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Editorial Office **KINESIOLOGY**
Faculty of Kinesiology
Horvaćanski zavoj 15, 10000 Zagreb, CROATIA
Tel: +385 1 3658 622; 3658 640
fax: +385 1 3634 146
e-mail: kinesiology.office@kif.hr
URL: http:/www.kif.hr

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ATTACKING PERFORMANCE ANALYSIS DURING 2-MINUTE SUSPENSIONS IN FEMALE HANDBALL GAMES AT THE RIO 2016 OLYMPIC GAMES

Alejandro Trejo-Silva[1,2,3], Miguel Angel Gomez-Ruano[4], Nimai Parmar[5], and Javier Brazo-Sayavera[6,7]

[1]Instituto Superior de Educación Física, Universidad de la República (ISEF-UdelaR), Montevideo, Uruguay
[2]Department of Sports, Instituto Universitario Asociación Cristiana de Jóvenes (IUACJ), Montevideo, Uruguay
[3]Faculty of Education and Psychology, University of Extremadura, Badajoz, Spain
[4]Department of Social Sciences, Physical Activity and Sport, INEF, Madrid, Spain
[5]London Sport Institute, Faculty of Science & Technology, Middlesex University, London, UK
[6]Department of Sports and Computer Science, Universidad Pablo de Olavide (UPO), Sevilla, Spain
[7]PDU EFISAL, Centro Universitario Regional Noreste, Universidad de la República, Rivera, Uruguay

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Abstract:

The aim of this study was to analyse the effect of the IHF 2016 rule change on attack efficacy during the different numerical asymmetry scenarios associated with 2-minute suspensions at the Rio 2016 OG. A total of 328 exclusion scenarios that were sanctioned during the 38 matches played at the Rio 2016 OG female handball tournament by 12 national teams were analysed using observational methodology. Chi-square test was applied to identify associations between the variables. Chi-square automatic interaction detection trees (CHAID) were used to identify which attacking performance variables during exclusions were associated with the different types of numerical asymmetry (superiority, inferiority with the goalkeeper at goal and inferiority with the empty net). Results during contexts of superiority showed that scoring in 58.0% of the total attacking finalizations (i.e., attack efficacy) ($p<.001$; ASR 8.2); playing fast transitions ($p<.001$; $x^2 = 17.692$) and using a 2:4 (with two pivots) offensive system were predictors of the attacking performance of the teams. Substitution of the goalkeeper for a court player during inferiority context was a predictor for teams ranked 9 to 12 and also for those playing for medals ($p<.001$; $x^2=26.590$) but conceding, as a consequence of their finalizations, a counterattack ($p<.001$; $x^2=112.107$). Despite teams showing similar attacking performance during numerical superiority compared to previous studies, findings in this study revealed a tendency for empty goals during numerical inferiority context. Coaches should therefore consider training retreat strategies when playing without a goalkeeper when faced with a numerical disadvantage.

Keywords: *exclusions, numerical inequality, empty goal, classification tree, offensive performance in elite handball*

Introduction

Analysts and coaches are using performance indicators (PIs) to assess team and athletes' performance, which enables them to assess their trainees quality of performance (Hughes & Bartlett, 2002). Performance analysis seeks to quantify sports performance (O'Donoghue, 2010), and can consider, for example, combination of physical, technical, or tactical parameters during competition (Rein & Memmert, 2016). Data collected during competition are relevant, as they allow for coaches to model and subsequently adapt athletes' performance (Franks & Goodman, 1986) according to training and match interventions (Prieto, Gomez, & Sampaio, 2015a).

Factors influencing players' performance are not easy to identify, particularly when considering complex and multifactorial team sports like handball (Wagner, Finkenzeller, Wurth, & von Duvillard, 2014). Notational analysis allows researchers to analyse the competition from an ecological view (Vilar, Araújo, Davids, & Button, 2012) that considers dynamic and complex systems, including individual and collective decision-making under different contexts (Araújo & Davids, 2016; Ortín, Olmedilla Zafra, & Lozano Martínez, 2003) in team sports (García Ordoñez & Touriño González, 2021; Gómez-Ruano, Serna, Lupo, & Sampaio, 2016; Low, et al., 2020; Prieto-Lage, et al., 2023). In handball, approaches have considered the type of competition (Bilge, 2012; Hansen, et al., 2017; Saavedra, Thorgeirsson, Chang, Kristjansdottir, & Garcia-Hermoso, 2018); a descriptive analysis of best-ranked teams (De Conti-Texeira, et al., 2017; Hansen, et al., 2017); and finally, attempting to discriminate winning from losing teams (Ferrari, Dias, Sousa, Sarmento, & Vaz, 2020; Þorgeirsson, et al., 2022a). However, academic advances in women's handball are less than in male handball (Wagner, et al., 2019). In particular, research on anthropometric parameters (Moss, McWhannell, Michalsik, & Twist, 2015; Rios, et al., 2023) and relative age effect (Bjørndal, Luteberget, Till, & Holm, 2018; Ferragut, Vila, Fernández, & Saavedra García, 2021; Rubia, et al., 2020) was done. Match analyses, studies comparing men's and women's performance indicators (Gómez-López, Rivilla-García, González-García, Sánchez-López, & Angosto, 2023; Þorgeirsson, et al., 2022a, 2022b) and analyses of only women's tournaments (de Paula, et al., 2020; Karalić, 2020; Trejo-Silva, Feu, Camacho-Cardenosa, Camacho-Cardenosa, & Brazo-Sayavera, 2022; Trejo-Silva, Gomez-Ruano, Feu, & Brazo-Sayavera, 2023; Yamada, Aida, Fujimoto, & Nakagawa, 2014) have been developed in recent years.

Gréhaigne (1991) indicated that team sports can have three categories of problems, relating to: i) space and time; ii) information; and finally, iii) the organization. In the latter, one player may deal with issues related to his/her behaviours in coordination with teammates, needing a constant adaptation to constraints brought by the dispute on the court. Actions that affect the numerical balance in the number of players on the court are seen as one of these constraints. Previous studies considering temporal numerical inequalities in team sports such as water polo (Bernardi, Davis, Graham, & Mayberry, 2022; Canossa, et al., 2022; Gómez-Ruano, et al., 2016; Sabio Lago, Argudo-Iturriaga, Guerra-Balic, & Cabedo-Sanromà, 2021), futsal (Gomez, Mendez, Indaburu, & Travassos, 2019), and ice hockey (Bedford & Baglin, 2009) have shown the importance of analysing these scenarios of the games. In handball, players' exclusions as a consequence of a 2-minute suspension generate a temporal numerical inequality in the on-court number of players, leading to two numerical asymmetry contexts (superiority context: the attacking team has at least one player more than the opponent; inferiority context: the attacking team is outnumbered by at least one player), these moments being a situational context of research. Attacking while suffering an exclusion needs a reorganization of the technical–tactical aspects in order to afford the limited number of players (Pueo & Espina-Agullo, 2017). Previous studies revealed that a team's performance during superiority and inferiority affects the final result of a match (Saavedra, Þorgeirsson, Kristjánsdóttir, Chang, & Halldórsson, 2017; Schucker, Hagemann, & Strauss, 2013; Trejo-Silva, A. Camacho, M. Camacho, González-Ramirez, & Brazo-Sayavera, 2020). Despite the fact that some studies have analysed the relationship between final outcome and final ranking in the number of exclusions, research about performance during 2-minute suspensions is scarce (Oliveira, Gomez, & Sampaio, 2012).

The Rio 2016 Olympic Games (OG) was the first tournament played under the new rule scenario, which allows the sanctioned team to substitute the goalkeeper (GK) with a field player, playing then with an empty goal (EG) (IHF, 2018). These changes in handball rules may affect the context of exclusions. Krahenbühl, Sousa, Leonardo, and Costa (2019) have studied the effect of playing inferiority attacks with EG in this new context during the knockout stages of the male Rio 2016 OG tournament. Results showed that changing the GK for an on-court player did not affect the attacking efficacy. Despite playing with EG during inferiority can be seen as a rule that goes against the "spirit of the game" and basic principles of teaching the game (Antón, 2019, p. 306), coaches have declared to use it the most in the intention to maintain numerical balance in inferiority situations (Krahenbühl, Menezes, & Leonardo, 2019). In addition, Krahenbühl, Pereira, Pombo-Menezes, Amazonas, and Leonardo (2021) confirmed this statement at the 2017 female World Championship (WCh) where teams often substituted the GK with a court player to maintain numerical symmetry. Therefore, in order to test the offensive performance during this specific context, the analysis from a multivariate approach is required (Gómez, Moral, & Lago-Peñas, 2015).

Assuming that this new numerical relationship scenario would be of interest to both coaches and academics, studying the performance during 2-minute suspensions in an elite female tournament would be needed. Thus, the aim of the present study was to analyse the effect of the IHF 2016 rule change on attack efficacy during the different numerical asymmetry scenarios associated with 2-minute suspensions in the female handball tournament at the Rio 2016 OG.

Methods

Sample

The inter-sessional sample consisted of all exclusions (n=328) sanctioned during the total number of matches (n=38) played at the Rio 2016 OG women's handball tournament. The intra-sessional sample consisted of every attack finalization during those 2-minute suspensions' offensive sequence, which involved numerical asymmetry in the court players' relationship. Antúnez, García-Rubio, Sáez, Valle, and García-Martín' (2013) definitions of the offensive sequence were considered. It was determined from the instant when one team recovers or gets possession of the ball until one of the following occurs: a) the opposite team gets possession; b) the team in possession of the ball gets to make a valid throwing, and immediately after regains ball possession or must restart the game from the side-line. Every attacking action of the game executed while at least one exclusion has been previously sanctioned was observed and registered. No attacking action was registered after a 2-minute suspension was sanctioned during the time of the previous exclusion. Actions that happened while both teams had the same number of court players (i.e., 6 vs 6, 5 vs 5, or 4 vs 4), and GK at goal, were not registered. No attacking sequence was registered when once the 2-minute exclusion time ended.

Instrument

Observational methodology procedures were followed for collecting data (Chacon-Moscoso, et al., 2018). An *ad-hoc* instrument consisting of a combination of field format and category systems was created. Criteria and their respective categories respected exhaustiveness and mutual exclusivity in the system of categories (Table 1). Categorical cores (n=60) and their corresponding register codes were generated and grouped into eight criteria (team, game time, type of asymmetry, match status, game phase, offensive system, finalization, and consequence of the finalization).

Procedures

The research team reviewed game footage and collected the data using the Lince 1.2.1 software (Gabin, Camerino, Anguera, & Castañer, 2012). The steps to verify the quality of the data followed Anguera and Hernández-Mendo (2014) indications. Five experts (all of them coaches with a minimum of 10 years of experience at a club level and at least one experience as a national coach; three of them with postgraduate qualifications) received a questionnaire and arrived at a 95% of agreement. Intra- and inter-observer reliability concordance was verified using Cohen's Kappa coefficient (Cohen, 1960) obtaining values rated as very good (K≥0.89). The game outcome (winner, loser, draw) and the final ranking of the teams (1 to 12) were directly inserted in the registration sheet, being part of the studied variables. Teams were grouped into three groups: teams ranked 1st to 4th; teams ranked 5th to 8th, and teams ranked 9th to 12th. Finalizations were clustered into three groups: i) Goal (finalizations registered as G [goal] and GE [goal and exclusion in the same action]); ii) No goal (finalizations registered as P [throws on post], S [goalkeeper's save], B [throws blocked by defenders]), Out (throws wide or high, neither post nor goalkeeper's save), and iii) Turnovers (finalizations registered as I [defender intercepts a pass], BP [error in passing the ball, not get by the defender], or RTE [regulatory or technical error]). Types of numerical asymmetry were gathered in three groups: i) Superiority (all finalizations registered as 6 vs 5, 5 vs 4, or 6 vs 4); ii) Inferiority with the goalkeeper at goal (GK at goal) (all finalizations registered as 5 vs 6, 4 vs 5, or 4 vs 6 and the team kept their GK at goal), and iii) Inferiority with empty goal (Empty goal) (all finalizations registered as 5 vs 6, 4 vs 5 or 4 vs 6 and the team played with EG). Game time, based on previous studies which found critical moments of the game for the exclusions being sanctioned (Prieto, et al., 2015b; Trejo-Silva, et al., 2020), was grouped into two groups: Critical moments (game time 2,4,5) and Non-critical moments (game time 1,3,6). Ethical principles established in the Helsinki Declaration (WMA, 2013) were followed.

Statistical analysis

Crosstabs command between the type of asymmetry (superiority, inferiority played with GK at goal and inferiority played with EG) and contextual indicators (game outcome, finalization, consequence of the finalization, phase of the game, offensive system, game time, match status, final ranking grouped in three groups) was used to study the relationship among them. Pearson's Chi-square test was performed. First, the effect size (ES) and the independence of the variables' cross-section were analysed via Cramer's V test and adjusted standardised residual (ASR; critical value = 1.96 and p=.05). When the expected frequency distribution was lower than 5 or the count of cases in one cell was lower than or equal to 5, Fisher's exact test was applied (Field, 2013). Secondly, an exhaustive CHAID (Chi-squared automatic interaction detection) classification tree analysis was used to determine the differences between the performance in the three types of numerical asymmetry and contextual indicators. All analyses were run using SPSS (v25, IBM, Corp., Armonk, NY, United States) statistical software package. A statistically significant relationship was established when p<.05 (confidence interval set at 95%).

Table 1. Observational tool to analyse offensive actions during 2-minute suspensions at the Rio 2016 OG female handball

Criterion	Categories	Categorical core
Team	RUS, FRA, NOR, NED, BRA, SPA, SWE, ANG, ROM, KOR, MNE, ARG.	In order of final ranking, from 1st to 12th: RUS: Russia; FRA: France; NOR: Norway; NED: Netherlands; BRA: Brazil; SPA: Spain; SWE: Sweden; ANG: Angola; ROM: Romania; KOR: South Korea; MNE: Montenegro; ARG: Argentina.
Game time	T1 T2 T3 T4 T5 T6 T7 T8	Minute 0 to 9:59 Minute 10:00 to 25:59 Minute 26:00 to 30:00 Minute 30:01 to 39:59 Minute 40:00 to 54:59 Minute 55:00 to 60:00 First period of extra time Second period of extra time
Match status	≥5, 4, 3, 2, 1 0 ≤5, -4, -3- 2, -1	Observed team leads by 5 (or more), 4, 3, 2 or 1. Teams are tied when behaviour is registered Observed team is down by 5 (or more), 4, 3, 2 or 1.
Type of asymmetry	6x5, 5x4, 6x4 5x6, 4x5, 4x6 EG	Numerical superiority of 1 or 2 players. Inferiority of 1 or 2 players with GK at goal Inferiority of 1 or 2 players with empty goal
Game phase	FB CA PA 7M	Fast break attack (1st wave) Counterattack (2nd and 3rd wave) Positional attack 7m throw
Offensive system	3:3 3:3 (2) 2:4 3:2 (0) 3:2 (1) NS	3:3 with 1 pivot and 2 wings 3:3 with 2 pivots and 1 wing 2 backs, 2 pivots, 2 wings 3 backs, no pivot, and 2 wings 3 backs, 1 pivot and 1 wing No system (counterattacks and 7m throws)
Finalization	G P S Out B GE I BP RTE	Goal Throw on post Goalkeeper's save Throw wide or high (not post, not goalkeeper's save) Throw blocked by a defender Goal and exclusion (in the same action) Defender intercepts a pass Error in passing the ball (not get it by a defender) Regulatory or technical error (attacking foul, double dribbling, steps, error while changing players, other sanctions)
Consequence of the finalization	NC CNG CG	Observed team concedes no counterattack Observed team concedes counterattack but no goal Observed team concedes goal via counterattack

Results

A total of 1.065 actions during the 328 exclusions sanctioned in 38 games were registered, resulting in an average of 8.6 ± 3.6 exclusions per game. A total of 590 actions were registered under the superiority context and 475 under inferiority. Playing with EG represented 35.0% of the total actions registered during the inferiority context and playing with GK at goal represented 65.0%. Table 2 presents the frequency distribution of attacking situations in numerical asymmetry contexts. The game outcome, finalization, consequence of the finalization, game phase, and offensive system presented a statistically significant relationship with the type of asymmetry. Winning teams presented a statistically significant relationship (p<.05; ASR -2.0) to not playing with EG during inferiority contexts. Attack efficacy (AE), which reached a level of 58.0% during the superiority context, showed the strongest statistically significant relationship to all finalizations (p<.01, ASR 8.2 and 2.1). AE when playing with EG was 37.5% and with GK at goal 30.3%. Turnovers (26.7% during GK at goal and 25.6% during EG) showed a statistically significant relationship (p<.01, ASR 3.6 and 2.1). In addition, being sanctioned with a 7m throw for, and playing 1st, 2nd and 3rd wave phases of the attack were statistically significantly related (p<.01; ASR 8.1, 2.9, and 7.9) with the context of superiority. The positional attack presented a statistically significant relationship (p<.01; ASR 7.1) to the context of inferiority. Using the 3:3 (with one pivot) offensive system appeared with a statistically significant relationship, specifically during the context of playing with EG under inferiority situations (p<.001; ASR 8.0).

