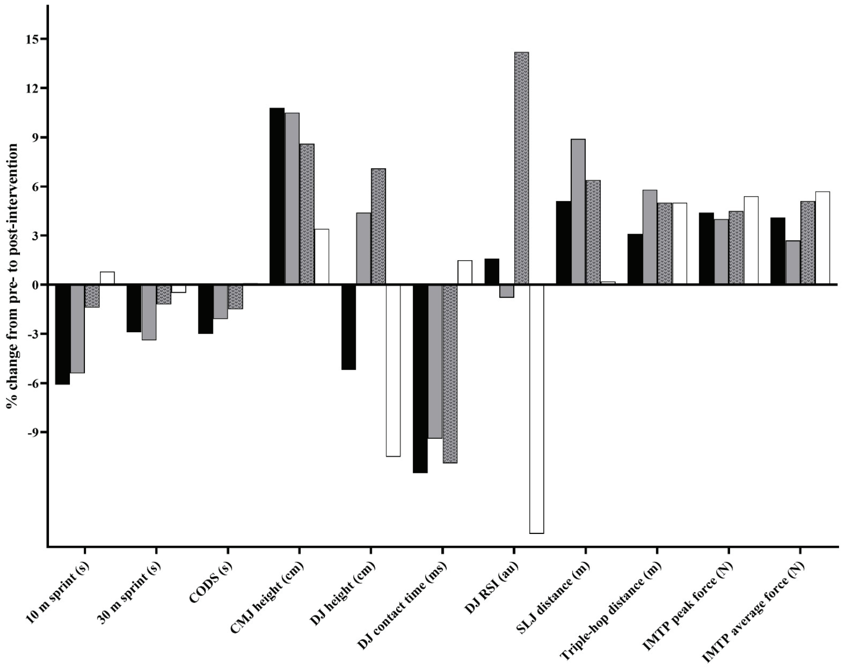

Figure 2. Graphical representation of pre- to post-intervention percentage change in outcome variables for each group. Note – black, gray, gray dotted, and white bars denote drop jump (DJ), countermovement jump (CMJ), COMB training groups, and control group, respectively. CODS – change of direction speed, RSI – reactive strength index, SLJ – standing long jump, IMTP – isometric mid-thigh pull.

Table 3. Comparisons for changes in outcome variables between drop jump (DJ), countermovement jump (CMJ), COMB (DJ combined CMJ), and control groups.

Variables	DJ group		CMJ group		COMB group		Control group		ANCOVA P-value
	Mean ± standard deviation/ Median (Interquartile range)								
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	
10 m sprint (s)	1.8±0.1	1.7±0.1*ab	1.8±0.1	1.7±0.1*cd	1.8±0.2	1.8±0.1	1.8±0.1	1.8±0.1	0.008#
30 m sprint (s)	4.5±0.2	4.4±0.2	4.4±0.3	4.2±0.2*	4.5±0.4	4.5±0.3	4.5 (3.3–4.6) †	4.4±0.3	0.160
CODS (s)	11.3±0.4	11.0±0.4*	11.1±0.8	10.9±0.5*	11.3±0.4	11.1±0.6	11.5±1.2	11.5±1.2	0.125
CMJ height (cm)	32.8±4.3	36.3±3.6*	34.8±2.6	38.4±3.6*	30.1±4.7	32.7±5.8*	31.5±5.2	32.5±5.0	0.125
DJ height (cm)	28.4±5.5	26.9±4.6	29.3±5.2	30.6±6.6	24.6±5.0	26.3±5.9	29.4±3.7	26.3±4.3	0.162
DJ contact time (ms)	0.24±0.05	0.22±0.02	0.22 (0.19–0.26) †	0.23±0.02	0.24±0.04	0.21±0.02	0.24±0.04	0.24±0.03	0.076
DJ RSI (au) ‡	1.8±0.4	1.2±0.3	1.2±0.4	1.3 (1.1–1.3) †	1.0±0.3	1.2±0.3	1.2±0.3	1.1±0.2	0.243
SLJ distance (m)	2.3±0.2	2.4±0.2*	2.4±0.2	2.5 (2.5–2.8) † *d	2.2±0.2	2.4±0.3*	2.3±0.2	2.3±0.1	0.037#
Triple-hop distance (m)	6.4±0.5	6.6±0.6	6.7±0.7	7.1±0.5	6.1±0.8	6.4±0.9	6.1±0.5	6.4±0.5	0.522
IMTP peak force (N)	1886±306	1969±236	2063±278	2146±445	1904±266	1991±315	1868±292	1970±241	0.979
IMTP average force (N)	1826±284	1900±193	1970±238	2023±417	1849±283	1945±307	1835±291	1939±130	0.989

Note: IMTP – isometric mid-thigh pulls, RSI – reactive strength index, ‡ – au: arbitrary units denoting the ratio between flight time and time contact), SLJ – standing long jump, a, b – significant difference compared to control and COMB groups, respectively. c, d – significant difference compared to COMB and control groups, respectively. * – within-group pre to post significant difference, # – significant group × time interaction, † – non-normally distributed data, presented as median and interquartile range.

Between-group changes

The ANCOVA revealed significant between-group differences in 10 m sprint time ($p = 0.008$, $\eta p2 = 0.311$) and SLJ distance ($p = 0.037$, $\eta p2 = 0.220$) at post-test. The post-hoc analysis with Bonferroni corrected t-test revealed improved 10 m sprint time in the DJ group and CMJ group compared to the control ($p = 0.018$ and $p = 0.009$, respectively) and COMB groups ($p = 0.018$ and $p = 0.010$, respectively). Further, SLJ improved in the CMJ group compared to control group ($p = 0.041$).

Discussion

This study aimed to conduct a comparative analysis of the effects resulting from six weeks of JT employing DJ (representing fast-SSC), CMJ (representing slow-SSC), or a combined

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protocol (COMB) on selected measures of physical fitness in healthy adult males. Based on the principle of training specificity (e.g., specific adaptation to imposed demands) (Ammann et al., 2016; Davies et al., 2015; Dos'Santos et al., 2020; Duda, 1988; McMahon et al., 2018; Pedley et al., 2017) we hypothesized that there would be i) greater improvements in sprinting and DJ performance after DJ training, ii) greater improvements in CMJ, SLJ, and triple hop test performance after CMJ training, and iii) greater CODS improvements after COMB training. Although all three JT interventions induced overall improvements in participants' physical fitness , particularly the isolated application of DJ and CMJ training exercises when compared to a control condition , the study's findings contradicted our hypotheses and the training specificity principle. Specifically, DJ training did not lead to more significant improvements in sprinting compared to CMJ training or greater enhancements in DJ performance compared to COMB or CMJ training. Similarly, CMJ training did not result in greater improvements in CMJ, SLJ, or the triple hop test compared to DJ or COMB training. Additionally, COMB training did not yield greater CODS improvements than all other interventions.