Table 2. Frequency distribution of offensive situations under inequality during the Rio 2016 Olympic Games

	Superiority *n* = 590		GK at goal *n* = 307		Empty goal *n* = 168		x^2	p	ES	ES p
	(%)	ASR	(%)	ASR	(%)	ASR				
Game outcome							17.250	<0.05	0.90	<0.05
Winner	48.6	*0.7*	49.8	*0.9*	40.5	-2.0				
Loser	47.8	*-0.6*	48.9	*0.1*	51.2	*0.7*				
Draw	3.6	*-0.2*	1.3	*-2.6*	8.3	*3.5*				
Finalization							70.634	<0.01	0.18	<0.01
Goal	58.0	*8.2*	30.3	*-6.9*	37.5	*-2.6*				
No goal	27.6	*-4.5*	43.0	*4.2*	36.9	*1.0*				
Turnover	14.4	*-4.9*	26.7	*3.6*	25.6	*2.1*				
Consequence										
No counter attack	94.4	*13.8*	61.9	*-8.6*	55.4	*-8.1*	197.474	<0.01	0.35	<0.01
Counter attack no goal	3.2	*-9.2*	21.2	*6.6*	20.8	*4.3*				
Counter attack goal	2.4	*-9.2*	6.9	*4.8*	23.8	*6.5*				
Game phase							161.039	<0.001	0.28	<0.001
Positional attack	56.1	*-12.1*	87.6	*7.5*	94.0	*7.1*				
1st wave	8.6	*2.9*	6.5	*-0.1*	0	*-3.8*				
2nd and 3rd wave	14.2	*7.1*	2.6	*-4.5*	0.6	*-4.1*				
7 meter	21.0	*8.1*	3.3	*-6.2*	5.4	*-3.3*				
Offensive system							357.739	<0.001	0.58	<0.001
3:3_1_Pivot	61.4	*-3.1*	58.3	*-3.1*	92.3	*8.0*				
2:4_2 Pivots	5.1	*5.0*	0	*-3.5*	0	*-2.4*				
3:2_No Pivot_1wing	0	*-11.2*	29.3	*15.3*	1.2	*-3.7*				
3:2_1 Pivot_1 wing	0.0	*-3.4*	2.6	*5.0*	0	*-1.0*				
No system	33.6	*9.8*	9.8	*-6.3*	6.0	*-5.6*				
Final ranking										
1st to 4th	94.4	*1.8*	61.9	*-2.0*	55.4	*0.1*	28.600	<0.01	0.12	<0.01
5th to 8th	3.2	*-3.4*	21.2	*5.2*	20.8	-1.8				
9th to 12th	2.4	*1.5*	6.9	*-3.0*	23.8	*1.7*				
Match status							0.657	>0.05	0.02	>0.05
2 goals	46.8		48.9		48.8					
3-4 goals	28.0		28.0		27.4					
5 or more goals	25.3		23.1		23.8					
Game time grouped							0.453	>0.05	0.02	>0.05
Periods 2,4,5	75.9		77.5		75.0					
Periods 1,3,6	24.1		22.5		25.0					

Note: Data presented as absolute frequencies (percentage). ES: effect size (Cramer's V for asymmetric tables and contingency coefficient for symmetric tables); ASR: adjusted standardized residual, calculated only for those variables that presented a statistically significant relationship (p<.05).

Figure 1 shows the decision tree model results (exhaustive CHAID) predicting the attacking performance during exclusions according to the type of asymmetry. The model presented an estimation of 94.7% for superiority, 40.1% for inferiority with GK at goal, and 35.7% for inferiority with EG (69.7% of the variance; estimated risk 0.30; SD 0.14). Specifically, Node 6 predicted that the transition phases (2nd and 3rd waves) and positional attacks were the main phases that predominated in superiority contexts ($p<.001$; x^2=17.692) followed by the 1st wave (Nodes 5 and 7). In addi-

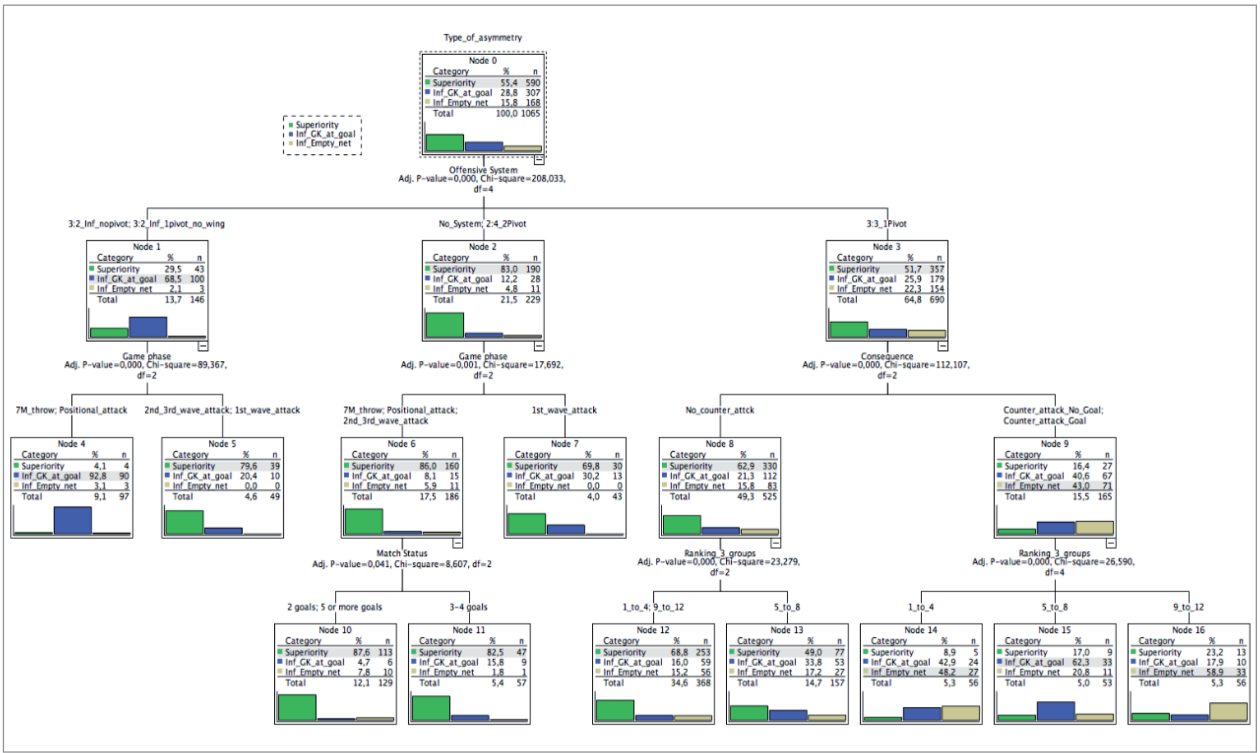

Figure 1. Exhaustive CHAID decision predicting the offensive performance during numerical asymmetry as a consequence of exclusions according to types of asymmetries.

tion, Node 2 predicted teams using a 2:4 offensive system and the use of NS, while Node 3 predicted the use of the 3:3 classic formation within the context of superiority (p<.001; x^2=208.033). Moreover, Node 4 predicted that the positional attack was the phase used the most when playing with GK at goal (p<.001; x^2=89.367). Moreover, Node 1 predicted that the offensive system with three backcourt players (3:2[0] with no pivot and 3:2[1] with one of the wings moving to the pivot position) was the preferred form when leaving the GK at goal during the inferiority context (p<.001; x^2=208.033). However, in the same numerical asymmetry context of inferiority, node 16 predicted that teams ranked 9 to 12 tend to play with EG (p<.001; x^2=26.590) but conceded, as a consequence of their finalizations, a counterattack (node 9; p<.001; x^2=112.107). Lastly, Nodes 14 and 16 predicted a similar use of the EG strategy for those teams playing to win a medal as opposed to those placed at the bottom of the ranking ladder.

Discussion and conclusions

This study aimed to analyse the effect of the IHF 2016 rule change on attack efficacy during the different numerical asymmetry scenarios associated with 2-minute suspensions at the Rio 2016 OG women's handball tournament. Findings in the present study showed that 8.6 ± 3.6 exclusions per game were sanctioned, meaning that around 17 minutes out of 60 were played either in numerical superiority or inferiority. Those results are similar to previous studies which found that around 30% of the game time is played under numerical asymmetries as a consequence of exclusions in elite handball matches of OG (Saavedra, et al., 2017) and Panamerican Games (PPGG) (Trejo-Silva, et al., 2020). However, exclusions at women's handball occurred to be slightly fewer than in men's handball, coinciding with previous studies where hostile aggression appeared to be more frequent in male than in female competitions; indeed, the upper the level the higher the difference (Coulomb-Cabagno & Rascle, 2006). This could be due to the difference in the criterion used by referees of male and female tournaments at the moment of sanctioning with exclusions those situations where the use of strength in one-to-one situations is evaluated, as found in previous studies in invasive team sports (Zhang, et al., 2022).

When a team is sanctioned with an exclusion, they are facing a numerical disadvantage for a period of time with the opposite team having possession of the ball in order to restart the game (an exception is when game time is stopped). Since finalization actions were collected solely during moments when an exclusion had been sanctioned in a match, the first finalization in each exclusion scenario corresponded to a team playing in a superiority context. This led to 55.4% of all actions occurring in the superiority context and 44.6% in the inferiority context. Recent studies have confirmed these differences in the number of possessions across both contexts of numerical asymmetry (Ferrari, et al., 2022). In competition contexts, psychological crises during certain moments or situations of the game are associated with exclusions or dismissals (Bar-Eli, Tenenbaum, & Elbaz, 1990; Bar-Eli & Tractinsky, 2000). However, players tend to have control over their actions and attitudes in order not to be excluded in balanced games (Bar-Eli, et al., 1990; Bar-Eli & Tractinsky, 2000; García-Martín, Argudo Iturriaga, & Alonso Roque, 2015). This body of research may explain why losing teams tend to play in inferiority during imbalanced contexts (namely when the difference in the score was five or more goals).

Context of superiority

Key Performance Indicators (KPIs) are often used in handball, examples include AE, Throwing Efficacy (TE), Turnovers, Throwing Position on the Court, and GK Saves. However, the relationship of KPIs with other contextual factors is limited, as well as when studying other collective aspects of the game. In particular, transitions can be performed in two main ways: a "fast-break" or the 1st wave of a counterattack and a "collective fast-break" or "2nd and 3rd waves". In both, the intention is to create and use open spaces and quick actions to throw from the 6m line, relying on players' quality and strategic spatial distribution. The offensive system aims to distribute players in the space using a 3:3 setup with one pivot or 2:4 (with two pivots), fundamentally during set (or the so-called positional) attacks.

During superiority situations and when playing positional attacks, teams may choose to keep a balanced use of the depth and width of the court (using the 3:3 with one pivot offensive system) or locate more players near the 6m line, getting then a deeper use of the court (the 2:4 offensive system). The classification tree model linked the 2:4 system with the positional attack, and having no system with 7m throws and collective fast-break (2nd and 3rd waves). Therefore, it may be argued that teams preferred to play fast transitions rather than set-piece attacks during superiority. They tried to use this numerical advantage in order to position players in a better situation for scoring (that is to say near the 6m zone), facing a duel with an advantage against the GK, coinciding with previous research made on female elite handball in the same numerical context (Amatria, Lapresa, Martín Santos, & Pérez Túrpin, 2020). It is also corroborated by Lozano, Camerino, and Hielino (2016) who state that the favourable situations for attackers that appear on 1st wave counterattacks entail scoring or optimal selection of throws from 6 metres. On the other hand, when playing positional attack, the tactical option of playing with two pivots (again intending to throw via easy breakthroughs, from pivot's, or wing's positions with a higher throwing angle) was the one that prevailed in this numerical context. Particularly, performance at the 2010 female Euro tournament showed that winning teams realized more counterattacks than losing teams where wings and pivots increased their participation between 70% and 76%, improving the AE in those phases (Ohnjec, Vuleta, Dizdar, & Milanovic, 2015).

All these facts can support the high level of AE (58.0%); indeed, scoring (among all types of finalizations selected in this research) was the type of finalization that had the strongest statistically significant relationship to both contexts (superiority and inferiority). Results in these specific contexts are sustained by a required aspect of the game which is to locate a player in open and clear situations allowing them to throw, heavily related to the concepts of depth and throwing's angle (Laguna, 2019, pp. 55-56). It could also be pointed out that, despite throwing from the 6m line led to better TE than from the 9m line (Gómez-López, et al., 2023; Hatzimanouil, 2019; Piovesan, Geremia, Luz, Pombo-Menezes, & Saravia, 2020), teams tried to throw from this zone of the court. The tactical intention of throwing from the 6m zone in superiority is also highlighted by Sierra-Guzmán, Sierra-Guzmán, Sánchez Sánchez, and Sánchez Sánchez (2015) when studying the performance of the Spanish national team at Euro 2012 and 2014 and finding that transforming one of the back players to the pivot position was one of the main means of playing superiority.

AE obtained during the superiority context was higher than in previous studies in female Pan American Games (Trejo-Silva, et al., 2020). AE could also be affected by an increase in the TE as a consequence of the quality and characteristics of players (Wagner, et al., 2014); then by the throwing distance (the closer the throw, the higher the TE) and the relation to the type of throw (Tuquet, Lozano, Antunez, Larroy, & Mainer-Pardos, 2021); by the improvement of the players' strength which is directly related to the success of the throws (De Conti, et al., 2020) as well as the throwing skill (variable and adaptive) of players (Vila, Zapardiel, & Ferragut, 2020).

Context of inferiority

The AE can be considered a KPI due to its association with the overall attacking performance of a team. Results at the Rio 2016 OG showed that performance during the inferiority context was negatively affected since AE presented a reduction from 58% in the superiority context, to 37.5% during EG and to 30.3% with GK at goal. The statistically significant findings of turnovers as a consequence of poor handling of the possession affected the chances of scoring during the numerical disadvantage context. The set-piece was the game phase that presented a tendency to be used by teams playing at a numerical disadvantage at the Rio 2016 OG, adopting preferably a 3:2 offensive system (with no pivot or with one pivot and without one wing) leaving their GK at goal coinciding with Antón (2010). Despite being a game phase where speed of the plays is slower than in the transition phase, the mishandling of the ball (registered at levels of 25% or higher) affected negatively the AE. These results of turnovers and AE are similar to the findings in the 2007 to 2017 female world championships (de Paula, et al., 2020).

The handball tournament at the Rio 2016 OG was the first tournament where a player (wearing a court player outfit) could substitute the GK at any moment of a match. This change of the rules allows teams sanctioned with an exclusion to equalize (or even reduce in case they have more than one player excluded) the numerical asymmetry of players in attack. Coaches have stated that the main use of this new rule is under this context of inferiority so that they can play in *numerical equality* (Krahenbühl, Menezes, et al., 2019) but leaving EG. The use of this strategy (35.0% of the total in the context of inferiority) represented an increment from previous international tournaments played before (Beiztegui-Casado, Oliver-Coronado, & Sosa-González, 2019; Trejo-Silva, et al., 2020). Results showed that female teams at the Rio 2016 OG started to explore the effect of the change in the rules related to GK substitution, mainly during exclusion contexts.

The CHAID model, however, revealed that lower-ranked teams employed this strategy with statistically significant frequency. Given that these weaker teams need to enhance various aspects of their performance to achieve better outcomes, leveraging the element of surprise could explain their frequent use of the (EG) strategy during the championship. Previous research in futsal, a sport that also permits the substitution of the goalkeeper with a field player, supports this finding (Mendez, Goncalves, Santos, Ribeiro, & Travassos, 2019). Additionally, teams competing for medals at the Rio 2016 Olympics displayed a similar tendency to use the EG tactic, consistent with studies indicating that higher-ranked teams strategically employ the goalkeeper substitution as a surprise element in closely contested games (Gómez, et al., 2019). Interestingly, the results of this study differ from those observed in the men's tournament at the Rio 2016 Olympics, where 86.7% of inferiority actions in the knockout stages were played with the EG tactic (Krahenbühl, Sousa, et al., 2019). Indeed, some studies suggest that male team coaches are more inclined to employ this tactic compared to female team coaches (Krahenbühl, Menezes, et al., 2019). The occurrence of counterattacks (ending in goals scored or not) was the consequence of the finalization that appeared the most when playing with EG during the inferiority context. This tendency showed that teams playing with EG are more likely to concede fast transitions immediately after their finalization, whether they have succeeded in scoring or not. Similar results were found for men's handball clubs competitions (Gümüs & Gençoğlu, 2020). This could be due to poor decisions taken by attacking players when attempting to keep longer possession of the ball (Korte & Lames, 2019), reflected in having the ball intercepted or not being able to throw (Prudente, Cardoso, Rodrigues, & Sousa, 2019). Finally, it can be argued that coaches at the Rio 2016 OG opted to start exploring maintaining the equality of court players during inferiority in attack, even though they took the risk of leaving the EG while their players developed individual and collective actions in this new offensive game structure (Musa, et al., 2017).