The findings of our study suggest that significant improvements can be achieved in 10 m linear sprint time (i.e., acceleration speed) through the execution of both DJ or CMJ after six weeks of training. Similarly, SLJ was improved in the CMJ group compared to the control group. Our results confirm the findings of previous studies that reported improvements in linear sprint performance (Sáez de Villarreal et al., 2012) and SLJ (Singh, Kushwah, Singh, Thapa, et al., 2022) after JT training. The observed improvement in the 10 m linear sprint time and SLJ distance may be related to the neuromuscular adaptations commonly observed after JT, including a greater number and/or rate of motor units recruited in agonist muscles, improved intra- and inter-muscular coordination via enhanced muscle activation strategies, changes in muscle architecture or improved stiffness of various elastic components of the muscle-tendon complex (Moran et al., 2023) (e.g., plantar flexors) leading to better SSC muscle function (e.g., re-utilization of elastic energy). These adaptations can improve force expression resulting in increased sprinting speed and jump distance (Markovic & Mikulic, 2010). In addition to these adaptations, DJ training could also have improved ground contact time during sprinting (Rimmer & Sleivert, 2000), while CMJ training may have improved the stride length during sprinting (Tottori & Fujita, 2019).

Of note, contrary to our hypothesis DJ training did not induce greater improvements in sprinting when compared to CMJ training. This hypothesis was primarily based on the assumptions (i.e., specificity training principle) that fast-SSC exercise (i.e., lower ground contact time) would improve the fast-SSC muscle function with greater magnitude compared to a slow-SSC exercise (i.e., higher ground contact time). However, we did not observe significant improvements in the ground contact time or the RSI after DJ training, which may partly explain why the sprinting performance did not improve when compared to CMJ training. Nonetheless, a previous JT study (8 weeks, 3 sessions/week) carried out in male physical education students aged 20.2 years reported improvements in sprinting performance with no concomitant decreases in ground contact time or RSI obtained from a DJ test (Coşkun et al., 2022). These findings suggest that improved sprinting performance through JT cannot be only attributed to ground contact time or RSI. These contrasting results demonstrate the multifactorial nature of sprinting performance (e.g., running speed; jump height-distance; CODS) (Coyle, 1995; Saunders et al., 2004; Sheppard & Young, 2006) and it is therefore plausible that both DJ and CMJ training can improve linear sprinting speed through differing adaptive neuromuscular pathways that were not identified in our study. For example, DJ training may improve the acceleration speed through reduced ground contact time during sprinting, without changes in stride length (Rimmer & Sleivert, 2000), while CMJ training may increase sprinting speed in line with increased stride length during sprinting, without changes in sprinting ground contact time (Tottori & Fujita, 2019). Indeed, it may also be possible that the CMJ training improved the propulsive impulse during the starting phase (i.e., the first few steps) resulting in an improved acceleration speed (Martín-Fuentes & van den Tillaar, 2022). Moreover, it may also be possible that both DJ and CMJ have increased the force production capabilities of the lower-limb muscles (without any influence in the GCT). However, future studies may consider the inclusion of ground contact time measurements not only during training sessions but also during sprinting test sessions.

In a similar vein to the above, we also hypothesized that slow-SSC-based CMJ training could stimulate greater improvements in similarly slow-SSC-based activities with resultant improvements in CMJ, SLJ and triple hop tests as compared to DJ training. However, contrary to our hypothesis, improvements of a similar magnitude were also observed in CMJ and SLJ through both DJ and CMJ training. As with sprinting speed performance, jumping performance is influenced by multiple intertwining factors (Aragón-Vargas & Gross, 1997). Accordingly, similar to the sprint speed tests described above, CMJ and DJ training might have improved jump performance to a similar magnitude through different adaptive mechanisms (e.g., motor unit recruitment vs. force production) (Markovic & Mikulic, 2010; Mero et al., 1992). Indeed, previous studies have also reported similar improvement in CMJ height after six weeks of bounce DJ (aiming to increase jump height while minimizing ground contact time) and countermovement DJ (aiming to increase jump height only) (Thomas et al., 2009; Young et al., 1999). In addition to this, the participants in our study were physically active adult males who did not have prior experience of executing DJ exercises. Accordingly, it may be plausible that the DJ training stimulus (producing force within a short timeframe) was sufficient to induce adaptations that resulted in improved CMJ performance.

We also hypothesized that greater improvements would be observed in CODS that utilizes both slow and fast SSC through a COMB training approach in comparison to DJ or CMJ training. However, we did not observe any significant difference in improvements between COMB training and DJ training or CMJ training and the control group. Our training intervention consisted exclusively of vertical jumps. A previous meta-analysis reported that a combination of depth jumps, vertical jumps and standing long jumps (i.e., vertical combined horizontal) induced greater improvements in CODS compared to depth jump or CMJs alone (Asadi et al., 2016). In addition, another study (Dello Iacono et al., 2017) also reported greater CODS improvements with horizontal drop jump training compared to vertical jump training in elite handball athletes. Indeed, Moran & colleagues (Moran et al.,

2021) also reported that horizontally-oriented JT was more effective than vertically-oriented JT in improving the horizontally-orientated movement, a key element in CODS. Indeed, CODS is heavily dependent on horizontally-orientated force production with faster athletes showing greater peak and mean horizontal propulsive forces, shorter ground contact times, more horizontally orientated peak resultant braking and propulsive forces, and greater horizontal to vertical mean and peak braking and propulsive force ratios over key instances of CODS movements (Dos'Santos et al., 2020). In this sense, a classification of exercises as fast-SSC or slow-SSC based only on ground contact time to prescribe JT exercises may not represent an optimal approach. A specification of other factors may be required, such as the pattern of force application (vertical vs horizontal), the symmetrical or asymmetrical nature of the exercise (e.g., unilateral vs bilateral) and the training status of the athlete (Moran et al., 2023).

Limitations

Some limitations should be acknowledged. Firstly, the participants in our study were physically active students but they had no prior experience of DJ training. The low training level of the participants may have distorted the specificity effect as untrained individuals appear more adaptable to neuromuscular training stimuli (Rhea et al., 2003). Thus, the training principle of specificity could be moderated by the training level of the participants. This is line with guidelines for exercise prescription across several groups and institutions (e.g., ACSM (2009) position stand on progression models for resistance exercise, etc.). Secondly, the duration of the study was limited to six weeks. However, this current study may be a basis for future long-term studies comparing fast- versus slow-SSC-based intervention across different populations (e.g., athletes) and confirm if similar findings are observed. Thirdly, although we computed the sample size requirements using appropriate methods prior to the start of the study, a larger sample may be appropriate for generalization of the findings. Fourthly, including biomechanical assessments as outcome variables during tests such as sprint, CODS, CMJs or DJs may provide deeper insights into the differences between kinetics as well as kinematic changes occurred during these tasks. Lastly, the inclusion of sRPE measurements could have provided an insight into the psycho-physiological aspects of the training load exerted by the experimental groups. Although our registered protocol included this measurement, we could not analyze the data due to low number of participants submitting the data (69 sRPE scores were submitted out of 348).

Conclusions

Although within-group improvements were observed in outcome variables after all three JT interventions, particularly notable for 10 m sprint after DJ training and CMJ training, and in SLJ after CMJ training, the present findings diverge from the conventional training principle of specificity, specifically the concept of ground contact time. Alternatively, it is conceivable that the classification of JT exercises based solely on fast-SSC (<250 ms ground contact time) and slow-SSC exercises (>250 ms ground contact time) might be an oversimplification of a multifaceted phenomenon. Therefore, to achieve more optimal and targeted JT exercise prescription, it might be wise to incorporate additional variables beyond ground contact time. These could encompass the direction-vector of force application (e.g., vertical, horizontal, combined), asymmetry movement pattern (e.g., unilateral jump, bilateral jump) and the training status of the individual, among other factor.

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Availability of data and material

All data generated or analyzed during this study will be/are included in the published article as Table(s) and Supplementary Table(s). Any other data requirement can be directed to the corresponding author upon reasonable request.

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ORIGINAL SCIENTIFIC PAPER

Differential ratings of perceived exertion to quantify weekly and sessional internal load in basketball: an exploratory team-based case series

Eider Iglesias-Torres[1], Asier Gonzalez-Artetxe[1], Aaron T. Scanlan[2], Asier Los Arcos[1,3]

Affiliations: [1]Department of Physical Education and Sport, Faculty of Education and Sport, University of the Basque Country, UPV/EHU, Vitoria-Gasteiz, Araba, Spain (AGA: https://orcid.org/0000-0001-5007-4524; https://twitter.com/3asiergonzalez), [2]Human Exercise and Training Laboratory, School of Health, Medical and Applied Sciences, Central Queensland University, Rockhampton, Queensland, Australia (https://orcid.org/0000-0002-0750-8697; https://twitter.com/AaronTScanlan), [3]Society, Sports and Physical Exercise Research Group (GIKAFIT), University of the Basque Country, UPV/EHU, Vitoria-Gasteiz, Araba, Spain (https://orcid.org/0000-0003-1001-7706)

Correspondence: Asier Gonzalez-Artetxe, Faculty of Education and Sport, University of the Basque Country, UPV/EHU, Lasarteko atea 71; 01007 Vitoria-Gasteiz, Araba, Spain. E-mail: asier.gonzalez@ehu.eus

Abstract

Although differential rating of perceived exertion (RPE) scales have been supported in quantifying internal load across various sports, their application in basketball remains to be comprehensively investigated. Consequently, we aimed to: (1) quantify and compare session- and weekly-RPE loads using global and differential RPE scales; and (2) compare session-RPE load between individual sessions across the week using each scale in basketball players. Ten semiprofessional, male players reported RPE using global and differential (respiratory and muscular) scales following each training session and game during the in-season. RPE was multiplied by session duration to derive session-RPE load, which were summed to determine weekly-RPE load. Weekly-RPE load was higher using global ($P = 0.003$, $\eta 2 = 0.343$, large) and muscular ($P = 0.004$, $\eta 2 = 0.209$, large) scales than the respiratory scale. Likewise, session-RPE load was higher using global ($P = 0.049$, $\eta 2 = 0.314$, large) and muscular ($P = 0.054$, $\eta 2 = 0.298$, large) scales than the respiratory scale only in games, with differences between scales during other sessions being trivial-to-medium ($P > 0.05$). Across all scales, higher session-RPE loads were apparent in the second training session than all other sessions in the week ($P < 0.05$, $\eta 2 = 0.105$–0.561, medium-to-large), and during games than the first training session ($P < 0.001$, $\eta 2 = 0.202$–0.223, large). While session-to-session load changes were similarly detected across scales, the greater weekly and game muscular loads than respiratory loads support the potential for differential RPE scales to provide more detailed internal load data in basketball settings.

Keywords: *periodization, training load, perceived exertion, performance, perceptual*

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Introduction

Monitoring player loads has become commonplace among basketball teams (Fox, Scanlan, et al., 2020). Player loads can be categorized as external or internal, whereby external load represents the physical stimuli applied while internal load represents the responses of players to the external stimuli (Bourdon et al., 2017). While basketball practitioners prescribe the training load according to the external load, it is the internal load that determines the training outcome in players (Impellizzeri et al., 2019). In this way, measuring player ratings of perceived exertion (RPE) following training sessions or games and multiplying these individualized ratings by the session duration to determine session-RPE load is the most frequently used approach to quantify internal load in basketball players (Piedra et al., 2021).

When applying the session-RPE method to measure internal load, it has been argued that a single RPE scale is insufficient to represent the various perceptual sensory responses experienced during exercise (Hutchinson & Tenenbaum, 2006). Consequently, differential RPE scales have been applied in several team sports for internal load monitoring to represent more distinct sensory inputs than traditional global RPE scales (Los Arcos et al., 2016; McLaren et al., 2017; Weston et al., 2015). Differential RPE scales were developed to distinguish between central and peripheral factors contributing to the global RPE (Ekblom & Golobarg, 1971). In this way, central factors are typically measured using perceptual RPE breathlessness scales, or respiratory RPE, and peripheral factors are typically measured using perceptual leg-muscle exertion scales, or muscular RPE (Borg et al., 2010; Ekblom & Golobarg, 1971; Pandolf et al., 1975). However, research using differential RPE scales to quantify internal load is lacking in basketball, with studies only examining basketball players during 3 vs. 3 national-level games within a two-day tournament (McGown et al., 2020) as well as 4 vs. 4 small-sided and competitive wheelchair games (Iturricastillo et al., 2016, 2017). Consequently, no research has applied differential RPE scales to quantify internal loads during training in any basketball populations and during games in traditional 5 vs. 5 competitions.

When examining load monitoring methods, it is important to ensure translatable outcomes stem from research. In this regard, basketball practitioners consistently implement load monitoring to understand how training demands differ between sessions and relative to games (Fox, Scanlan, et al., 2020). Indeed, research has supported differential RPE scales in providing unique insight compared to global RPE scales regarding differences in session-RPE loads encountered between training sessions in field-based team sport (McLaren et al., 2017); however, these findings should not be simply transferred to basketball given the varied demands encountered (Taylor et al., 2017) will likely impose specific perceived respiratory and muscular exertion across sports. Nevertheless, differential RPE scales to measure session-RPE load specifically in basketball players has been encouraged in the literature to identify whether they provide added insight into the training response (Fox et al., 2022). Therefore, this study aimed to: (1) quantify and compare session- and weekly-RPE loads using global and differential RPE scales; and (2) compare session-RPE load between individual sessions across the week using each scale in basketball players.

Materials and methods

Participants

Ten semiprofessional, male basketball players (age: 23.3 ± 3.0 years [range: 19–28 years]; height: 1.94 ± 0.12 m; body mass: 87.1 ± 13.2 kg; competitive basketball experience: 14.9 ± 3.1 years) competing in the Liga Española de Baloncesto Aficionado (EBA) were recruited for this study. Players completed 84–100% of sessions during the monitoring period. Players completed three on-court team training sessions lasting between 50–140 min and one official game each week (Table 1). All procedures conformed to the Declaration of Helsinki and the Code of Conduct Ethics Committee of Publications. This study was approved in advance by the Institutional Review Committee of the Sports and Youth Institute of Navarre. Each participant voluntarily provided written informed consent before participating.