Some limitations were identified in this research and need to be addressed in further research: i) the different zones where final actions (throws or turnovers) occurred; ii) the level of opposition (whether the attacking player was facing no defender or a certain degree of defense action); iii) include other tournaments to have a longitudinal perspective; and iv) analyse the influence of unequal scenarios of play different than the 2-minute exclusions on team's effectiveness and the game outcome. Upcoming studies may consider those variables, especially considering the EG rule's impact on the game throughout the last Olympic games (2016-2020-2024) as well as continental or world championships. Addressing coaches' and players' opinions might be also an important input to get a deeper knowledge of the exclusion context in handball matches.

In conclusion, during the Rio 2016 OG handball tournament, playing with EG reached 35% of the total actions registered during inferiority, being a predictor of a tactical predictable factor for teams ranked 9 to 12 but also for those teams playing for winning a medal. However, teams playing with EG conceded, as a consequence, more counterattacks from their opponents. Moreover, the AE when using this strategy was higher than playing with GK at goal (37.5% vs 30.3%). Additionally, 2:4 (with two pivots) was the offensive system associated with superiority context, as well as the use of fast transitions via 1st, 2nd, and 3rd waves.

Coaches may consider the results of this study to develop team game solutions affecting their player's actions. Either during games or training sessions, focused on the numerical asymmetry (during exclusions scenarios), and especially when training to play inferiority situations with EG, given that teams tend to concede counterattacks immediately after the ball possession ended.

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Correspondence to:
Alejandro Trejo-Silva, Ph.D.
Instituto Superior de Educación Física,
Universidad de la República (ISEF-UdelaR)
Montevideo, Uruguay
Department of Sports, Instituto Universitario
Asociación Cristiana de Jóvenes (IUACJ)
Montevideo, Uruguay
Faculty of Education and Psychology,
University of Extremadura
Badajoz, Spain
E-mail: tititrejo@hotmail.com

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PARKOUR PRACTITIONERS' TRAINING HABITS, MOTIVES, GOALS AND PERCEIVED PERFORMANCE FACTORS: AN INTERNATIONAL APPROACH

Andoni Elizondo-Donado[1], Sidney Grosprêtre[2,3], David Pagnon[2,4], Uxue Fernandez-Lasa[5], Josune Rodríguez-Negro[5,6], and Javier Yanci[5,6]

[1]Faculty of Education and Sport, University of the Basque Country, UPV/EHU, Vitoria-Gasteiz, Spain
[2]PRESS (Pôle de Ressources et d'Expertise Sportive et Scientifique), Fédération de Parkour, Strasbourg, France
[3]EA4660, C3S Culture Sport Health Society, University of Franche-Comté, Besançon, France.
[4]Laboratoire Jean Kuntzmann, Université Grenoble Alpes, Saint-Martin-d'Hères, France
[5]Society, Sport and Physical Activity (GIKAFIT) Research Group, Department of Physical Education and Sports, Faculty of Education and Sport, University of the Basque Country (UPV/EHU), Vitoria-Gasteiz, Spain
[6]AKTIBOki: Research group in physical activity, physical exercise and sport, Department of Physical Education and Sports, Faculty of Education and Sport, University of the Basque Country (UPV/EHU), Vitoria-Gasteiz, Spain

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Abstract:

This study aimed to describe frequent parkour practitioners' training habits, training motives and goals, and perceived performance factors of practitioners from different countries and continents. An *ad hoc* questionnaire (PARK-Q) was developed in four languages by the research group and validated by active experts with 12-18 years of experience practising and coaching parkour. The PARK-Q is a multidimensional questionnaire that explores demographics, habits, goals, motivation and perceived performance factors from the practitioner's perspective. The PARK-Q presented overall great internal consistency (Cronbach's α=.902) and was answered by one hundred and forty-one parkour practitioners (N=141, 26.2±5.0 years old) from 15 countries and four continents. Parkour could still be considered a masculine action sport with a low level of federated participation, mostly practised outdoors, with friends, in an unstructured way, and learnt freely: with friends, autodidact, etc. Parkour practitioners' motivation mainly comes from within and could be considered intrinsic motivation. To parkour practitioners, precision, environmental adaptability, and movement techniques may be considered the most important performance factors, whereas flip repertoire, suffering capacity, and keeping yourself distracted are the least important. Thus, new measuring instruments or assessments that align better with the discipline should be explored, considering the performance factors perceived by international parkour practitioners.

Keywords: *art du déplacement, freerunning, questionnaire, measuring instrument, training*

Introduction

Parkour was created in Evry and Lisses (France) in the late 1980s within the group Yamakasi (Angel, 2016; Pagnon, Faity, Maldonado, Daout, & Grosprêtre, 2022; Puddle, 2019; Sampayo & Fererro, 2020; Torchia, 2021). In its beginnings, it consisted of games and exercises involving strength and agility but later developed into more complex training systems (Stagi, 2015). Years go by, and the founder group split apart due to personal circumstances. It was at this point when three disciplines with the same root emerged: parkour, Art Du Déplacement (ADD, i.e., art of movement) and freerunning (Pagnon, et al., 2022; Puddle, 2019;

Sampayo, 2020; Sampayo & Fererro, 2020). In this study, parkour will be used as an umbrella term for all expressions of the discipline except when the different disciplines are addressed independently or when quoting participants, as some authors have done in previous works (Puddle, 2019). In 2001 the practice became a global phenomenon with the release of the film Yamakasi: Les samouraïs des temps modernes and in 2003 with the release of the documentary Jump London. At this point, parkour started to develop far from the founders, and new practitioners started to shape the sport (Stagi, 2015; Torchia, 2021). Although the three disciplines (parkour, ADD, and freerunning) were non-competitive in their roots, parkour began to follow a process of sportization (O'Grady, 2012; Stagi, 2015) and in 2007 the first competition was held, organised by the brand Redbull® and named Art of Motion (Red Bull, 2021). There was a backlash from the general parkour community and competing was somewhat controversial in the early days. Years later, new leaders who did not identify with the founders emerged and formed the World Freerunning Parkour Federation (WFPF). They created the 'Ultimate Parkour Challenge' for MTV, which aired in 2009 to an audience of 3.5 million people (World Freerunning Parkour Federation, n.d.). This show potentially attracted viewers interested in competition, leading them to practice outside the founders' influence. The trend was multifactorial, and the WFPF was not the only reason behind it. Other factors, such as the rebranding under the name freerunning and the use of safety mats, also played a role (WebWire, n.d.). Additionally, as some athletes and companies increased their revenue through these events, more practitioners showed interest in competition. To satisfy this demand, brands, communities and federations started to organise leagues, tournaments and a broad kind of competitive events around the world, such as: Redbull's Art of Motion (Red Bull, 2021), Origins Parkour's North American Parkour Championships (NAPC) (Origins Parkour, 2022), Air Wipp's Air Wipp Challenge (Air Wipp Academy, 2018), FISE's and International Gymnastics Federation's (FIG) speed and style competitions (FIG, 2020; FIG, 2022; FISE, 2022), and World Chase Tag (World Chase Tag, 2022).

Despite parkour's popularity in the media and the streets, scientific knowledge is relatively scarce in the performance and motivation fields. Several authors have studied specific aspects of parkour from different academic perspectives (Lawrence, 2019), giving a rather fragmentary understanding of the discipline. For example, a recent review by Pagnon et al. (2022) characterised the profile of its practitioners through an extensive, multidisciplinary literature review. Many authors have tried to assess performance within parkour but with common physical tests, and some are not closely related to the sport. For instance, some authors (Torres Larrea & Romero Frómeta, 2021) measured standing long jumps, and so did Grosprêtre and Lepers (2016) with additional tests such as vertical jumps (countermovement jump - CMJ and drop jump - DJ), squat jumps and knee extension strength. Solano et al.(2017) also measured standing long jumps, sit and reach, CMJ and 15 second continuous jump test. Overall, traceurs demonstrated similar or greater jumping skills than other high-level athletes. Dvorak et al. (2017) assessed the effect of parkour training with an incremental test in a treadmill to determine maximal oxygen uptake (VO2max), and the Eurofit physical fitness test battery to test strength in their sample. They concluded that parkour was a good form of exercise to improve the physical health of youth. Similar to previous studies, Seyhan et al. (2019) showed that the CMJ performance of traceurs increased after 8 weeks of strength training. On the other hand, there have also been attempts to create parkour-specific performance tests. Madureira et al. (2016) used a circuit to test performance when testing the efficacy of caffeine beverages in parkour. Dvorak et al. (2018) further stepped forward and developed an obstacle course in which parkour skills were assessed. Participants performed the obstacle course while testers filled a checklist giving points if the parkour technique performed met the specifications suggested by the authors. Similarly, Strafford et al. (2022) examined what functional movement skills correlated with the time of a parkour speed run performed in an indoor facility. They suggested that the agility T-test, the standing long jump, and CMJ could form a coherent battery of tests to evaluate traceurs' physical shape. Padulo et al. (2019) suggested the specific parkour repeated sprint ability test (SPRSA). This test assesses specific parkour repeated sprint ability. The SPRSA is a 15 metre, 10 time, maximal-speed shuttle run with a 15 second recovery jogging way back. Within these 15 metres the participant has to perform several techniques in the following order: Monkey vault (also named kong vault, cat or *saut du chat*), front flip, precision and roll. Although some interesting studies analysing performance cognitive aspects, such as Grosprêtre and Gabriel's (2021), most scientific research regarding parkour is based on sociology and politics (Kuldova, 2019; Marshall, 2010; Raymen, 2019), education (Acosta-Montoro, 2015; D. T. Maldonado & Silva, 2015; Suárez & Fernández-Río, 2012), and biomechanics (Jabnoun, Borji, & Sahli, 2019; G. Maldonado, Bailly, Soueres, & Watier, 2017; G. Maldonado, Bailly, Souères, & Watier, 2019), and not sport-specific performance analysis. Furthermore, practitioners' intrinsic factors, such as demographics, training habits, motivations, and goals, may influence their performance objectives and, consequently, the sport-specific performance analysis. Some variables, such as motivation and habits, have been studied by various authors using qualitative research methods, primarily through interviews with practitioners (Clegg & Butryn, 2012; Meokahar & Martilova, 2021; O'Grady, 2012) or via questionnaires to map dietary habits of Czech parkour competitors (Srovnal, 2024). However, comparative analysis can become cumbersome if it is not conducted within a common framework. That is why complementary studies that assess these other dimensions within the sport may be necessary to better understand the discipline.

Moreover, it has to be considered that parkour has some unique features that differentiate it from other sports disciplines. According to Saville (2008), practitioners connect closely with their environment, linking their fears to distance, texture, and form. While engaging with this connection can be risky and may lead to injury, it can also transform their emotional relationship with the space. For experienced practitioners, parkour enhances spatial awareness and allows for deeper emotional engagement with the places they explore. An analysis of motivation could shed some light on this topic. Alternatively, most sports are based on structured organisations (federations, sports licenses, competitions…), but, in reality, parkour has originally been practised in less structured and controlled contexts. This makes parkour very difficult to assess and keep track of. Thus, further research is needed and might be interesting to explore practice habits, goals, motives and perceived performance factors from the global community's perspective. Therefore, the aim of this study was to describe frequent parkour practitioners' training habits, training motives and goals and perceived performance factors in practitioners from different countries and continents.

Methods

Design

This study was split into two phases. First, a group of experts developed and revised the design and content validity of an *ad hoc* questionnaire in four languages. Then, the Practice Habits, Goals, Motives, and Perceived Performance Factors in Parkour Questionnaire *(*PARK-Q) was shared to gather and analyse descriptive results.

Participants

In the first phase two researchers composed *ad hoc* questionnaire. Then, three experts in parkour were chosen through purposive sampling to analyse content validity. These experts were selected regarding their experience in parkour practice (12-18 years) and teaching (7-12 years), and being active in the area as self-organised and full-time coaches. Once the content was validated, it was translated from Spanish to English by the research team and French and Italian by native speakers and parkour practitioners. The second phase consisted of sharing the questionnaire with parkour practitioners. One hundred and forty-one parkour practitioners (N=141, 26.2±5.0 years old) participated in this study from 15 countries and four continents (Table 1). These practitioners had experience within the sport ranging from a single year up to 23 years (8.5±5.0 years). Further information is presented in Table 1. The inclusion criteria for entering this study were frequent practitioners of parkour, ADD, or freerunning as a principal or secondary practice and their willingness to participate in the study. Participation was voluntary, anonymous and followed the guidelines established in the Declaration of Helsinki (2013). Participants had the chance to withdraw while filling in the form, but the anonymousness of the answers made it impossible to withdraw from the research once the questionnaire was fully answered and sent.

Procedure

After noticing the gap in the existing literature regarding performance factors, goals and practice motives, the research group created the first version of the PARK-Q questionnaire *ad hoc*. It was later revised and subject to validation by a group of field experts in the first phase. Having revised and implemented experts' contributions, a final version was translated into English, French and Italian, adapted to Google Forms and distributed. The questionnaire was distributed online in different parkour training and debate groups hosted on various platforms such as Instagram, Facebook, Discord and WhatsApp during March and April of 2022. The results were gathered in Excel for later processing.

Measuring instrument

The PARK-Q questionnaire (appendix 1): is an *ad hoc* developed multidimensional questionnaire created to assess practice habits, goals, motives and perceived factors in parkour from the practitioner's perspective. The initial design was created in Spanish and later translated into English, French and Italian by native speakers and parkour practitioners. This procedure was for all blocks except block 2 (BRSQ questionnaire). In this case, the original questionnaire in English was used (Lonsdale, Hodge, & Rose, 2008), extrinsic motivation, and amotivation (self-determination theory; Deci & Ryan, 1985) and so was the validated version in Spanish (Moreno-Murcia, Marzo, Martínez-Galindo, & Marín, 2011).

The PARK-Q consists of four main blocks and a total of 88 items. The first block (items 01-16) aims to gather information about the practitioner's general information (language, age, gender, country

Table 1. Participants' choice for language, gender and country of residence in the Practice Habits, Goals, Motives and Perceived Performance Factors in Parkour Questionnaire (PARK-Q)

Variable	Options	n	Percentage (%)
Language	Spanish	102	72.3
	English	17	12.1
	French	12	8.5
	Italian	10	7.1
Gender	Male	127	90.1
	Female	13	9.2
	Non – binary	1	0.7
Country of residence	Australia	1	0.7
	Canada	1	0.7
	Chile	5	3.6
	Colombia	2	1.4
	Ecuador	13	9.2
	Finland	1	0.7
	France	12	8.5
	Israel	1	0.7
	Italy	11	7.8
	Japan	1	0.7
	Peru	1	0.7
	Singapore	2	1.4
	Spain	81	57.5
	United Kingdom	5	3.4
	United States of America	4	2.8

of residence and city of residence), training habits and level of expertise. As for training habits, the following items are asked: training space (indoor gyms, outdoors, parkour parks…), development and learning (freely, classes, events, tutorials, physical education…), sessions per week, whether they do conditioning and how often, the duration of their training, years they have been training, company during training, if the participant was federated and whether they compete. The final item asks participants to rank themselves according to their practice level (beginner, novice, intermediate, advanced or expert). Some of the possible answers for these questions are binary (Yes/ No) with the option to choose *N/A*, other questions are multiple-choice with an extra blank space following *Other* to fill in as the participant finds convenient, and some others are open questions where participants are asked to type their answers. Block number two consists of the standardised, 36-item Behavioural Regulation in Sport Questionnaire (BRSQ) (Lonsdale, et al., 2008) with an additional three items suggested by the group of parkour experts. This block assesses the participant's goals and motivation to practice by in a 7-point Likert scale, which ranges from *Not true at all* to *Very true*, with an additional *N/A* column. The third block aims to assess the importance of several performance factors within parkour, some of which have been explored in previous studies and some new ones suggested by the research team or the expert group. This block has a 7-point Likert scale structure ranging from *Not important at all* to *Very important* with an additional *N/A* column. The fourth and last block is an open space for participants to express if they felt any kind of performance factor or other item was missing and worth mentioning. This block is processed from a qualitative perspective.

Statistical analysis

Results are presented as mean±standard deviation (M±SD), frequencies, and percentages. Cronbach's alpha statistic was used to describe the questionnaire's internal consistency. The analysis was conducted with the Statistical Package for Social Sciences (SPSS Inc., version 26.0 Chicago, IL, USA).

Results

PARK-Q content validity

To elaborate the PARK-Q, all experts' suggestions were considered. The qualitative assessments made by the experts are shown in Table 2.

Table 2. Experts' assessment and suggestions for the Practice Habits, Goals, Motives and Perceived Performance Factors in Parkour Questionnaire (PARK-Q)

Expert (E)	Qualitative assessment
E1	(B1P5) Something that has always been strange to me is that usually there's no choice such as *Parkour/ ADD/ Freerunning as the same global practice*. (B2) In the second part, I would also add *because it`s the only thing it helps me socialise*, *because it is the only way I can exercise* and *because it is an environment in which I have friends*.
E2	(B3P21) Reading *Jump height (drop jump)* for the third time, I think it's the height you are able to jump from, but first, I thought it was the drop jump test, like RSI, a vertical jump after a little drop jump. Then, overall, the scope of perceived performance factors may be mixed because most peoples' answers probably won't be about performance and will be about unlocking challenges and, maybe, counting steps between gaps.
E3	I find it complete and I have nothing to add.

Note. ADD: art du deplacement, RSI: Reactive Strength Index

PARK-Q internal consistency

Regarding the internal consistency of the different dimensions between the two items, Cronbach's alpha values are shown in Table 3. Cronbach's alpha coefficient measures a set of survey items' internal consistency or reliability. This statistic helps determine whether a collection of items consistently measures the same characteristic. Cronbach's alpha quantifies the level of agreement on a standardised 0 to 1 scale. Higher values indicate higher agreement between items. Cronbach's alpha for the whole PARK-Q was high with an alpha of .902. All blocks followed this trend except for the first block (general information and practice habits), which had a Cronbach's alpha of .264. On the other hand, blocks two and three had an alpha of .957 and .994, respectively. Similarly, their sub-blocks presented alphas ranging between .778 – .999.

PARK-Q descriptive results

In this section, the descriptive results of the PARK-Q questionnaire are presented. In the first block, items gather information about general aspects and participants' practice habits. As for *Which of the following is your main practice?*, the choice with most answers was *Parkour/ ADD/ Free-*

Table 3. Internal consistency (Cronbach's alpha) values for Practice Habits, Goals, Motives and Perceived Performance Factors in Parkour Questionnaire (PARK-Q)

Block	Block (B), sub-block (S) and item number (P)	Cronbach's alpha	Number of elements
Block 1: Habits	B1 (P1, P3, P5-P7, P9-P16)	.264	13
Block 2: Behavioural Regulation in Sport	B2 (P17-P55)	.957	39
Amotivation	B2S1 (P25, P34, P43, P55)	.999	4
External regulation	B2S2 (P24, P33, P42, P51)	.995	4
Identified regulation	B2S3 (P22, P31, P40, P49)	.985	4
IM to accomplish	B2S4 (P20, P29, P38, P47)	.988	4
IM general	B2S5 (P17, P26, P35, P44)	.884	4
IM to know	B2S6 (P18, P27, P36, P45)	.993	4
IM to experience stimulation	B2S7 (P19, P38, P37, P46)	.990	4
Integrated regulation	B2S8 (P21, P30, P39, P48)	.996	4
Introjected regulation	B2S9 (P23, P32, P41, P50)	.960	4
Extra items	B2S10 (P53, P54, P55)	.778	3
Block 3: Performance Factors	B3 (P56-P87)	.994	32
Explored Performance Factors	B3S1 (P74, P75, P77-P83)	.990	9
New Performance Factors	B3S2 (P56-P73, P76, P87)	.990	20
Social Performance Factors	B3S3 (P84-P86)	.957	3
Total	**B1P1-B3P87**	**.902**	**84**

Note. IM: intrinsic motivation.

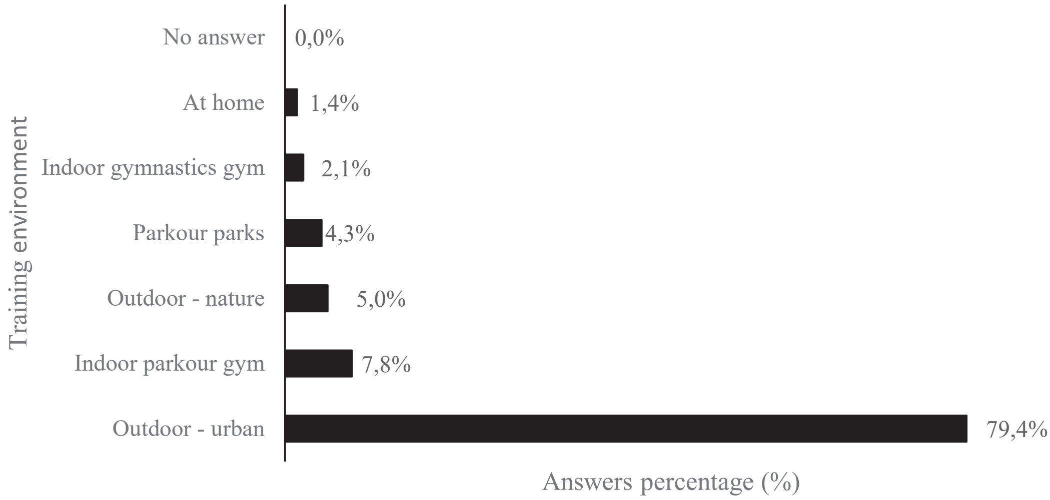

Figure 1. Training environment.

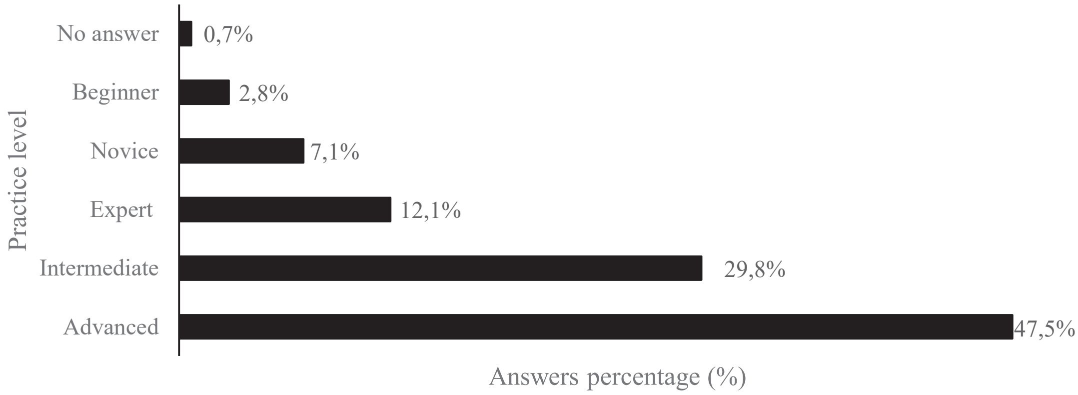

Figure 2. Participants practice level.

running as the same global practice (i.e., parkour, ADD and freerunning understood as the same practice, regardless of the name) with a 43.3% of the total. Following this option, Parkour obtained 35.5% of the total answers, ADD 13.5%, freerunning 2.1%, and callisthenics and fitness-related answers represented 2.1%. Last, climbing, tricking, kung fu, krav maga, and *N/A* represented 0.7% of the answers. There were no answers on gymnastics. The answers about the training environment are shown in Figure 1. The 79.4% stated the type of environment they usually trained in was outdoors and urban.

When the learning development within the sport was asked, 75.9% of the total picked *Freely: with friends, autodidact, etc.*, 20.6% of the participants chose *Scheduled activities: classes, workshops, events...*, and the remaining 3.6% picked *Internet: tutorials, videos, guides...* whereas nobody learnt through *Physical Education*. The results related to participants' experience and expertise level are presented in Figure 2. In this case, 47.5% identified their level as *Advanced*.

When asked whether the participant was federated, the answers were 12.8% for *Yes*, 85.8% for *No* and 1.4% for *N/A*. Regarding the average number of sessions per week, 12.8% selected *<1 session/week*, 42.6% *1-2 sessions/ week*, 30.5% *3-4 sessions/week* and 14.2% *5+ sessions/week*. Then, when asked about the duration of those sessions, 2.8% of the participants chose *<1h*, 48.9% of them *1-2h*, 38.3% picked *3-4h*, 8.5% trained *+5h* and 1.4% selected *N/A*. When asked, *Do you programme or schedule your training*? 48.2% said *Yes*, 48.9% said *No*, and the remaining 2.8% picked *N/A*. As regards being accompanied during training, 18.4% of the participants claimed to train *Alone*, 71.6% *With friends*, and the remaining 9.9% trained *In classes*. Finally, participants were asked about how often they did conditioning. 8.5% said *Never*, 15.6% of all participants stated they did conditioning *<1 sessions/ week*, 38.3% said *1-2 sessions/week*, 24.8% chose *3-4 sessions/week*, 9.9% of all participants chose *5+ sessions/week* and 2.8% selected *N/A*. As for competition, 87.2% of all participants said they did not participate in parkour competitions. The results are shown in Figure 3:

Table 4 presents the results for the second block, which assessed the participant's goals and motivation to practice.

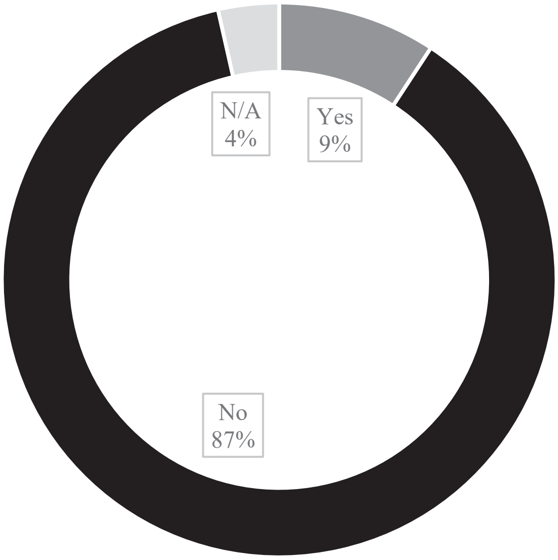

Figure 3. Participation in parkour competitions in percentage (%).

The third block in the PARK-Q questionnaire addresses different performance factors that can be split into three groups: factors used in previous studies, factors often involved in habitual training, and factors less connected with performance or social performance factors. These results are presented in Tables 5, 6, and 7, respectively. As regards factors that have been explored beforehand, they are presented in Table 5. Notably, the factor with the highest percentage at the *Very important* level, with 44.7%, was jump power.

As for the factors often involved in usual training, the highest percentage at the *Very important* level was speed, with 69.5%. All other results are shown in Table 6:

Last, results regarding factors less connected to performance during training are presented in Table 7, in which *Collaboration/ cooperation/ altruism* can be highlighted. It is the factor with the highest percentage in the *Very important* level among the three, with 40.4%.

The 4th block and last part of the PARK-Q questionnaire was an open question on performance factors or other aspects that participants felt were missing in PARK-Q. Although 62% left this space blank, most answers were connected to psychology. To the question *Are there any other factors you consider important that have not been mentioned before?,* a participant stated *Psychological factors or factors related to emotional intelligence, such as identifying frustration or blocking feelings, and being able to determine their cause*. Another participant pointed out *Mental strength (not only when breaking a jump, but also as a skill to concentrate, proprioception and body auto control)*. Also linked to psychology, some participants mentioned *Jump visualisation and mental preparation* or philosophy. A participant stated it was essential to consider concentration and mental agility as performance factors. That mental agility concept could be also linked to the answer of another participant who mentioned *reaction time in unexpected situations*. Following psychology, another subgroup could gather responses addressing emotions. A participant mentioned *emotional balance* without further elaboration. In contrast, others considered important *The empathy an individual strengthens in each group training and individual training*, *motivation*, and *Motivation, concentration, the use of the senses as the sight, coping with injuries, and remaining constant; to be and to last*.

The often repeated mantra amongst the parkour community, *Être et Durer* (to be and to last), was also part of another answer in this space, but this time linked to health. This participant pointed out *Health. Postural hygiene, abstaining from doing thing one is not physically capable of. To be and to last*. Health has also been addressed in other comments, such as *Prioritising safety and integrity. Continue practising until an old age. Therefore, it is important to take care of yourself.* Connected to taking care of oneself, a participant commented, *I consider fundamental the capacity of coping with and overcoming injuries, as it's a determinant factor in the practice's continuity.*

Another subgroup could be training or factors linked to it. On the one hand, some participants mentioned physical skills such as *Elasticity and proprioception*, *flexibility*, *coordination*, *adaptability*, and *gymnastics training*. Somebody elaborated, *Heredity plays an important role. It's true you can get better with more training, but I think you need a basic physical form to have a chance to improve*. A participant considered remarkable *Body to body combat, it's a basic in natural method.*

Two other participants agreed on training alone: *For example, how much you consider training alone, or whether you think it can be positive and help you progress and unlock challenges* and *Practicing alone is fundamental and necessary sometimes to know yourself better, as which are the limits you put to yourself without external influence. Teamwork is important, too; one of the things I like the most about the practice is sharing and helping one another. I see including this information as very positive and beneficial because it keeps our feet on the ground*.

Two participants agreed on creativity and the relationship with the environment. As one said, *Creativity development, visualising techniques in different architecture, for instance. Or knowing how the environment interacts with you with surfaces and friction forces.* The other participant mentioned, *It is important to me to learn the geography and feel the textures of my environment.* Probably linked to the environment concept,

Table 4. Participants' answers (% and M±SD) regarding practice motives and goals in the Practice Habits, Goals, Motives and Perceived Performance Factors in Parkour Questionnaire (PARK-Q)

Item - Question	Not true at all	Untrue	Somewhat untrue	Neutral	Somewhat true	True	Very true	N/A	M±SD
17-Because I enjoy it.	2.1	2.8	1.4	0.0	0.7	8.5	84.4	0.0	6.6±1.28
18-For the pleasure it gives me to know more about my sport	3.5	5.0	1.4	6.4	12.8	24.8	48.2	0.0	5.9±1.53
19-Because I love the extreme highs that I feel during sport.	4.3	2.1	2.8	6.4	14.9	22.7	44.0	0.0	5.7±1.69
20-Because I enjoy the feeling of achievement when trying to reach long-term goals.	2.8	1.4	2.1	6.4	9.2	24.1	53.2	0.0	6.0±1.46
21-Because it's a part of who I am.	2.8	2.8	2.1	7.1	10.6	16.3	58.2	1.4	6.1±1.47
22-Because the benefits of sport are important to me.	4.3	18.4	1.4	2.8	19.9	24.1	44.0	0.7	5.8±1.55
23-Because I would feel ashamed if I quit.	35.5	16.3	9.9	12.8	10.6	5.0	7.8	0.0	2.9±1.97
24-Because if I don't other people will not be pleased with me.	69.5	14.9	5.0	5.0	1.4	0.7	2.1	0.0	1.6±1.26
25-But I wonder what the point is.	68.8	4.3	2.8	4.3	2.8	1.4	3.5	1.4	1.7±1.66
26-Because I like it.	2.1	4.3	1.4	0.7	5.0	7.1	71.6	7.8	6.4±1.49
27-Because I like learning how to apply new techniques.	2.8	3.5	0.7	1.4	7.8	19.1	59.6	4.3	6.2±1.52
28-Because of the excitement I feel when I am really involved in the activity.	2.1	2.8	1.4	4.3	7.1	21.3	57.4	2.8	6.1±1.46
29-Because I enjoy the feeling of success when I am working towards achieving something important.	3.5	3.5	2.1	2.8	13.5	24.8	48.2	2.1	5.9±1.54
30-Because what I do in sport is an expression of who I am.	4.3	4.3	2.1	10.6	5.7	17.0	52.5	4.3	5.8±1.74
31-Because it teaches me self-discipline.	3.5	19.1	2.1	6.4	19.1	20.6	41.1	2.8	5.7±1.64
32-Because I would feel guilty if I quit.	36.2	10.6	2.8	11.3	7.8	8.5	14.2	0.0	3.2±2.26
33-Because people push me to participate.	75.2	12.8	4.3	3.5	2.8	0.7	2.1	0.7	1.6±1.40
34-But I question why I continue.	63.1	2.8	9.2	4.3	5.7	2.1	2.8	0.0	1.9±1.57
35-Because it's fun.	2.1	4.3	2.1	1.4	2.1	13.5	69.5	6.4	6.4±1.41
36-Because I enjoy learning something new about my sport.	2.1	3.5	2.1	3.5	7.1	20.6	54.6	5.7	6.1±1.54
37-Because of the pleasure I experience when I feel completely absorbed in my sport.	2.1	2.1	2.8	5.0	7.1	18.4	58.9	2.1	6.1±1.52
38-Because I enjoy doing something to the best of my ability.	2.1	2.8	2.1	2.1	10.6	16.3	60.3	4.3	6.2±1.40
39-Because it's an opportunity to just be who I am.	3.5	4.3	1.4	4.3	7.1	17.7	57.4	5.7	6.1±1.58
40-Because I value the benefits of my sport.	2.8	20.6	1.4	0.7	7.1	21.3	56.0	6.4	6.1±1.55
41-Because I feel obligated to continue.	61.7	16.3	2.1	4.3	3.5	2.1	5.7	0.0	2.0±1.70
42-Because I feel pressure from other people to play.	60.3	14.9	4.3	4.3	6.4	2.1	5.0	1.4	2.1±1.87
43-But the reasons why are not clear to me anymore.	67.4	2.8	5.0	4.3	2.1	1.4	4.3	0.7	1.8±1.62
44-Because I find it pleasurable.	2.8	5.7	2.1	0.7	7.8	15.6	61.0	7.1	6.2±1.50
45-Because I enjoy learning new techniques.	2.1	3.5	0.7	1.4	8.5	19.1	56.0	6.4	6.1±1.56
46-Because of the positive feelings that I experience while playing my sport.	2.1	2.8	0.7	1.4	6.4	19.1	61.7	5.0	6.3±1.41
47-Because I get a sense of accomplishment when I strive to achieve my goals.	2.8	3.5	1.4	0.0	5.0	14.9	68.1	5.0	6.4±1.43
48-Because it allows me to live in a way that is true to my values.	4.3	7.1	0.0	2.1	10.6	16.3	57.4	5.7	6.1±1.62
49-Because it is a good way to learn things which could be useful to me in my life.	2.8	17.7	2.1	3.5	11.3	17.0	50.4	5.7	5.8±1.74
50-Because I would feel like a failure if I quit.	56.0	12.1	5.0	5.0	3.5	4.3	5.7	2.8	2.2±2.04
51-In order to satisfy people who want me to participate.	75.9	16.3	3.5	2.1	0.7	0.7	3.5	1.4	1.5±1.53
52-But I question why I am putting myself through this.	66.0	12.1	5.0	5.0	1.4	1.4	3.5	1.4	1.8±1.63
53-Because it is the only thing it helps me socialise.	57.4	17.0	9.2	4.3	7.8	3.5	5.0	0.7	2.2±1.89
54-Because it is the only way I can exercise.	49.6	6.4	9.2	5.0	9.2	2.1	5.7	2.1	2.3±1.99
55-Because it is an environment in which I have friends.	17.7	2.8	9.9	6.4	14.2	15.6	27.7	2.1	4.5±2.28