Table 1. The weekly training and game schedule completed by the semiprofessional, male basketball players throughout the monitoring phase in this study.

Day	Physical fitness contents	Basketball-specific contents
Monday	Core stability or agility	Technique
Tuesday	Rest	Rest
Wednesday	Strength or speed	Technique + tactics
Thursday	Rest	Rest
Friday	Injury prevention	Tactics + shooting
Saturday/Sunday	Official game played on either day	

Study design

An exploratory team-based case series study design was adopted. This observational approach involved all players from the same semiprofessional basketball team being monitored during a 6-week in-season period (January–March) across the 2021/22 season (Figure 1). Internal load was measured throughout the monitoring period via individualized session-RPE being collected from each player following training and games using global, respiratory, and muscular scales. Session-RPE was used to derive loads for each individual session within the week and cumulatively across the week. Comparisons in load were then made between scales (for each session and weekly) and between sessions within the week (for each scale).

Procedures

Players reported individualized RPE from 0 (rest) to 10 (maximal) using Foster's 0-10 scale (Foster et al., 2001) sep-

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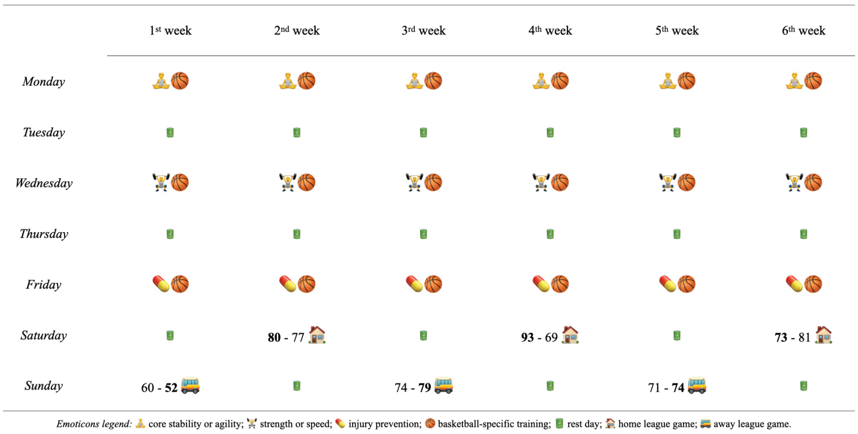

Figure 1. The training and match schedule completed by the semiprofessional, male basketball players throughout the six weeks of this study

arately for global, central (respiratory), and peripheral (muscular) exertion 10–20 min following each training session and game (Iturricastillo et al., 2017; Los Arcos et al., 2016; McLaren et al., 2017). Each player provided their RPE to the strength and conditioning coach in the absence of other players to avoid peer influence (Minett et al., 2022). Players consistently answered the following questions when providing their RPE (Foster et al., 2001): How hard has the session been? How hard has the session been at the respiratory level? How hard has the session been at muscular level?

The duration of each training session was recorded from the commencement of the warm-up to the completion of training activity with rest periods included and cool-down exercises excluded (Ferioli et al., 2018). The duration of each game was recorded from commencement (tip-off) to completion including rest periods (Ferioli et al., 2018). RPE using each scale were multiplied by the duration (minutes) for each training session and game to calculate session-RPE load (Foster et al., 2001). When players completed all scheduled training sessions and were available to compete in the game for a given week, their data were tabulated to calculate weekly-RPE load using each scale. Players were familiarized with using each RPE scale for four weeks prior to data collection.

Analysis

All variables did not meet the assumptions for a normal (Gaussian) distribution, and therefore were log-transformed (Newans et al., 2022). In turn, data are described using means and 95% confidence intervals (CI). Linear mixed models were used to compare weekly session-RPE load between scales with scale inputted as a fixed effect (43 samples per scale) and player (n = 10) inputted as a random effect to account for repeated observations. Furthermore, separate linear mixed models were used to compare session-RPE load between sessions within the week for each scale (i.e., first training session [52 samples] vs. second training session [53 samples] vs. third training session [59 samples] vs. game [48 samples]), where session number was inputted as a fixed effect, while week (n = 6) and players (n = 10) were inputted as random effects. Eta squared (η2) was calculated to assess the magnitude of pairwise differences – interpreted as: trivial, <0.01; small, 0.01–0.06; medium, 0.06–0.14; and large, >0.14 (Cohen, 1988). Statistical significance was set at P <0.05 and analyses were performed using Jamovi software (The jamovi project [2022], version 2.3.2).

Results

Mean weekly- and session RPE loads using each scale are presented in Table 2 with effect sizes for all pairwise comparisons shown in Table 3. Comparisons between scales revealed weekly-RPE load was higher using global (P = 0.003, large) and muscular (P = 0.004, large) scales than the respiratory scale. In contrast, trivial-to-medium differences (P >0.05) in session-RPE loads were evident between scales in each session, except during games where global (P = 0.049, large) and muscular (P = 0.054, large) scales yielded higher session-RPE loads than the respiratory scale.

Table 2. Mean [95% CI] weekly- and session-RPE load using different RPE scales in a semiprofessional, male basketball team.

RPE load	RPE scale		
	Global (AU)	Respiratory (AU)	Muscular (AU)
Weekly-RPE load	2407 [1933; 2880]*	2187 [1714; 2660]	2414 [1942; 2888]*
Session-RPE load			
Training session 1	483 [363; 602]	442 [322; 562]	488 [368; 608]
Training session 2	791 [646; 937]†	745 [600; 891]†	787 [642; 933]†
Training session 3	558 [456; 660]‡	517 [415; 618]‡	559 [457; 660]
Game	633 [495; 770]‡#	571 [433; 708]‡	651 [513; 788]‡

Abbreviations: CI, confidence intervals; RPE, rating of perceived exertion; AU, arbitrary units. Note: * significantly (P <0.01) higher weekly-RPE load than respiratory scale; † significantly (P <0.05) higher session-RPE load than training session 1, training session 3, and game for that scale; ‡ significantly (P <0.05) higher session-RPE load than training session 1 for that scale; # significantly (P <0.05) higher session-RPE load than respiratory scale during games.

Table 3. Effect sizes (η2) for pairwise comparisons in weekly- and session-RPE load between scales and in session-RPE load between sessions for each scale in a semiprofessional, male basketball team.

	RPE scale		
	Global vs. respiratory	Global vs. muscular	Respiratory vs. muscular
Weekly-RPE load	0.343, large	0.016, small	0.209, large
Session-RPE load			
Training session 1	0.020, small	0.001, trivial	0.021, small
Training session 2	0.064, medium	0.001, trivial	0.028, small
Training session 3	0.162, large	0.002, trivial	0.113, medium
Game	0.314, large	0.028, small	0.298, large
Comparison	Global	Respiratory	Muscular
Training session 1 vs. 2	0.561, large	0.426, large	0.450, large
Training session 1 vs. 3	0.045, small	0.036, small	0.042, small
Training session 2 vs. 3	0.433, large	0.302, large	0.331, large
Training session 1 vs. game	0.223, large	0.217, large	0.202, large
Training session 2 vs. game	0.182, large	0.145, large	0.105, medium
Training session 3 vs. game	0.104, medium	0.053, small	0.115, medium

Abbreviations: RPE, rating of perceived exertion. Note: All effect sizes are presented as positive values to show the magnitude of differences in pairwise comparisons.