Table 5. Participants' answers (% and M±SD) for previously used performance factors in the Practice Habits, Goals, Motives and Perceived Performance Factors in Parkour Questionnaire (PARK-Q)

Item - Factor	Totally unimportant	Unimportant	Slightly unimportant	Neutral	Slightly important	Important	Very important	N/A	M±SD
74-Horizontal jump distance	0.7	0.7	2.8	9.9	12.8	36.2	35.5	1.4	6.16±1.19
75-Jump power	0.7	0.7	0.7	5.7	16.3	29.8	44.7	1.4	5.84±1.11
77-Drop Jump (DJ)	1.4	2.1	2.1	12.1	24.8	22.0	29.1	6.4	6.62±0.74
78-Vertical jump height (CMJ)	0.7	1.4	1.4	12.8	18.4	30.5	33.3	1.4	4.97±1.71
79-Repeated Sprint ability	2.1	5.0	2.1	12.8	24.1	22.7	28.4	2.8	6.34±0.98
80-Running jump distance	1.4	1.4	0.7	9.9	17.0	34.0	32.6	2.8	6.57±0.81
81-Core stability	0.7	0.0	2.8	6.4	16.3	36.9	34.8	2.1	6.38±1.01
82-Grip strength	0.7	0.0	2.1	6.4	14.2	35.5	37.6	3.5	5.72±1.52
83-Maximal oxygen uptake ($VO2_{max}$)	5.0	2.1	5.7	17.0	15.6	24.1	25.5	5.0	5.65±1.36

Table 6. Participants' answers (% and M±SD) for suggested performance factors in the Practice Habits, Goals, Motives and Perceived Performance Factors in Parkour Questionnaire (PARK-Q)

Item - Factor	Totally unimportant	Unimportant	Slightly unimportant	Neutral	Slightly important	Important	Very important	N/A	M±SD
56-Balance	1.4	0.0	2.8	5.0	9.2	30.5	50.4	0.7	6.49±0.89
57-Speed	0.7	0.7	1.4	7.1	23.4	34.8	31.9	0.0	5.80±1.40
58-Precision	0.7	0.0	0.0	1.4	0.7	27.7	69.5	0.0	6.14±1.18
59-Suffering capacity	4.3	5.0	9.2	19.1	18.4	19.9	23.4	0.7	5.41±1.68
60-Perseverance	0.7	0.7	0.7	1.4	10.6	29.8	56.0	0.0	5.86±1.37
61-Environmental adaptability	0.7	0.0	0.7	0.0	5.7	24.8	68.1	0.0	4.44±2.00
62-Commitment	0.7	0.7	0.7	2.8	8.5	25.5	61.0	0.0	6.42±0.96
63-Breaking a jump	4.3	0.0	2.8	9.2	19.1	22.7	39.7	2.1	6.01±1.24
64-Cardiovascular resistance	1.4	0.7	3.5	14.2	19.1	26.2	33.3	1.4	5.01±1.78
65-Movement techniques	0.7	0.0	0.0	2.1	6.4	25.5	61.7	3.5	5.88±1.22
66-Bilateralism	1.4	1.4	2.8	10.6	16.3	24.1	39.7	3.5	6.09±1.12
67-Creativity	1.4	0.0	2.8	3.5	12.1	30.5	48.2	1.4	5.68±1.44
68-Movement. acrobatic or route aesthetics	4.3	3.5	5.7	10.6	16.3	26.2	31.9	1.4	5.55±1.45
69-Parkour movement repertoire	1.4	1.4	2.8	9.9	14.2	26.2	41.8	2.1	5.76±1.26
70-Flip repertoire	13.5	7.8	8.5	14.2	19.1	19.9	16.3	0.7	5.40±1.55
71-Flow	0.7	0.0	1.4	1.4	7.1	28.4	58.2	2.8	5.80±1.28
72-Relative strength - Bodyweight strength	1.4	0.7	2.1	5.7	14.9	30.5	43.3	1.4	5.93±1.14
73-Absolute strength - Against weight strength	7.1	3.5	8.5	12.1	24.1	19.1	24.8	0.7	6.01±1.13
76-Jump height (saut du fond)	2.8	1.4	3.5	8.5	20.6	27.0	36.2	0.0	5.22±1.73
87-Distance after a movement (Eg. Catpass pre)	2.8	1.4	5.0	12.1	14.9	24.8	37.6	1.4	5.29±1.60

Table 7. Participants' answers (% and M±SD) for factors less connected with performance in the Practice Habits, Goals, Motives and Perceived Performance Factors in Parkour Questionnaire (PARK-Q)

Item - Factor	Totally unimportant	Unimportant	Slightly unimportant	Neutral	Slightly important	Important	Very important	N/A	M±SD
84-Socialising	3.5	2.8	6.4	15.6	18.4	24.8	27.7	0.7	4.98±1.87
85-Keep yourself distracted	6.4	5.7	7.8	15.6	15.6	20.6	25.5	2.8	5.80±1.43
86-Collaboration/ cooperation/ altruism	2.1	1.4	2.8	9.9	14.9	26.2	40.4	2.1	5.63±1.53

another participant pointed out the weather as an important performance factor.

Other participants commented on transmitting the discipline and its applicability to day-to-day life and community. Someone pointed out *social support* as an important factor, others addressed values *I think you could talk more about the benefits and values we get and develop through the sport*, and *I'd say knowledge transmission and maturity to apply it in my everyday life*. Linked to transmission, there was an answer about coaching: *Coaching, or doing Parkour because it is part of your profession. Responsibility to others to continue training/ coaching.*

Lastly, some answers cannot be classified under any topic. These comments mentioned *critical thinking*, no competition *parkour is not competing against others; you don't have to measure or compare to others; you have to see what you are and take that into consideration, improve*, another participant expressed *the sensation of freedom and success*, resilience *Getting up after failure and staying decent*, nutrition *A question to ask whether someone thinks you need energy drinks or sports foods for your training*; and a final answer that wrapped some of the previous points with need ideas *Breathing, nutrition, injury prevention, hydration, sleep importance, intuition development, environment adaptability, creativity and identity.*

Discussion and conclusion

Although there are previous studies that explored physical condition in parkour (Daneshjoo & Raeisi, 2020; Dvořák, et al., 2018; Grosprêtre & Lepers, 2016; Grosprêtre, Ufland, & Jecker, 2018; Marchetti, et al., 2012; Padulo, et al., 2019; Pagnon, et al., 2022; Seyhan, 2019), this is the first time that research is conducted to study parkour practitioners' training habits, training motives and goals, and performance factors perceived by frequent practitioners from different countries and continents. The main finding regarding habits was that 43.3% of all participants did not make distinctions between names and claimed they practised 'Parkour/ADD/ Freerunning' as the same global practice, 79.4% trained outdoors in an urban environment, 75.9% learned parkour *Freely: with friends, autodidact, etc*., the 47.5% considered themselves as *Advanced*, and 87.2% did not participate in parkour competitions. As regards motivation, on one hand, 84.4% found *Very true* to practice *because I enjoy it*, 69.5% *because it's fun*, and 68.1% *because I get a sense of accomplishment when I strive to achieve my goals*. On the other hand, 75.9% of the participants felt it was *Not true at all* that they practice *In order to satisfy people who want me to participate*, 75.2% found the statement *because people push me to participate* to be *Not true at all* and 69.5% of participants picked that same choice for the phrase *Because if I don't other people will not be pleased with me*. Regarding performance factors, the options that most participants found *Very important* were *Precision* with 69.5%, *Environment adaptability* with 68.1% and *Movement techniques* with 61.7%. The factors most participants considered *Totally unimportant* were *Flip repertoire* with 13.5%, *Absolute strength* with 7.1% and *Keep yourself distracted* with 6.4%. The results obtained in the present study provide relevant information for a better understanding of this discipline.

Internal consistency

In disciplines or sports with scarce research, it is essential to develop valid measuring instruments that allow researchers to further study the subject rigorously. The PARK-Q followed a similar development as other questionnaires (Lonsdale, et al., 2008; Moreno-Murcia, et al., 2011), created *ad hoc* and previously validated before sharing it with practitioners because there were no previous surveys developed to explore habits, motives and/or performance factors in parkour. The PARK-Q was shared among a group of experts to assess its validity, and probably due to researchers' experience in the topic, the suggestions made by the expert group were few. Overall internal consistency for the 88 items of the questionnaire was great (α=.902), and other consistency results were superior to others found in similar questionnaires where Cronbach's α ≥ .70 (Alexe, et al., 2022; Farmanbar, Niknami, Hidarnia, &

Lubans, 2011). Cronbach's alpha for the *Habits* block (P1-P16) was considerably low (α=.264). Nevertheless, this result may show low internal consistency because items regarding country, environment, training frequency, years of practice, etc., could mean the sample for this study was very diverse. Comparing the PARK-Q's block (P17-P55), which includes the BRSQ, to other studies using the same questionnaire, important differences can be pointed out in each sub-block regarding internal consistency. In this study Cronbach's alpha for *Amotivation* was .999, while in other studies these values were lower (α=.66-.86) for the same block (Farmanbar, et al., 2011; Guedes, Caus, & Sofiati, 2019; Monteiro, Moutao, & Cid, 2018; Moreno-Murcia, et al., 2011; Tsitskari, Vernadakis, Foridou, & Bebetsos, 2015). Cronbach's alpha for *External Regulation* resulted in .995 in the PARK-Q, while other authors ranged α=.63-.90 (Alexe, et al., 2022; Farmanbar et al., 2011; Guedes, et al., 2019; Monteiro et al., 2018; Moreno-Murcia, et al., 2011; Tsitskari, et al., 2015). *Identified regulation* (α=.985) had a higher α value compared to the previous authors, too (α=.68-.93) (Farmanbar, et al., 2011; Guedes, et al., 2019; Monteiro, et al., 2018; Moreno-Murcia, et al., 2011; Tsitskari, et al., 2015). The tendency remains similar to the sub-block *IM to accomplish* (α=.988), where other authors scored a lower alpha (α=.79-.80) (Guedes, et al., 2019; Moreno-Murcia, et al., 2011). The rest of the authors did not present results for this sub-block. Cronbach's alpha for *IM general* in the PARK-Q was .884, similar to Tsitskari et al. (2015) (α=.85) and Pinto et al. (α=.82) (Guedes, et al., 2019), but higher than Moreno et al's (α=.75) (Moreno-Murcia, et al., 2011). Within the same authors, *IM to know* had an internal consistency ranging from .78-.85, whereas the PARK-Q scored an alpha of .993. As regards to *IM to experience stimulation* sub-block, Cronbach's alpha for PARK-Q was .990, close to Tsitskari et al.'s (α=.92) (Tsitskari, et al., 2015) and higher than in Moreno's study (α=.78) (Moreno-Murcia, et al., 2011) and Pinto's research (α=.83) (Guedes et al., 2019). *Integrated regulation* sub-block internal consistency was α=.996, while previously mentioned authors' ranged .71-.93 (Alexe, et al., 2022; Farmanbar, et al., 2011; Guedes, et al., 2019; DMonteiro, et al., 2018; Moreno-Murcia, et al., 2011; Tsitskari, et al., 2015). The last block to compare, *Introjected regulation*, followed the trend from the previous motivation forms and with an alpha of .960 outscored other authors', ranging .74-.86 (Alexe, et al., 2022; Farmanbar, et al., 2011; Guedes, et al., 2019; Moreno-Murcia, et al., 2011; Rodrigues, Macedo, Teixeira, Cid, & Monteiro, 2020; Tsitskari, et al., 2015). Finally, the new sub-block with extra items scored α=.778, although lower than the rest, showing good internal consistency. The performance factors block showed a great consistency overall (α=.994) and was divided into three sub-blocks: *Explored performance factors* (α=.990), *New performance factors* (α=.990) and *Social performance factors* (α=.957). These results show that the whole structure of the PARK-Q was adequate.

Demographics

Exploring demographics gathered in the PARK-Q, the results share great similarities with previous research: 90.1% of the practitioners who answered the PARK-Q were male, 9.2% were female, and the remaining 0.7% were non-binary. These numbers go along with the review by Pagnon et al. (2022), where it is mentioned that the percentage of men taking part in parkour studies represents 87-96% of the sample, and this gap was the strongest between age 15-24 years. A study by Grosprêtre and Khattabi (2022) also found a gap between parkour-practising men (78.3%) and women (21.7%). Interestingly, a study in Denmark (Engell, Larsen, & Elmose-Østerlund, 2023) showed a narrower gender gap than previous studies, reporting that 17.3 to 21.4% of parkour practitioners were women and 78.6 to 82.7% were men, with the lower percentages representing those who practiced at least once in the past 12 months and the higher percentages reflecting weekly or more frequent practice. As Stagi (2015) mentioned, these results can be expected because parkour could be considered a masculine sport, connected with being risky and practised in public spaces. Addressing minorities within the New Zealand parkour community, Puddle (2019) also identified a barrier in women's practice: *A lack of formal hierarchies does not mean that all social groups in parkour are accessible. There are still informal hierarchies in the parkour community where male bodies dominate, even while attempts are made to promote and encourage women's participation*. These statements are supported by other authors who explored gender in parkour, too, such as Carbo-González (2013), Kidder (2013) and Wheaton (2016). An analysis by Lawrence (2019) concluded that football's extensive history, institutionalised over more than a century, has solidified the social and cultural capital primarily afforded to white men. In contrast, parkour emerged in a socio-historical context distinct from traditional sports, which are now striving to adapt to the conditions of late modernity rather than originating from it. In comparison to other action sports, females and non-binary represented a minority in skateboarding (10.7%) (Rodríguez-Rivadulla, Saavedra-García, & Arriaza-Loureda, 2020), snowboarding (47.57%) (Ronconi, 2015), snowboarding and skiing (17.6%) (De Roulet, et al., 2017) and base jumping (13.2%) (Mei-Dan, Carmont, & Monasterio, 2012). It has to be taken into account that Ronconi's study (2015) aimed to explore gender differences, which might be why females had greater representation than in

Roulet's sample. On the other hand, compared to Fari et al.'s study on rhythmic and artistic gymnastics, the results were the complete opposite, with a female participation of 98.7% (Farì, et al., 2021). When asked about their primary practice, the majority (43.3%) answered: *Parkour/ ADD/ Freerunning as the same global practice*. This result reflects Puddle's terminology conflict within the community (2019).

Federative practice and space

In the PARK-Q, participants were asked whether they were federated, and the main answer was No, with 85.8% of the total. Although parkour has been absorbed as a new gymnastic discipline by the Fédération Internationale de Gymnastique (FIG, 2020, 2022; Santandreu Sosa, 2022), and some practitioners may have competed in their format, it is surprising to see such a low percentage, despite FIG's interest to federate parkour. A hypothesis for this result could be that the communication channels used to spread the PARK-Q are not used by practitioners enrolled in the FIG, or the massive criticism of FIG inside parkour communities (Elizondo-Donado & Jauregi, 2021; Santandreu Sosa, 2022). Moreover, although there has been a recent formation of national and international federations, such as Plataforma Española de Parkour y Arte del Desplazamiento (i.e., Spanish Parkour and ADD Platform; PEPADD), Parkour Singapore, Parkour and Freerunning Malagasy Federation, or Parkour Earth (Parkour Earth, n.d.), this increase does not align with the number of people who declared being federated. Furthermore, assessing the training environment for parkour, a great percentage (79.4%) claimed to practice outdoors in urban spaces, followed by indoor parkour gyms (7.8%) and outdoors in nature (5.0%). Overall, parkour focuses on adaptability to new environments, which might lead practitioners to seek different spaces outdoors in urban environments. It is also worth noting that parkour was originally founded as an outdoor activity in urban environments, and practitioners may feel firmly attached to this concept. Grosprêtre and Khattabi's (2022) results align with PARK-Q's findings, as in their study 32.2% reported practising parkour only outdoors and 2.2% only indoors in parkour facilities. These results could be linked to Pagnon et al.'s statement (2022) regarding parkour environments: Parkour is usually multi-site, practitioners train in a multitude of spots, i.e., places with interesting features for parkour (walls, trees, rails, benches, etc.). Nonetheless, these authors also mentioned that indoor parkour gyms and parkour parks have been built recently as a process of indoorization of outdoor sports as a trend that has been observed in other lifestyle outdoor practices (van Bottenburg & Salome, 2010; Wheaton, 2004). This could explain indoor parkour gyms as the second option with the highest percentage.