Comparisons between individual sessions in the week using each RPE scale revealed higher ($P < 0.05$, medium-to-large) session-RPE loads in the second training session than all other sessions, as well as during games than the first training session ($P < 0.05$, large). Moreover, while significantly higher session-RPE loads were detected in the third training session than the first training session using global ($P = 0.009$) and respiratory ($P = 0.024$) scales, these differences were only small in magnitude.

Discussion

Our exploratory team-based case series provides the first internal load data derived using differential RPE scales during training and games in basketball players, with some notable findings, including: (1) higher weekly-RPE loads and session-RPE loads during games were measured using global and muscular scales than the respiratory scale; and (2) all scales yielded the highest session-RPE load in the second training session as well as in games than the first training session within the week.

The comparisons made in weekly-RPE load and session-RPE load between scales suggest that deconstructing global RPE into respiratory and muscular components elucidates a lower central and higher peripheral contribution to perceptual loading accumulated across the week and in games, but not during individual training sessions. Unlike our findings, similar loads have been reported using respiratory and muscular RPE scales across the week (Gil-Rey et al., 2015) and during games (Los Arcos et al., 2014) among male soccer players. These discrepancies across sports might be expected given the greater running requirements across longer periods, and therefore higher cardiopulmonary demands, during soccer activity (Bangsbo et al., 2006) compared to basketball (Stojanović et al., 2018). Consequently, muscular RPE scales may be particularly useful in quantifying internal load accumulated across weekly timeframes and during games in basketball given the high neuromuscular stress relative to the cardiopulmonary demands encountered (Stojanović et al., 2018); however, further research is warranted to explore this notion given we also found comparable weekly and game loads between global and muscular scales. The limited differences in session-RPE load between respiratory and muscular scales during individual training sessions concurs with previous research exploring entire training sessions in male soccer players (Los Arcos et al., 2014) and 16-min 4v4 small-sided games among male, wheelchair basketball players (Iturricastillo et al., 2017). Therefore, the collective evidence suggests that the combined central and peripheral inputs may limit the ability of differential RPE scales to provide unique insight into the perceptual demands experienced at the session level in training settings.

Comparisons in session-RPE load within the week revealed similar load periodization schemes were detected across scales, with elevated loads in the second training session and game alongside reduced loads in the first and third training sessions in the week. This trend mirrors those reported previously in professional, male basketball players (Manzi et al., 2010), suggesting coaches in senior basketball teams likely prescribe less stressful sessions early in the week to promote post-game recovery and late in the week as a taper to mitigate players carrying residual fatigue into games (Mujika et al., 2018). Interestingly, the game did not yield the highest session-RPE load within the week using any scale, probably due to variations in playing time during games among the monitored players (mean live playing time: 10-28 min). In this way, significantly higher session-RPE loads have been observed during games but not training in players completing high playing times compared to players completing low playing times among national-level, female basketball players (Paulauskas et al., 2019).

While our exploratory investigation provides novel insight into the use of differential RPE scales in basketball players, the team-based case series we implemented limited the sample size for each analysis. Further research incorporating larger and wider (i.e., different age groups and competition encompassing males and females) basketball player samples are encouraged to confirm our findings. Moreover, we determined internal load during on-court team training sessions in their entirety. In turn, more research is encouraged quantifying

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session-RPE load using different scales during specific training modes in basketball players (e.g., conditioning, technical, tactical, resistance) given variations between scales have been documented to emerge according to training mode in other team sports (McLaren et al., 2017; Wright et al., 2020). Nevertheless, our study supports the potential utility of differential RPE scales in providing unique insight into the internal loads experienced among basketball teams given variations in the accumulated weekly loads and game loads observed between scales.

Conclusions

Given the simplicity and cost-effectiveness of using RPE scales combined with the minimal burden placed on players in collecting data, basketball coaching staff may be able to easily include differential RPE reporting within team monitoring systems to gain more detailed insight into the internal load encountered among their players. More precisely, the higher weekly-RPE load and session-RPE load during games we observed with the muscular compared to respiratory scale suggests basketball activities involve a greater contribution of peripheral neuromuscular stress than central cardiopulmonary stress in eliciting perceptual demands. Consequently, differential RPE scales may inform the development of more precise player preparation strategies considering respiratory and muscular exertion each provoke specific recovery requirements and adaptive responses. Also, session-to-session fluctuations in perceptual demands across the week appear to be similarly detected using global, respiratory, and muscular RPE scales in a basketball team environment.

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ORIGINAL SCIENTIFIC PAPER

Static alignment of the upper limb and performance of athletes with spinal cord injuries

Lale Pooryamanesh[1], Miran Kondrič[2,3], Petra Rajković Vuletić[4], Mateo Blažević[4], Hassan Daneshmandi[1]

Affiliations: [1]University of Guilan, Faculty of Physical Education and Sports Science, Khalij-e-Fars Highway, Qazvin Rasht, Rasht, Guilan, Iran, [2]University of Ljubljana, Faculty of Sport, Gortanova ulica 22, 1000 Ljubljana, Slovenia, [3]International Table Tennis Federation, Lausanne, Avenue de Rhodanie 54, 1007 Lausanne, Switzerland, [4]University of Split, Faculty of Kinesiology, Teslina 6, 21000 Split, Croatia

Correspondence: L. Pooryamanesh. University of Guilan, Faculty of Physical Education and Sports Science, Khalij-e-Fars Highway, Qazvin Rasht, Rasht Guilan, Iran. Email: lale.pooryamanesh@gmail.com

Abstract

In athletes with spinal cord injuries, due to relying on upper limbs and activities such as driving a wheelchair and repeating specific movement patterns, significant structural changes occur in their upper limbs. Those changes lead to muscle imbalance and disorders in the shoulder girdle and upper limb. Investigation of the relationship between forward head angle, round shoulder, and kyphosis with physical capabilities (power, range of motion, wheelchair propulsion and sitting balance) in wheelchair athletes. 15 male and 13 female wheelchair athletes with Spinal cord injury (age 27.64±7.24) in basketball, pétanque and table tennis were selected. The sagittal view photogrammetry method was used to measure the forward head angle and round shoulder angle. A flexible ruler was used to measure the thoracic kyphosis angle. Additionally, a medicine ball throw to measure power, a goniometer to estimate the range of motion, a 20-meter propulsion test to measure propulsion speed, and a sitting balance test to measure balance were used. Descriptive statistics, Pearson correlation coefficient and stepwise multiple regression were applied to analyse the data at the 0.05 significance level. There was only a significant relationship between the round shoulder with the balance in three directions and throwing the ball. However, in other variables, there is no significant relationship with static alignment. Despite the slight difference in the investigated indicators in this study, it is important from a clinical point of view. For coaches, including the necessary preventive and corrective measures in athlete's training programs is better.

Keywords: *Disability, spinal cord injury, correlation, elite athletes*

@MJSSMontenegro
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Introduction

Disability is a long-term, substantial condition that affects all or part of a person's body and impairs or limits physical function, mobility, or skill. Loss of physical capacity decreases a person's ability to perform physical movements such as walking, moving hands and arms, sitting and standing, and muscle control. As a part of society, people with physical disabilities need sports and movement programs. Adopting a continuous

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and incredibly inactive posture in a wheelchair can cause the spine to become out of alignment. Disabled athletes with spinal cord injuries have lost part of their ability based on the type of disability. Therefore, they can be exposed to spine abnormalities due to their sedentary life. Any deformity in the trunk and thoracic spinal cord (such as hyper kyphosis) may reduce muscle strength and range of motion and decrease lung volume (Roshani et al., 2018). In addition, disabled athletes with spinal cord injuries who participate in high-level sports activities are continuously exposed to musculoskeletal disorders, which seem to be caused by exercise and the nature of each sport (Fullerton et al., 2003). Athletes with spinal cord injury suffer from muscle fatigue and eventually pain due to relying on the upper limb in the movement of pushing the wheelchair forward and performing repetitive movements for a long time with the upper limb (Samuelsson et al., 2004). Muscle imbalance plays an essential role in the development of musculoskeletal pain when using a wheelchair. It can affect the body's natural alignment and cause a person to suffer from various postural abnormalities (Freitas et al., 2021). People with spinal cord injuries have skeletal abnormalities of the upper body, leading to muscle imbalance (Wilbanks & Bickel, 2016).

On the other hand, people with spinal cord injuries who use wheelchairs adopt the wrong sitting position due to the imbalance of the trunk muscles, which causes kyphosis, rounded shoulder, and forward head angle in the long term (Medicine, 2005). Sahrmann (2010) states that repetitive movements or continuous positions can change the relationship between length-tension, strength, and stiffness of muscles. As a result, these adaptations may cause movement disorders. Among the complications that may occur due to a change in static alignment are a change in the physical capabilities of the upper limb and a decrease in its function. The muscle group of the shoulder girdle movement includes the pectoralis major, upper trapezius, shoulder elevator and upper deltoid (Williams Jr et al., 2020). The group of stabilisers includes rhomboid, anterior, serratus posterior deltoid, supraspinatus, and teres minor, which are the group of moving muscles prone to shortening and the group of stabilising muscles prone to weakness and stretching (Williams Jr et al., 2020). Disturbances in the static alignment of the upper limbs lead to a decrease in the subarachnoid space, rotator cuff and biceps tendonitis, impingement syndrome and other musculoskeletal disorders, which are more common in wheelchair users and athletes who are participating in sports activities (Yazdani et al., 2021).

Clinical theory suggests that changes in the static alignment of the upper body cause a decrease in muscle function (Turbanski & Schmidtbleicher, 2010). Therefore, we hypothesised that the angles of the forward head angle, kyphosis and round shoulder can be related to the physical capabilities of the upper limb. Therefore, the present research aims to investigate the relationship between the static alignment of the upper limb and the movement performance of athletes with spinal cord injuries.

Methods

Participants

15 male and 13 female (age 27.64±7.24) wheelchair athletes with Spinal cord injuries were randomly selected and participated in this study. The criteria for entering the study included: 1- Female and male athletes with spinal cord injuries who are classified in the sitting group in the relevant sports classification of the Federation of Veterans and Disabled Sports of the Islamic Republic of Iran. 2- Willingness to participate in the research. 3- Age above 18 years. 4- Having at least two years of experience in wheelchair basketball, table tennis and pétanque. 5- Having the conditions and requirements listed in the physical activity readiness questionnaire (PARQ).

Design

Table 1 shows the demographic information of the participants. The results of similar previous studies and Gpower software were used to determine the sample size in this research. Tests related to muscle power, sitting balance, range of motion, wheelchair propulsion, forward head angle, rounded shoulder and kyphosis were measured. To prevent fatigue during the execution of each test, a 5-minute rest interval was considered. Seca 664 digital scale (Seca, Germany) was used to measure the subjects' body weight. To measure sitting height, the distance from the base of the head to the base of the sitting surface was calculated. The body profile photography method measured forward head and rounded shoulder angles. This method has good reproducibility and has been used in the research of Rajabi et al. (2008). Using this method, three anatomical signs of the earlobe, the right acromion protrusion, and the spinous appendage of the seventh cervical vertebra should be determined. They are marked with a marker. Then, the subject was asked to sit in his/her wheelchair at the designated place next to the wall at a distance of 23 cm so that his left/right arm was towards the wall. Then, the photo tripod, on which the digital camera is also placed, was placed at a distance of 105 cm from the wall and its height was set at the level of the subject's right shoulder. In such conditions, the subject was asked to bend forward three times and raise his/her hands above his/her head three times and then sit comfortably and naturally on the wheelchair and look at an imaginary point on the opposite wall (eyes in line with the horizon) then, after a five-second pause, the examiner starts taking pictures of the sagittal view of the body. Finally, the mentioned photo was transferred to the computer and using the angle calculation software (Protractor, vers 1.6.1., Google Commerce Ltd), the angle of the line connecting the earlobe and the seventh cervical vertebra with the vertical line (head forward angle) and the angle of the line connecting the seventh cervical vertebra and the acromion appendage with the perpendicular line (rounded shoulder angle) was measured (Cheshomi & Rajabi, 2011; Rostamizalani et al., 2019). A flexible ruler was used to check the amount of back kyphosis. In such a way that the subject is sitting in the wheelchair so that his hands are placed on the wheelchair handles from the forearm and does not use the back support, the spinous process of the second dorsal vertebra T2 was used as the starting point of the arch and the spinous process of the 12th dorsal vertebra was used as the end of the arc. To find the T2 spinous process, the person was asked to put his neck in flexion and identify the most prominent spinous process, which is the C7 vertebra. Two vertebrae below the mentioned process to identify the T2 vertebra. Since the location of the spinous appendage of the T12 vertebra is on the same level as the lower edge of the twelfth ribs on both sides, the edges of these ribs are simultaneously touched with the tips of the thumbs, and their path will be followed upwards and inwards until the soft tissue of the body disappears. By drawing a straight line connecting the tips of two thumbs, the location of the spinous process of

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the T12 vertebra was estimated. Then, the measurer puts the flexible ruler on the spine and applies gentle pressure so that the ruler takes the shape of the spine. Then, T2 and T12 points were marked on the ruler. The ruler was slowly removed from the spine and placed on the paper, and after drawing the arc on the paper, its marks were determined. In the next step, to obtain quantitative information, two points marked on the arc were connected, the length of this line was recorded, and L was considered. Also, the deepest part of the arch was identified and considered as H. Then, the back-kyphosis angle was calculated using the trigonometric formula θ=4ARCTAN (2H/L) (Rajabi et al., 2008). The range of motion of flexion, extension, internal rotation, external rotation and shoulder abduction was measured by a universal goniometer using the Clarkson method (Clarkson, 2000). To measure balance in a sitting position, a modified functional reach test was used in three directions: front, left and right. The subject performed the movement three times in each direction and recorded all three records. The average of the second and third attempts was considered the overall score of each direction. To measure power, while the subject was sitting in a wheelchair, he threw a two-kilogram medicine ball forward as far as possible. The throw was done twice, and the distance from the launch to hit the ground was measured with a meter, and the longest distance was recorded as a personal record.