Learning and training company

Regarding learning and development within the discipline, in the PARK-Q, 75.9% of the participants claimed their learning and development was *Freely: with friends, autodidact, etc*. This result aligns with Pagnon et al.'s statement (2022): *Learning takes place as a process of trial and error more than via verbal instructions. But it is also a collaborative process with limited amounts of traditional coaching, where traceurs learn by observation and comparison, mentoring and peer coaching, and frequently give feedback to each other, whether they are veterans or beginners, skilled or less so.* Grosprêtre and Khattabi (2022) found that 40.6% of the practitioners started parkour independently without supervision, whereas 20% reported beginning under the supervision of experienced practitioners and 35.6% under the supervision of a professional coach. Assessing training company, most of the answers (71.6%) for PARK-Q were *With friends*. These results follow Stagi's (2015) findings, in which some participants claimed they never trained alone because it is difficult and certain places are dangerous. It seems that group training has been since the early days in the Yamakasi (Torchia, 2021), even though parkour can be considered an individual sport (Fonseca Díaz & Palacios Peña, 2021). Torchia (2021) also mentioned that *for one of the founders, David Belle, as his training progressed, he created a core group who followed him in his training, moving his practice from an individualistic to a more shared endeavour*. So did Pagnon et al. (2022) mention in their review *Collective and individual elements are welded together: even when practitioners attempt together the same challenge, they leave space for individual interpretation, style and standards*. These behaviours can be better understood when analysed and compared to O'Grady's (2012) work. Parkour training typically develops through peer interaction in public spaces rather than formal settings, fostering a shared repertoire of moves and embodied knowledge. It exemplifies collaborative, social learning where participants support one another, provide feedback, and value contributions regardless of experience. Situated in real-world environments, parkour aligns with social learning theory (Wenger, 1998), emphasising learning through doing, belonging, and becoming. With the sport's ongoing formalisation, informal peer-led sessions contrast with structured physical education programmes. Online platforms like YouTube and social media enhance this networked learning by helping practitioners set goals and exchange knowledge.

Training habits

In addition, exploring training frequency, the most answers for the PARK-Q were *1-2 sessions/ week* at 42.6% and *3-4 sessions/week* at 30.5%. Although Pagnon et al. (2022) gathered some training frequencies from other studies in their review, those cannot be compared to current data as they were inclusion criteria and lacked a number for frequency or percentage of the participants. According to Grosprêtre and Khattabi's (2022) findings, training frequency varied from 1 to 7 sessions/ week, averaging 2.42 parkour sessions/week. PARK-Q's results are similar compared to skateboarding, with 3.3±1.7 sessions/week (Rodríguez-Rivadulla, et al., 2020) but inferior compared to gymnastics (Farì, et al., 2021), which averages 4.1±1.3 sessions/week ranging 2-8 sessions/ week. Regarding the duration of those sessions, an important part was between *1-2 h* (48.9%) and *3-4 h* (38.3%) of the participants in the PARK-Q. These results cannot be compared to previous data. Nevertheless, compared to skateboarding, parkour training's duration was similar, as skateboarding averages 3.3±1.5 h (Rodríguez-Rivadulla, et al., 2020), but compared to gymnastics parkour was outscored, as gymnasts trained a weekly average of 25-30 h and up to 40 h per week (Farì, et al., 2021). Continuing with items connected to training, PARK-Q's answers for structured training were 48.2%. This result goes along with previous information Pagnon et al. (2022) suggested, when they compared performance between parkour practitioners and other sports practitioners, *despite a less controlled and structured training, traceurs could achieve similar or even better performances than other athletes* meaning that with fewer years of practice and less structured training traceurs achieved similar or higher countermovement jump (CMJ) and longer standing long jump (SLJ) values as other athletes. Compared to other sports, Rodriguez-Rivadulla (2020) claimed that *Like younger skateboarders, participants with less experience reported longer sessions. More experienced skateboarders seemed to be more organised in the practice of their sessions, as they usually performed a warm-up and cool down*. This suggests that more experienced traceurs may tend to structure their training sessions. When asked about conditioning frequency in the PARK-Q, the option with the most answers was *1-2 sessions/ week*, with 38.3% of the total. This result could be linked to parkour's high physical and technical skill requirements (Pagnon, et al., 2022). According to Grosprêtre and Khattabi (2022), 75.6% of the individuals reported practising specific physical conditioning in parkour. Nevertheless, as reflected in Stagi's work (2015), some female practitioners *believed that the males who practice parkour tended to exaggerate their strength training when this was unnecessary*. Those thoughts of an exaggeration of physical conditioning could probably be linked to those participants (9.9%) who claimed to do conditioning *5+ sessions/ week*.

Competition

Competition in parkour has always been controversial. The answers for the PARK-Q in this matter could be linked to that perception because 87.2% of participants said they did not participate in parkour competitions. These results may be rooted in the definition of parkour for some practitioners: *Parkour is a lifestyle sport, and as such provides an alternative to mainstream ones, away from strict rules, standardised settings, and necessary competitions* (Pagnon, et al., 2022). As is quoted from Pagnon et al.'s review (2022), *Currently, parkour is mostly non-competitive, and its rules are non-written and rather flexible in contrast to other sports*. Parkour fits perfectly with Suits' definition of game: *a voluntary attempt to overcome unnecessary obstacles*, and less so with Borge's (2021) understanding of sport: *an extra-ordinary, unnecessary, rule-based, competitive, skill-based physical activity*. Torchia's (2021) findings also provide context for these results. In the words of some participants *structured competition being destructive to parkour, sometimes describing having come to this conclusion through negative experiences of competition-embedded class content, and the costs they perceived from it and Participants also expressed fear towards parkour moving towards competition*. Nevertheless, as Puddle (2019) mentioned in his work, *parkour competitions have existed since at least 2007 and there is a growing support for competitive formats*. As in other lifestyle sports, the performance is never fixed or determinate, but is in a state of flux and change. This context might explain why 9% of participants still take part in parkour competitions. Compared to other action sports, such as skateboarding (Rodríguez-Rivadulla, et al., 2020), the authors mention that only *27.4%* participants in their study participated in competitions. This perception of a low percentage is in great contrast to the 9% of the answers for parkour. Rodríguez-Rivadulla (2020) explains that young skateboarders (<18 years) participated more in competitions than their older counterparts. As they say, *this may be explained by the evolution of skateboarding into a more conventional competitive sport. On the other hand, respondents 18 years or older reported performing other sports more than those younger than 18 years, suggesting that skateboarding was mostly practised as a recreational activity in this group*. Another approach to understanding this low percentage of participation in parkour competitions could be comparing it to other action sports such as BASE jumping (Mei-Dan, et al., 2012) and surfing in second-hand. As cited in Mei-Dan et al.'s work (2012), *Nathanson et* *al. (2007) evaluated acute competitive surfing injuries, concluding it to be much riskier than recreational surfing. Torjussen and Bahr (2006) studied the injuries among elite snowboarders during World Cup events and found the injury incidence to be almost twice as high as that of recreational snowboarders. Accordingly, some extreme sports fields, like BASE jumping, tend to eliminate official events where more fatalities could be expected.* Parkour practitioners may be aware of this reality and prefer to engage recreationally rather than at a higher or competitive level. Similarly, competition hosts may also seek to avoid injury-related scenarios. Closing the habits block of the PARK-Q, when participants were asked to rate their training level, the majority (47.5%) identified their level as *Advanced* followed by *Intermediate* (29.8%) and *Expert* (12.1%).

Motivation

To date, different tools have been used to assess goals and motivation in different sports, disciplines and samples, such as: young Brazilian athletes (Guedes, et al., 2019), young Spanish athletes (Moreno-Murcia, et al., 2011), professional Romanian athletes (Alexe, et al., 2022), young European athletes (Viladrich, et al., 2013), young Swedish skiers and football players (Stenling, Ivarsson, Lindwall, & Gucciardi, 2018), recreational dancers (Hancox, Quested, Viladrich, & Duda, 2015) and Portuguese swimmers and football players (Monteiro, et al., 2019), to mention a few. One of these measuring instruments is the *Behavioural Regulation in Sports Questionnaire* (BRSQ) (Lonsdale, et al., 2008). This measuring instrument presents different motivation forms. Intrinsic motivation (IM), the most self-determined form, exists when an individual participates because of interest or enjoyment in the activity (Lonsdale, et al., 2008). IM has three equal forms: IM to know, IM to accomplish, and IM to stimulate. These forms of motivation refer to the pleasure an individual experiences while learning, when attempting to accomplish something and when one acts to experience pleasurable sensations, respectively. In all these forms of IM, parkour practitioners showed higher average results (6.04 – 6.13) than Brazilian young athletes (5.48- 6.01) (Guedes, et al., 2019) and young Spanish athletes (5.81- 5.93) (Moreno-Murcia, et al., 2011). On the other end of the motivation spectrum, extrinsic motivation (EM) is also present. The different motivation forms among EM are *External regulation*, *Introjected regulation*, *Identified regulation* and *Amotivation*. Individuals who are extrinsically motivated participate to obtain separable outcomes. External regulation is the least self-determined form and occurs when an athlete participates to obtain rewards, avoid punishment, or satisfy an external demand (Lonsdale, et al., 2008). Similar to IM, in the case of EM, parkour practitioners differed from other sports and samples. The average answers for EM in the PARK-Q ranged (1.70 – 2.55) whereas young Brazilian athletes averaged (1.91 -2.62) (Guedes, et al., 2019), young Spanish athletes averaged (2.31 – 3.13) (Moreno-Murcia, et al., 2011) and professional Romanian athletes averaged (1.99 – 2.38) (Alexe, et al., 2022). Parkour practitioners' answers were in all forms of motivation lower compared to other studies except for *Introjected regulation* in professional Romanian athletes (2.38±1.46) (Alexe, et al., 2022). Among EM forms, identified regulation exists when an athlete values and judges the separable outcomes of sport as personally meaningful. If the athlete came to view sport not only as important but also in congruence with deeply held values and his or her sense of self, then the behaviour would be regulated by the most autonomous (i.e., self-determined) form of EM, integrated regulation (Lonsdale, et al., 2008). In this case, parkour practitioners scored on average 5.86±1.62, while Pinto's results were 5.45±0.76 (2019), Moreno's 5.39±1.10 (2011) and Alexe's 6.32±0.84 (2022). Overall, parkour practitioners, on average, scored higher in intrinsic motivation forms and lower in extrinsic motivation forms than athletes in other studies. These results can be interpreted in different ways. On the one hand, the lack of a strong federative structure, an absence of a competitive calendar (or competition on its own), no expected or required sports performance by teams, clubs, parents or coaches; nor the need to acquire specific skills to practice, might make parkour a unique discipline that does not put pressure on practitioners, and as a consequence, their motivation comes within and not from external agents. On the other hand, these results may not be compared with one another, as there were differences among samples (i.e., age, sport, characteristics of the sport, country, etc.), and this variability is enough to show these differences that stand out. According to Clegg and Butryn (2012), lifestyle sports and activities are shaped by what Wheaton (2004) refers to as a participatory ideology, which emphasises enjoyment, engagement, flow (Csikszentmihalyi, 1990), risk, and self-actualisation, along with various intrinsic rewards. Therefore, as parkour is considered a lifestyle sport, it may be more influenced by IM than other sports.

Perceived performance factors

Another relevant characteristic in the knowledge of a sports discipline may be the perception its practitioners have about performance factors. Unfortunately, until now, there have not been studies exploring this field among parkour practitioners. The results obtained in the current study show that the factor with the highest average was jump power, followed by grip strength. The least important in this group were VO_{2max} (5.22±1.73) and repeated sprint ability (5.40±1.55). Participants perceived more relevant neuromuscular capacity rather than cardiovascular capacity. Along with these results, when addressing new performance factors, the factors with higher averages were the same as the overall highest: precision, environmental adaptability, and movement techniques with 6.42±0.74, 6.57±0.81 and 6.49±0.89, respectively. On the other hand, two of the lowest averages were also in this group. These were suffering capacity (4.97±1.71) and flip repertoire (4.44±2.00). It seems that parkour practitioners consider the technique and adaptation more important than acrobatics or the suffering capacity more linked to the conditioning sessions from the early days (Angel, 2016). In the last sub-block or social performance factors, one of which was rated as one of the three with the lowest averages overall (4.98±1.87) was *keeping yourself distracted*. With higher averages in the same block, there were *socialising* (5.29±1.60) and *collaboration/ cooperation/ altruism* (5.80±1.43). Although, as seen in previous parts of this work, parkour has been shown to be practised accompanied, the *social performance factors* were not rated as high as *previous performance factors* or *new performance factors*.

These results show that, although some physical condition tests might be useful to compare parkour to other sports (Pagnon, et al., 2022), the reality is that parkour practitioners consider more important other factors than the ones mentioned beforehand. To solve this problem, there have been some attempts to elaborate parkour-specific tests (Dvořák, et al., 2018; Padulo, et al., 2019; Strafford, et al., 2022). On the one hand, Dvorak et al. (2018) made a *Parkour Skills Assessment* that consists of an obstacle course in which points are given to participants if the techniques used meet criteria written in a checklist. This approach could be compared to the performance factor suggested by this research team, *movement techniques* and *parkour movement repertoire*. In the PARK-Q, *movement techniques* was one of the highest-rated performance factors, as well as *parkour movement repertoire*, so it could be said that this assessment aligns with the perception of international parkour practitioners. As for Strafford et al.'s (2022) speed-run course, speed was assessed and compared to jump power and handgrip strength. These performance factors were taken into account in the PARK-Q, and *jump power* was positioned in 9th place with an average of 6.09±1.12 as the first performance factor in the category of *explored performance factors*, followed by *grip strength* with 6.01±1.13 average. Nevertheless, these assessments (Dvořák, et al., 2018; Strafford, et al., 2022) are environment-dependent to the place this research was conducted and may not apply to other contexts. On the other hand, the specific parkour repeated sprint ability test (SPRSA) by Padulo et al. (2019) mainly assesses repeated sprint ability. This performance factor in particular averaged 5.40±1.55; if ordered by average scores, this performance factor was the 7th before the last. Moreover, from the fitness battery used to validate the SPRSA (core stability, grip strength, vertical jump, long jump, pull up, 300 m shuttle run, Léger test), only grip strength made it to the top 10 in a matter of average. Furthermore, considering a front flip is required within the SPRSA, it is important to remember that *flip repertoire* was the performance factor with the lowest average overall. As the results of the current study show, there were multiple performance factors perceived by the practitioners that gather physical, technical, cognitive (Grosprêtre & Gabriel, 2021) and social aspects. Despite the fact that important attempts have been made to measure performance in parkour practitioners (Dvořák, et al., 2018; Grosprêtre & Lepers, 2016; Padulo, et al., 2019; Pagnon, et al., 2022; Strafford, et al., 2022), it might be necessary to take into account other performance factors considered relevant by international parkour practitioners, and not only factors exclusively linked to physical capacity.

Study limitations

Even though the present study has been conducted under high scientific rigour, it is not exempt from limitations. First, although the sample is big, probably it does not represent the whole parkour practitioner population. It is possible that practitioners in different places did not have access to the PARK-Q, and habits, goals, motivation, and perceived performance factors in those communities may vary due to different demographic and socio-cultural contexts. On the other hand, no comparative analysis has been done in the present study regarding different contextual values such as country of residence, practice context, gender, age… Last, the absence of similar studies in the same discipline has hindered comparing results with other works. Further research is needed to analyse these characteristics connected to parkour.

Conclusion

The PARK-Q questionnaire appears to be a useful tool for analysing parkour training habits, motives and performance factors. The PARK-Q showed greater internal consistency than previous studies. Parkour could still be considered a masculine action sport with low federated participation and average experience over eight years. Conflict with terminology seems to continue as some participants consider parkour/ ADD/ freerunning the same global practice. It would be fair to state that parkour is mostly practised outdoors, with friends, in an unstructured way, with 1-2 sessions per week with an average duration of 1-2 hours per session. Conditioning is probably done once or twice a week on average. Most practitioners seem to abstain from participating in parkour competitions. Practitioners' learning process is primarily free (with friends, autodidacts, etc.), and they consider their level of expertise to be advanced. Parkour practitioners' motivation might mainly come within and could be considered intrinsic motivation. Precision, environmental adaptability, and movement techniques can be considered the most important factors, whereas flip repertoire, suffering capacity, and keeping yourself distracted are the least important. New measuring instruments or assessments that align better with the discipline should be explored, considering the performance factors perceived by international parkour practitioners.