Statistical analysis

In this research, descriptive statistics were used to describe the data of each group (age, height, and weight of subjects). Mean index and standard deviation were used to describe the data. The Shapiro-Wilk test was used to detect the normality of the data, indicating a normal distribution in the research data. To check the homogeneity of variances, Levene's test was used to check the homogeneity of variances. Also, the Pearson correlation coefficient and stepwise multiple regression were applied to examine the relationship between the variables at the 0.05 significance. Statistical operations were performed with SPSS software version 23.

Results

To describe the information of the participants, the mean and standard deviation of the research variables, including age, height, weight, kyphosis, and rounded shoulder angles, are presented in Table 1.

Table 1. The demographic information of the participants

	Male (n=15)		Female (n=13)	
	Mean	Std. Deviation	Mean	Std. Deviation
Age	29.86	7.25	25.07	6.57
Weight	80.15	5.60	58.30	5.32
Seating height	84.04	3.53	71.34	4.54
Kyphosis angle	42.68	2.73	43.08	1.98
Rounded shoulder angle	53.34	2.07	56.15	1.16
Forward head angle	46.40	2.08	47.19	3.30

The correlations between research parameters with static alignment, including kyphosis and rounded shoulder angles, are presented in Table 2. As can be seen, there is only a significant relationship between the round shoulder with the balance in three directions and throwing the ball. However, in other variables, there is no significant relationship with static alignment.

Table 2. Pearson correlation between parameters

Parameters	Medicine ball throw	Seated balance front	Seated balance left	Seated balance right	Shoulder flexion ROM	Shoulder extension ROM	Shoulder internal rotation ROM	Shoulder external rotation ROM	Shoulder abduction ROM	20-meter wheelchair propulsion
Kyphosis	0.760	0.667	0.635	0.505	0.948	0.699	0.989	0.952	0.732	0.351
Forward head angle	0.216	0.344	0.595	0.955	0.774	0.824	0.999	0.832	0.199	0.402
Rounded shoulder	0.00*	0.012*	0.009*	0.041*	0.226	0.287	0.339	0.871	0.090	0.374

*Sig p<0.05

According to the output of the stepwise multiple regression test, we observed that only shoulder flexion ROM is entered into the regression equation, and this change alone in the amount of kyphosis is expressed according to the value of R square (.997). Other variables could not pass the desired criterion and were removed from the model. Therefore, the variable shoulder flexion ROM is the best predictor for kyphosis (p<0.05). Also, for the forward head variable, considering R square (0.996), only the shoulder flexion ROM variable can be a good predictor for forward head angle (p<0.05). Finally, the variables of abduction and flexion ROM of the shoulder, power through medicine ball throwing and seated balance on the left side considering R square (.998, .999, .999, .999), were the variables that can predict the rounded shoulder (p<0.05).

Discussion

The purpose of the present research was to study the relationship between the static alignment of the upper limb and the movement performance of athletes with spinal cord injuries. One of the research findings was a significant relationship between the round shoulder and the balance in three directions and power. The shoulder is the most active part of the body, and it is directed under pressure by wheelchair users and sports with repetitive movements in the upper limbs. Wheelchair athletes use their upper body constantly, and many forces are applied to the shoulder complex from various directions every day. The combination of posterior and superior shoulder forces increases the risk of rounded shoulder and its outcomes in wheelchair athletes (Finley & Rodgers, 2004). The rounded shoulder posture is associated with tightness of the serratus anterior, pectoralis minor, pectoralis major, and upper trapezius muscle and weakness of the middle and lower trapezius (Hasan et al., 2023). In the literature, rounded shoulder posture is described as abduction, the elevation of the scapula giving the appearance of a hollow chest (Kendall et al., 2023). Biomechanical studies show that the rounded shoulder posture causes hypertrophy and bulking of the internal shoulder rotator and adductor muscles compared to their antagonists. This will result in muscle imbalance that reduces the stability and efficiency of the shoulder (Ambrosio et al., 2005; Nejati et al., 2014). Muscle imbalance, which should function as one of the risk factors related to protective and stabilising mechanisms in the shoulder, can reduce functional stability in wheelchair users. As a result, lower scores are observed in the balance test. The inefficiency of the sensory-motor system and shoulder proprioceptiveness are other issues that occur after a rounded shoulder. It can cause shoulder instability, reducing achievement in different directions of the sitting balance test (Myers et al., 2006). A rounded shoulder would lead to the shortening of the pectoral muscles and elongating of the scapular retractors. The shortened pectoral muscles might then exhibit increased strength and power, and more importantly, the elongated scapular retractors might become relatively weaker (Kendall et al., 2023). Protruding shoulder posture causes other defective conditions such as kyphosis and forward head, which over time leads to stabilisation of muscle shortness/weakness of antagonistic groups, disturbance in the communication between agonistic and antagonistic muscle groups, and the dominance of synergistic muscle groups (Yip et al., 2008). As a result of shoulder joint instability, the dysfunction of joint mechanical receptors leads to the inhibition of joint stabilising neuromuscular reactions (Barden et al., 2005). It leads to decreased upper limb muscle strength, stability, and balance.

Among the limitations of this study, we can mention the limited number of qualified samples and the impossibility of accurately controlling the mental and motivational state of participants in the research process.

Conclusion

In the present research, which investigated the relationship between the forward head angle, round shoulder, and kyphosis with the physical capabilities of athletes with spinal cord injury, we concluded that the rounded shoulder angle is related to upper limb balance and power. In addition, the round shoulder is related to other disorders and injuries. Therefore, with some considerations, this can reduce the probability of damage. These actions include screening and evaluating the alignment of the upper limbs, teaching the correct movement patterns of the upper limbs of wheelchair athletes and providing a suitable exercise program to establish muscle balance in the upper limbs. Despite the slight difference in the investigated indicators in this study, the results are significant from a clinical point of view. Movement performance is improved by improving the alignment of the upper limb by modifying movement patterns and muscle balance. For coaches, including the necessary preventive and corrective measures in athlete's training programs is better.

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Ethical Approval Information

The University of Ljubljana, Committee for Ethical Issues in Sports approved the study (Nr. 10:2023).

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Availability of data and material

All data generated or analysed during this study will be/are included in the published article as Table(s). Any other data requirement can be directed to the corresponding author upon reasonable request.