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Correspondence to:
Andoni Elizondo-Donado
ORCID: 0000-0001-5017-4402
Faculty of Education and Sport, University of the Basque Country (UPV/EHU).
Portal de Lasarte, 71, 01007 Vitoria-Gasteiz, Spain.
E-mail address: aelizondo014@ikasle.ehu.eus

EFFECTS OF DIFFERENT CUTTING TECHNIQUES ON CHANGE OF DIRECTION SPEED IN TEAM HANDBALL

Patrick Engel, Deborah Seipp, Stefanie Klatt, and Frowin Fasold

German Sport University Cologne, Institute of Exercise Training and Sport Informatics, Departement of Cognition in Team Sports, Cologne, Germany

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Abstract:

Change of direction (COD) actions play a crucial role in team handball performance. Achieving equal speed during specific cutting manoeuvres on the left and right side is believed to be advantageous for successful tactical behaviour. Although studies have investigated lateral disparities in movements towards and against the throwing arm, there is a lack of sport-specific evidence regarding the advantages and disadvantages of different cutting techniques in terms of direction and speed. This study aimed to explore the impact of technique on COD speed with the ball during team handball-specific cutting maneuvers. Change of direction speed was evaluated and compared under three conditions: (1) split-step technique, (2) side-step technique, and (3) individually preferred skill. A total of 19 male, active, injury-free team handball players (mean age 21.59 ± 2.60 years) with an average of 15.26 ± 4.33 years of team handball experience participated. *Post-hoc* video analysis was employed to calculate COD speed. No significant interaction between the direction of movement (towards or against the throwing arm) and technique was found ($p=.09$). However, a significant main effect of direction ($p<.001$) and technique ($p=.013$) was observed. Results indicated a higher COD speed when moving in the direction of the throwing arm. Additionally, a significant difference was found between individual skill and split-step technique ($p=.01$). Overall, the findings suggest that differences in COD speed, whether towards or against the throwing arm, are not attributable to movement technique.

Keywords: *agility, team sports, cutting manoeuvre*

Introduction

Team handball is characterized by a considerable frequency of change of direction (COD) actions (Karcher & Buchheit, 2014). On average, athletes engage in 13 offensive and 17 defensive COD movements per game (Póvoas, et al., 2012). Agility and COD skills play key roles in determining the success of individual actions, such as one-on-one situations, consequently influencing the overall match outcome (David, Komnik, Peters, Funken, & Potthast, 2017; Forster, Uthoff, Rumpf, & Cronin, 2022; Keiner, Kapsecker, Stefer, Kadlubowski, & Wirth, 2021; Nimphius, Callaghan, Bezodis, & Lockie, 2018; Wagner, Finkenzeller, Würth, & von Duvillard, 2014).

Agility, as defined by Haff, Triplett, National Strength and Conditioning Association (2016, p. 522) encompasses "[…] the skills and abilities needed to change direction, velocity, or mode in response to a stimulus". This performance factor is differentiated into two levels – a cognitive level and a motor level. The cognitive level comprises visual scanning, anticipation pattern recognition, and situational knowledge (Young & Farrow, 2006). The motor level pertains to the ability to change direction or speed (Haff, et al., 2016; Young & Farrow, 2006). Change of direction speed encompasses elements of technique, linear sprinting speed, and leg muscle quality (Young & Farrow, 2006). While both the motor and cognitive levels are performance-relevant, our study specifically focuses on the motor level of agility.

Numerous factors, such as the relationship between COD speed and maximum strength (Andersen, Lockie, & Dawes, 2018; Delaney, et al., 2015; Spiteri, et al., 2014), reactive strength (Castillo-Rodríguez, Fernández-García, Chinchilla-Minguet, & Carnero, 2012; Delaney, et al., 2015; Thomas, Comfort, Jones, & Dos'Santos, 2017), or linear sprinting ability (Horníková & Zemková, 2021) have been thoroughly examined in previous research. Additionally, investigations into handball-specific scenarios have revealed lateral differences in directional changes related to the throwing arm (Fasold, Braun, & Klatt, 2022). Notably, movements to the side of the throwing arm (right-handers to the right, left-handers to the left) demonstrate significantly higher speeds than movements against the throwing arm. Fasold et al. (2022) assume that the observed speed difference between sides may be attributed to variations in technique.

While Marshall et al. (2014) and Young and Farrow (2006) assert the existence of generalizable technique features for change of direction, such as: generating explosive force around the ankle, maintaining pelvic control during a single-legged support, and rotating the torso in the intended direction of movement, it is crucial to recognize the sport-specific nature of techniques. Generalizable technique characteristics alone are insufficient, as COD tests must be conducted in a sport-specific manner (Loturco, et al., 2022; Salaj & Markovic, 2011).

In team handball, various COD techniques are commonly observed in practice (Karcher & Buchheit, 2014). These techniques are frequently applied in both offensive and defensive situations, such as feinting with or without the ball, changing direction while dribbling, closing space defensively, or stepping out to challenge an opposing player. In basketball, similar patterns of directional change are observed, where agility and rapid movement adjustments are crucial for effective offensive drives and defensive positioning. Studies, such as the review by Sugiyama, Maeo, Kurihara, Kanehisa, and Isaka (2021), highlight that basketball players frequently perform changes in direction to maintain competitive performance during games. These maneuvers, like cutting, are comparable to the requirements in team handball. However, there is a lack of sport-specific evidence regarding the advantages and disadvantages of these techniques in terms of speed. Dos'Santos, McBurnie, Thomas, Comfort, and Jones (2019) summarized and discussed the most prevalent COD techniques in multidirectional sports, including the split-step, the side-step, and the crossover cut. The split-step involves a small preparatory jump followed by a push-off using the contralateral foot, enabling quick lateral movements. In contrast, the side-step consists of planting the outside foot and pivoting toward the desired direction (examples for both techniques in Fig. 1). Recent studies have focused on technique and training in handball, exploring areas such as plyometric and strength training or directional change performance. However, these studies did not directly address the influence of technique on performance outcomes during gameplay (Falch, Haugen, Kristiansen, & van den Tillaar, 2022; Gaamouri, et al., 2023; Noutsos, Meletakos, Kepesidou, & Bogdanis, 2024).

Our investigation focuses on the split- and the side-step as these techniques are commonly applied in team handball. Although the crossover cut is referenced for comparison, it was not directly included in our study. By analyzing these techniques, this study aims to provide actionable insights for the teaching and training of change-of-direction movements in handball (Dos'Santos, et al., 2019, p. 42). Trewartha, Munro, and Steele (2008) have showed that the split-step not only results in a greater lateral velocity during unplanned changes of direction but also involves a longer ground contact time compared to the side-step.

The findings align with the Bradshaw, Young, Russell, and Burge's (2011) study, wherein the side-step was proved to be faster than the split-step in pre-planned changes of direction among Australian Rules football players. This temporal discrepancy is manifested in a shorter total time attributed to a shorter initial ground contact and achieved through a swifter approach time. However, Bradshaw et al. (2011) demonstrated that defenders exhibited slower decision making when executing a split-step compared to a side-step. Notably, frequent decision errors are observed when reacting to the split-step, underscoring its effectiveness as an offensive agility technique and its challenging predictability. These findings are supported by Connor, Crowther, and Sinclair (2018), attributing the differences to the preceding jump with the double-leg landing. The double-leg landing impedes early anticipation of the movement direction. Summarizing these statements, the side-step appears to be faster than the split-step for planned directional changes. In conditions necessitating agility, the split-step appears

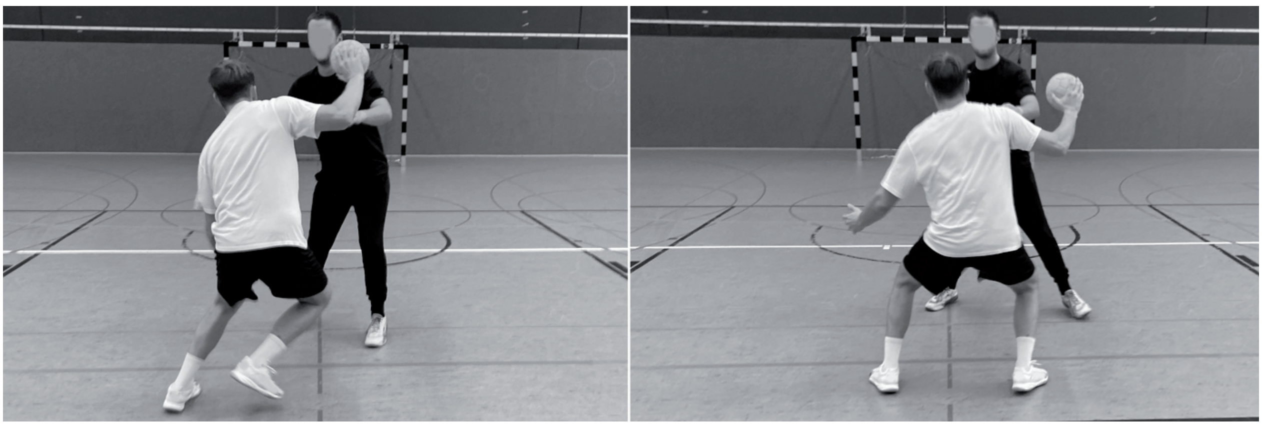

Figure 1. Illustration of handball-specific examples of the side-step (on the left) and the split-step (on the right) cutting techniques.

advantageous (Bradshaw, et al., 2011; Connor, et al., 2018). Despite these insights, team handball-specific studies on cutting maneuvers, with a focus on technique and movement speed, are notably absent.

Research in other sports, such as Australian Rules football, has explored diverse techniques for changing direction (Bradshaw, et al., 2011; Trewartha, et al., 2008). However, individual preferences for direction changes may exist in team handball. These individual techniques, which often combine elements of both the split-step and the side-step, form the individual skill. Hence, this study specifically focuses on the split-step and the side-step techniques (Fig. 1), along with an individual skill.

Based on the model developed by Young and Farrow (2006) and the results of Fasold et al. (2022), this paper specifically evaluates the motor level of agility, focusing on movement techniques and their impact on COD speed with the ball during team handball-specific cutting maneuvers. We hypothesize that (1) change of direction speed is influenced by different techniques, depending on the direction of movement. Furthermore, based on the results of prior studies (Bradshaw, et al., 2011; Connor, et al, 2018; Fasold, et al., 2022), we expect effects related to (2) techniques and (3) direction on speed.

Method

Participants

We conducted an *a priori* power analysis to calculate the appropriate sample size (using G*Power; Faul, Erdfelder, Buchner, & Lang, 2009). A total of eleven participants was required to detect a large effect size ($\eta_p^2 = 0.47$; Fasold, et al., 2022) with a significance level (α) of .05 and a statistical power of .95. To avoid false-positive results (Simmons, Nelson, & Simonsohn, 2011) and being robust against possible variances in the measurement, we calculated a sample size of N = 20 for the study.

In this study, male, active, injury-free team handball players were examined (N = 20). One participant left the experiment due to reported ankle pain after the warm-up. Thus, three left-handed and 16 right-handed players participated in the study (height in m: 1.86(*M*) ± 0.08(*SD*), body weight in kg: 82.84 ± 9.82, age in years: 21.59 ± 2.60, team handball experience in years: 15.26 ± 4.33). Inclusion criteria for the study were age ≥ 18, gender (male), no known injuries to the cruciate, medial, and lateral ligaments within the last 18 months and injuries to the ankle joint within the last three months. Participants were required to frequently change direction during training and gameplay to be included in the study. Goalkeepers, who do not frequently perform comparable changes of direction like the field players, were not included in the study. The test group ultimately consisted of eleven back players, seven wing players, and one line player. Two participants reported their actual playing level by playing in the seventh league, three in the sixth, ten in the fifth, two in the third league, and one in the second league in Germany. The study was approved by the ethics committee of the German Sport University Cologne (nr. 018/2023) and was conducted in accordance with the Declaration of Helsinki of 1975 and its later revisions. Written informed consent was obtained from all participants prior to the investigation.

Design

In a 3 x 2 design, the influence of the within-subject factors *change of direction technique* (individual skill vs. side-step vs. split-step) and *direction* (towards the throwing arm vs. against the throwing arm) on the dependent variable *change of direction speed* were analysed.

Materials and procedure

The participants performed an individual warm-up and conducted three counter-movement-jumps followed by three broad jumps as a standardized activation. The warm-up was followed by a team handball-specific COD test. The team handball-specific COD test, developed by Fasold et al. (2022), was used and adapted to simplify test administration and to improve the validity of the results. The adapted test allowed us to differentiate the depth and width of the movements. Figure 2 and Table 1 show the test set-up. The participants started at the same, standardized starting point (the right-handers from the left, the left-handers from the right). After passing the ball to the player, the participants performed an arc-shaped run-up towards the defender. Approximately one meter in front of the defender, the participants received the ball and changed movement direction. During the execution of the techniques, defenders acted as static obstacles rather than active participants to ensure standardization across trials.

For the first measurement (individual skill), each participant performed three COD to each side (towards and against the throwing arm). The individual skill represents a unique combination of features from both the side-step and split-step techniques, mixed in varying degrees according to the athlete's personal style and preference. In contrast, the split-step and side-step techniques were explicitly planned and executed under controlled experimental conditions, with participants following precise instructions provided by the researchers. Subsequently, the participants were instructed to perform six changes of direction using the corresponding technique (split- or side-step), with three in the direction and three against the direction of the

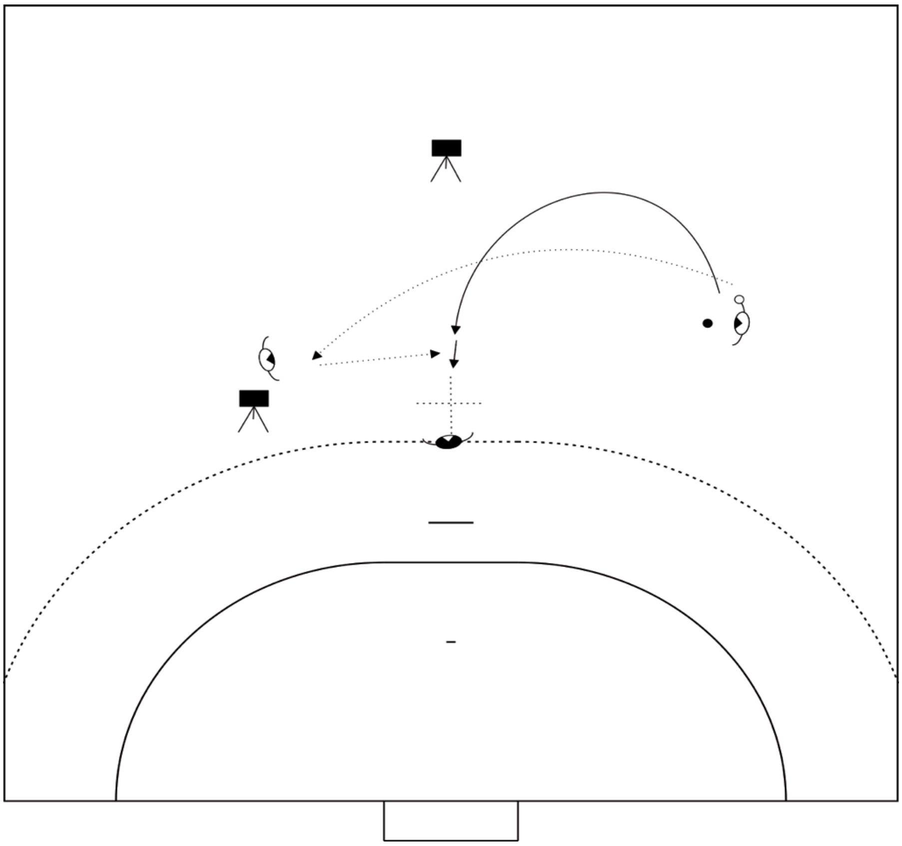

Figure 2. Structure and procedure of the change of direction test. The starting position is only marked for the right-handers; the left-handers started from the other side of the field from the corresponding position.

Table 1. Positioning of the starting points, cameras, and the defender and face-off player from Figure 2

	Distance from the goal-line (in meters)	Distance from the side-line (in meters)
Starting points	12	3
Defenders	9	10
Face-off player	11	7.50
Position camera 1 (back-view)	14	10
Position camera 2 (sideview)	10	7.50

throwing arm. Afterwards, six changes of direction were conducted with the alternate technique. The split-step and side-step techniques were balanced based on the participant's number. Within each technique, the direction towards the throwing arm and against the throwing arm was also balanced by the participant's number.

Before the first trial, participants were given instructions to perform CODs as close to the game-like as possible. Between each repetition, the participants had a break of 30 seconds to rest. This rest time roughly corresponds to the time between two game situations in a team handball match (Karcher & Buchheit, 2014). Two cameras were used to measure the depth (sideview) and width (back-view) of the directional movement changes (positions can be seen in Tab. 1). A GoPro Hero 8 (model number C3331352520026) was used to capture the sideview (camera 2). The back-view (camera 1) was captured using a Sony dsc-rx100 m4. The recording frequency was 120Hz.