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

[1]Middle East Technical University, Physical Education and Sports Department, Ankara, Turkey
[2]University of Montenegro, Faculty for Sport and Physical Education, Niksic, Montenegro

Corresponding author:
S. Popovic
University of Montenegro
Faculty for Sport and Physical Education
Narodne omladine bb, 84000 Niksic, Montenegro
E-mail: stevop@ac.me

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Abstract word count: 236

Number of Tables: 3

Number of Figures: 3

2.1.1. Title

Title should be short and informative and the recommended length is no more than 20 words. The title should be in Title Case, written in uppercase and lowercase letters (initial uppercase for all words except articles, conjunctions, short prepositions no longer than four letters etc.) so that first letters of the words in the title are capitalized. Exceptions are words like: "and", "or", "between" etc. The word following a colon (:) or a hyphen (-) in the title is always capitalized.

2.1.2. Type of publication

Authors should suggest the type of their submission.

2.1.3. Running head

Short running title should not exceed 50 characters including spaces.

2.1.4. Authors

The form of an author's name is first name, middle initial(s), and last name. In one line list all authors with full names separated by a comma (and space). Avoid any abbreviations of academic or professional titles. If authors belong to different institutions, following a family name of the author there should be a number in superscript designating affiliation.

2.1.5. Affiliations

Affiliation consists of the name of an institution, department, city, country/territory(in this order) to which the author(s) belong and to which the presented / submitted work should be attributed. List all affiliations (each in a separate line) in the order corresponding to the list of authors. Affiliations must be written in English, so carefully check the official English translation of the names of institutions and departments.

Only if there is more than one affiliation, should a number be given to each affiliation in order of appearance. This number should be written in superscript at the beginning of the line, separated from corresponding affiliation with a space. This number should also be put after corresponding name of the author, in superscript with no space in between.

If an author belongs to more than one institution, all corresponding superscript digits, separated with a comma with no space in between, should be present behind the family name of this author.

In case all authors belong to the same institution affiliation numbering is not needed.

Whenever possible expand your authors' affiliations with departments, or some other, specific and lower levels of organization.

2.1.6. Corresponding author

Corresponding author's name with full postal address in English and e-mail address should appear, after the affiliations. It is preferred that submitted address is institutional and not private. Corresponding author's name should include only initials of the first and middle names separated by a full stop (and a space) and the last name. Postal address should be written in the following line in sentence case. Parts of the address should be separated by a comma instead of a line break. E-mail (if possible) should be placed in the line following the postal address. Author should clearly state whether or not the e- mail should be published.

2.1.7. Manuscript information

All authors are required to provide word count (excluding title page, abstract, tables/figures, figure legends, Acknowledgements, Conflict of Interest, and References), the Abstract word count, the number of Tables, and the number of Figures.

2.2. Abstract

The second page of the manuscripts should be the abstract and key words. It should be placed on second page of the manuscripts after the standard title written in upper and lower case letters, bold.

Since abstract is independent part of your paper, all abbreviations used in the abstract should also be explained in it. If an abbreviation is used, the term should always be first written in full with the abbreviation in parentheses immediately after it. Abstract should not have any special headings (e.g., Aim, Results…).

Authors should provide up to six key words that capture the main topics of the article. Terms from the Medical Subject Headings (MeSH) list of Index Medicus are recommended to be used.

Key words should be placed on the second page of the manuscript right below the abstract, written in italic. Separate each key word by a comma (and a space). Do not put a full stop after the last key word. *See example:*

Abstract

Results of the analysis of…
Key words: spatial memory, blind, transfer of learning, feedback

2.3. Main Chapters

Starting from the third page of the manuscripts, it should be the main chapters. Depending on the type of publication main manuscript chapters may vary. The general outline is: Introduction, Methods, Results, Discussion, Acknowledgements (optional), Conflict of Interest (optional), and Title and Abstract in Montenegrin (only for the authors from former Yugoslavia, excluding Macedonians and Slovenes). However, this scheme may not be suitable for reviews or publications from some areas and authors should then adjust their chapters accordingly but use the general outline as much as possible.

2.3.1. Headings

Main chapter headings: written in bold and in Title Case. *See* example:

- ✓ **Methods**

Sub-headings: written in italic and in normal sentence case. Do not put a full stop or any other sign at the end of the title. Do not create more than one level of sub-heading. *See* example:

- ✓ *Table position of the research football team*

2.3.2 Ethics

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*

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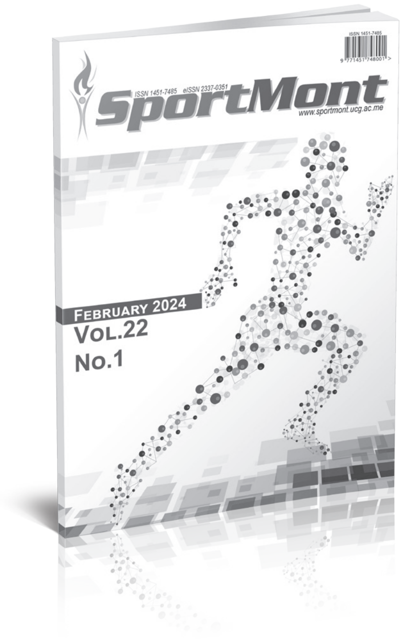

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Autumn issue – October 2024
Winter issue – February 2025

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.

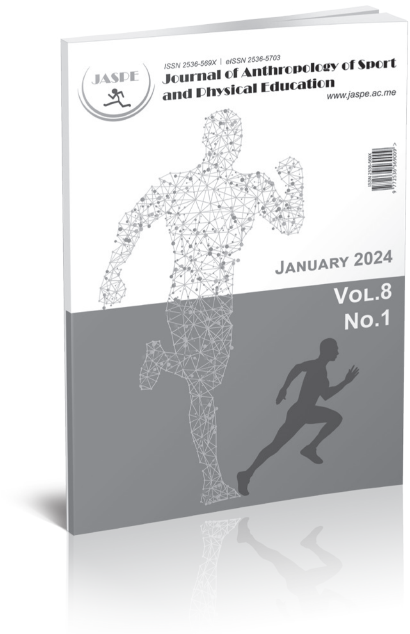
It is our great pleasure to announce the upcoming 21th Annual Scientific Conference of Montenegrin Sports Academy “Sport, Physical Activity and Health: Contemporary Perspectives” to be held in Dubrovnik, Croatia, from 18 to 21 April, 2024. It is planned to be once again organized by the Montenegrin Sports Academy, in cooperation with the Faculty of Sport and Physical Education, University of Montenegro and other international partner institutions (specified in the partner section).

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.

JASPE

Journal of Anthropology of Sport and Physical Education



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Journal of Anthropology of Sport and Physical Education (JASPE) is a print (ISSN 2536-569X) and electronic scientific journal (eISSN 2536-5703) aims to present easy access to the scientific knowledge for sport-conscious individuals using contemporary methods. The purpose is to minimize the problems like the delays in publishing process of the articles or to acquire previous issues by drawing advantage from electronic medium. Hence, it provides:

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JASPE is published four times a year, in January, April, July and October of each year. JASPE publishes original scientific papers, review papers, editorials, short reports, peer review - fair review, as well as invited papers and award papers in the fields of Anthropology of Sport and Physical Education, as well as it can function as an open discussion forum on significant issues of current interest.

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