Data analysis

The video analysis software Kinovea (version 0.9.5-x64) was used to evaluate the videos, as Kinovea enables a two-dimensional determination of the speed. According to Balsalobre-Fernández, Tejero-González, Del Campo-Vecino, and Bavaresco (2014) and Pueo, Penichet-Tomas, and Jimenez-Olmedo (2020), Kinovea can be classified as a valid tool for testing distances and is also valid for measuring time, such as the determination of jump height via flight time. The analysis was conducted by an experienced rater skilled in 2D video analysis and individual skill training in team handball. The reliability of the procedure was checked by the second rater with the same experience. Both raters were two experts (with a coaching license) with many years of experience in sport science and team handball coaching. Interrater reliability was assessed using the Spearman rank correlation coefficient, as the data did not follow a normal distribution. The analysis revealed a high agreement between the two raters (ρ = .896, $p < .001$), indicating consistent evaluation of COD speed.

The movement depth recorded by camera 2 and the lateral movements captured by camera 1 were evaluated separately. For this purpose, the basketball free throw area (part of the standardized sports hall, where the study was conducted) was used as calibration zone for both videos in Kinovea to adjust for depth distortions and camera positioning. The synchronization of the video recordings from the two cameras was achieved using a light signal. This signal served as a common reference point to align the recordings accurately. Camera 1 (backview) was used to measure the COD time and how far the step of the COD was set to the side. In the recordings, the first complete touchdown of the foot was defined as the starting point. The end point was defined as the complete foot touchdown of the direction-changing step. The measurement was taken between the medial point of the foot (determined by the investigator) that initiated the change of direction (for the movement to the right the left foot, for the movement to the left the right foot) and the medial point of the foot from the subsequent foot strike. If the participants used a cross-step, the distance from the first contact with the right foot to the second contact with the right foot was measured for the right-handers (for the left-handers it was the left foot). The distance of the movement depth was recorded via camera 2 (sideview). The distance measurement was taken from the heel of the direction change-initiating step to the subsequent foot strike's heel. The time was taken from the camera 1 measurement. If the wrong technique (split- instead of side-step or side- instead of split-step) was performed or a technical error was made, the attempt was excluded (2.9% attempts had to be excluded).

The data collected via Kinovea were entered into an Excel spreadsheet to calculate the COD speed. For this purpose, the distance of the direction-changing step in depth and in width (in meters) and the time required (in seconds) was measured. The Pythagorean theorem

$$\sqrt{(\text{distance width}^2) + (\text{distance depth}^2)} = \text{change of direction distance}$$

was used to calculate the total distance of the change of direction. Using the time and the total distance, the speed for the total change of direction was calculated as the dependent variable in $m \cdot s^{-1}$.

Statistical analysis

A multifactorial analysis of variance with repeated measures was run to analyse the effect of the within-subject factors on the dependent variable in a 3 x 2 design. The average COD speed of the respective technique and the direction of movement were calculated from the three attempts in every condition of the participants to increase the robustness against outliers. If one attempt was missing (due to technical errors), the mean speed was calculated out of the other two attempts. A Shapiro-Wilk test ($p < .001$) and a Mauchly test ($p = .023$) were performed to check distribution and sphericity of the data. The violation of normality can be disregarded due to the sample size (Knief & Forstmeier, 2021). If sphericity violations were observed in the model ($p < .05$), the Greenhouse-Geisser correction was applied.

Results

Table 2 shows the descriptive statistics of the COD speed in the three technique conditions divided by the directions of the movement. The repeated measures MANOVA revealed a non-significant interaction between the effects of technique and movement direction, $F(1.47, 26.49) = 2.83$, $p = .09$, $\eta_p^2 = .14$. The analysis revealed a significant main effect for the movement direction (towards the throwing arm 4.40 ± 0.90 $m \cdot s^{-1}$ vs. against the throwing arm 3.64 ± 0.66 $m \cdot s^{-1}$) on the COD speed, $F(1, 18.00) = 29.68$, $p < .001$, $\eta_p^2 = .62$. In addition, a significant effect of technique was shown (individual skill 4.21 ± 0.85 $m \cdot s^{-1}$, 95%-*CI* [3.82, 4.59]; split-step 3.99 ± 0.72 $m \cdot s^{-1}$, 95%-*CI* [3.42, 4.33]; side-step 3.87 ± 1.01 $m \cdot s^{-1}$, 95%-*CI* [3.66, 4.31]; $F(1.43, 25.67) = 4.88$, $p = .013$. $\eta_p^2 = .22$). A *post-hoc* comparison using the t-test with Bonferroni correction indicated a significant difference ($p = .01$) between the individual skill and the split-step ($M_{Diff} = .22$, *95%-CI* [.39, .45]). No significant differences between the individual skill and the side-step ($M_{Diff} = .33$, *95%-CI* [-.01, .67], $p = .057$) and between the split-step and the side-step ($M_{Dif} = -.11$, *95%-CI* [-.42, .20], $p = 1.0$) were found. Table 2 provides a detailed breakdown of the data for additional insight.

Discussion and conclusions

The aim of the current study was to examine differences in COD speed across various movement techniques in team handball-specific cuttings. Based on previous studies, an interaction between technique and direction of movement, a difference in speed between movements towards and against the throwing arm, and a difference in speed between the split-step and side-step techniques were assumed prior to the conduction of this study. The results did not confirm the first assumption, as no interac-

Table 2. Mean, standard deviation, and 95% confidence interval of the change of direction speed in the three technique conditions divided by the directions of movement

		Technique					
		Individual skill*		Side-step		Split-step*	
		Of the throwing arm [m·s^{-1}]†	Against the throwing arm [m·s^{-1}]†	Of the throwing arm [m·s^{-1}]†	Against the throwing arm [m·s^{-1}]†	Of the throwing arm [m·s^{-1}]†	Against the throwing arm [m·s^{-1}]†
M		4.51	3.90	4.38	3.37	4.32	3.65
SD		0.96	0.60	0.97	0.80	0.78	0.48
CI	*UL*	4.95	4.17	4.81	3.73	4.67	3.87
	LL	4.08	3.62	3.94	3.01	3.97	3.44

Note. M – mean, SD – standard deviation, LL – lower limit, UL – upper limit, * – shows a significant effect between the techniques ($p < .05$), † – shows a significant effect between the directions of movement of the arm and against the arm ($p < .001$).

tion between technique and direction of movement was observed. However, higher speed values were obtained for all techniques when performed towards the throwing arm**.** Thus, there is not technique that reduces the velocity difference between moving towards and against the throwing arm. These results contradict the findings of Fasold et al. (2022), who proposed technical reasons to explain the lateral speed differences. The discrepancy with Fasold et al.'s results (2022) may be attributed to differences in testing conditions and the specific test setup used in our study, which focused on handball-specific scenarios. It is important to note that Fasold et al. (2022) did not analyze movement techniques, which highlights the distinctive foci and methodological approaches between the two studies.

Due to the lack of interaction between technique and direction of movement, it cannot be approved that technique reduces the speed difference, although Connor et al. (2018) suggested a higher tactical flexibility with the split-step technique. This tactical flexibility is thought to arise from equal speeds of COD movements, whether towards or against the throwing arm. However, this connection could not be determined in the current study based on the parameter of speed.

In their studies Bradshaw et al. (2011) and Connor et al. (2018) propose that, in Australian Rules football and rugby players, the side-step proves to be the swifter cutting technique for COD movements, whereas the split-step is deemed more advantageous for agility movements. However, our study failed to replicate the observation that the side-step is the faster COD technique. This discrepancy arises from the inherent sport-specific nature of skills, such as chance of direction techniques, making their transferability to other sports challenging (Nimphius, et al., 2018).

The execution of a side-step against the throwing arm consistently led to a reduction in speed, irrespective of the moving technique. According to Arboix-Alió et al. (2021) this limits tactical flexibility as the defender anticipates that changes of direction against the throwing arm with a side-step are slower and thus easier to defend. According to Table 2, only the side-step against the throwing arm shows a clear negative deviation from the other conditions. Therefore, we do not particularly recommend prioritizing this technique. Another reason to avoid the side-step against the throwing arm is the higher number of technical errors (e.g., step violations) compared to the other techniques in our study. However, given the marginal differences between the techniques, all of them can be applied to both sides. These findings imply that all techniques are relevant for practical training. For movements against the arm, emphasizing the split-step is advisable. Since no technique demonstrated a clear advantage, it is suggested to individualize technique training and determine the most suitable technique for each player, aligning with practices in team sports such as goalkeeping in soccer (Otte, Millar, & Klatt, 2019). The findings of this study can be applied to tactical situations in handball. The split-step technique is particularly effective for one-on-one confrontations when directly facing a defender, as its unpredictability and agility can create opportunities to bypass the opponent. Conversely, the side-step proves most effective in situations where the player attacks open space, especially when the defender is already moving laterally. This tactical application aligns with scenarios where exploiting gaps in defensive positioning is critical.

In accordance with the findings of Fasold et al. (2022), the current study confirms that CODs towards the throwing arm are significantly faster than the directional changes against the throwing arm, thus proving the effect's robustness. However, no cause has yet been found that fully elucidates the speed differences between the directions of movement. As team handball is a sport that is unilateral in nature (Janicijevic, et al., 2023), lateral differences may develop over time due to training.

As a limitation of our study we can ask ourselves whether the search for the fastest technique indeed represents the search for the most decisive technique. It is possible that in one-on-one situations in team handball, the maximum speed of COD may not be as important as the optimal speed at which cognitive and tactical components can be executed. Consequently, the investigation of the change direction ability without a cognitive component can be discussed. Young, Rayner, and Talpey (2021) highlight the lack of ecological validity of COD tests. While the current study employs a handball-specific movement, it does not simulate agility conditions typically observed in the game. This could be problematic, as knee loading under agility conditions can be higher than with pre-planned directional changes (Brown, Brughelli, & Hume, 2014). Pre-planned directional changes appear to differ not only in their cognitive but also in their physical aspects. Therefore, the translatability of pre-planned changes of direction to the game sport context appears to be limited.

One limitation of the current study is the use of a 30-second recovery interval between repetitions, which was selected to simulate the recovery times typically observed during match play in team handball. While this interval reflects practical competition conditions, it may not have allowed for complete phosphocreatine resynthesis in all participants. As a result, the repeated high-intensity efforts might have influenced the observed COD performance, particularly in later trials. However, the balanced order of trials across participants minimized the risk of systematic fatigue affecting the results. Nevertheless, it would also be valuable to investigate longer recovery intervals to assess whether complete recovery influences outcomes differently, providing a clearer distinction between the effects of fatigue and technique on performance.

The focus of this study was on average speed as a practical indicator of performance in directional changes. However, we acknowledge that accelerations, decelerations, and other kinematic variables may provide additional insights in feint techniques. Future research could incorporate such kinematic variables to provide a more detailed understanding of the biomechanics underlying directional changes. As highlighted by Robertson, Caldwell, Hamill, Kamen, and Whittlesey (2013), such analyses could offer valuable insights into movement strategies, complementing findings on average speed and further enriching our knowledge of performance in handball-specific scenarios. A potential extension of this work could further involve analyzing the behavior of the center of gravity during COD maneuvers. This additional focus would offer deeper kinematic insights and complement the current findings, as highlighted by Nimphius et al. (2018). Future studies could build on our results by incorporating center of gravity analysis to explore the interplay between movement strategies and biomechanical efficiency in greater detail.

The split-step action proves particularly relevant in one-on-one confrontations, as it leverages unpredictability and agility to overcome direct defensive pressure. In contrast, the side-step technique seems to be more effective in open-space situations, especially when defenders are already moving laterally. These position-specific tactical scenarios should be analyzed further to better understand their impact on team strategy and player effectiveness. Furthermore, future research could also evaluate the integration of actions like intended throws or passes to investigate the interplay between cutting maneuvers, COD speed, and tactical success. A focus on categorizing and ranking individual COD techniques could provide additional insights for training methodologies.

Additionally, expanding this study to include top professional handball players could help determine whether their advanced skill level, experience, and physical condition may lead to different outcomes. Such an approach could provide valuable insights into how performance techniques vary across different levels of play and enhance the applicability of findings to elite handball contexts.

Future research should focus on a detailed analysis of specific technique characteristics that result in successful changes of direction or one-on-one situations in the game. The first step here should be qualitative research that lists the individual characteristics of successful CODs. Subsequently, quantitative research is recommended to determine the extent to which the individual characteristics clarify the variance in one-on-one performance. In addition, psychological effects should also be investigated. Athletes' performance improves when they feel comfortable with their movements, as this increases their confidence in executing them effectively (Wulf & Lewthwaite, 2016).

In conclusion, no significant interaction between technique and direction of movement was found, while the side difference between directional changes towards and against the throwing arm remained as in the previous work by Fasold et al. (2022). In summary, all techniques can be trained in practice, considering that split-step movements are advantageous especially in terms of agility (predicting the direction of movement by the defender). Further research should focus on the ecological validity of COD tests, investigate psychological aspects, and collect technique characteristics that make one-on-one situations successful.

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Highlights:

Agility actions, including cutting manoeuvres with the ball, play a crucial role in team handball performance.

Although, a balanced bilaterality in agility actions seems to be beneficial for sports performance, team handball athletes exhibit an imbalance, with cuts in the direction of the throwing arm executed faster than those against it.

The results indicate that differences in technique cannot account for the observed lateral variations in change of direction speed during team handball-specific cutting manoeuvres.

Further research should explore alternative factors contributing to lateral differences in sport-specific agility movements.

Conflicts of Interest

The authors declare no conflict of interest**.**

Author Contributions

Conceptualization, PE, FF, DS; methodology, PE, FF; validation, SK, FF; formal analysis, PE, FF, SK; investigation, PE, FF, DS; data curation, PE; writing—original draft preparation, PE, DS, FF; writing—review and editing, PE, DS, SK, FF; supervision, SK, FF.; project administration, PE, FF. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

The study was carried out in accordance with the Helsinki Declaration of 1975. The study was approved from the lead institution's ethics board.

Informed Consent Statement

Not applicable.

Data Availability Statement

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Correspondence to:
Frowin Fasold
Institute of Exercise Training and Sport Informatics
Section Cognition in Team Sports, German Sport University Cologne
Am Sportpark Muengersdorf 6, 50933 Cologne, Germany
E-mail: f.fasold@dshs-koeln.de

THE EFFECT OF SQUARE STEPPING EXERCISES TRAINING ON LOWER EXTREMITY MOTOR PERFORMANCE, MUSCLE STRENGTH, AND MUSCLE QUALITY IN HEALTHY YOUNG PEOPLE: A SINGLE-BLIND, RANDOMIZED, CONTROLLED CLINICAL TRIAL

Asli Demirtas[1], Filiz Altug[2], and Ayse Unal[3]

[1]Nigde Omer Halisdemir University, Faculty of Bor Health Science, Department of Physiotherapy and Rehabilitation, Niğde, Türkiye
[2]Pamukkale University, Faculty of Physiotherapy and Rehabilitation, Department of Neurological Rehabilitation, Denizli, Türkiye
[3]Alanya Alaaddin Keykubat University, Faculty of Health Science, Department of Physiotherapy and Rehabilitation, Antalya, Türkiye

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Abstract:

The square stepping exercise (SSE), which is a new type of aerobic exercise, is preferred for various purposes. This study attempted to explore the effect of SSE training on lower-extremity motor performance, muscle strength, and muscle quality in healthy young individuals. Participants were 120 healthy young individuals aged between 20-25 years, who were randomly divided into two groups as the treatment group, which received SSE training (Group 1; n=60) and control group (Group 2; n=60). The participants' lower-extremity motor performance was analyzed through vertical jumping, side jumping, one leg squat, and step-up tests, whereas their muscle strength was analyzed through a hand-held dynamometer and their muscle quality was analyzed through Muscle Quality Index. The SSE was employed to the treatment group in 12 sessions, four days a week for three weeks and each session lasted 45 minutes. The control group did not receive any treatment and only evaluation was implemented. A significant improvement was observed in lower-extremity motor performance (p<.001), muscle strength of quadriceps femoris muscle (p<.001), and muscle quality (p<.001) in Group 1 in the post-training evaluations. This study revealed a significant improvement in favor of Group 1 in side jumping (p<.001), one leg squat (p<.001), step-up test (p<.001), quadriceps femoris muscle strength (p<.001), and muscle quality (p<.001). However, no significant change was observed between the groups in the vertical jumping test (p=.099). The results showed the effect of SSE training on the lower-extremity motor performance, muscle strength, and muscle quality of healthy young individuals.

Keywords: *square-stepping exercise, healthy young individuals, motor performance, muscle strength, muscle quality*

Introduction

Physical activity (PA) is defined as activities including energy expenditure through using muscles and joints in daily life, increasing heart and respiratory rate, performed at different intensities, and resulting in fatigue (Dhuli, et al., 2022). Failure to regularly perform PA at a sufficient level causes many health problems. Therefore, regular PA is among the most important recommendations of national and international public health guidelines to increase an active lifestyle. The American Association of Sports Medicine (AASM) and the American Dietetic Association guidelines recommended exercise five days a week and at least 30 minutes of moderate-intensity activity a day to adults (Piercy, et al., 2018). Regular PA is known to have positive effects on physical and mental health (Guo & Jiang, 2023). Regular PA is also found to maintain and increase muscle strength and joint mobility, to improve movement skills, to maintain and increase muscle and joint flexibility, to reduce fatigue, and to improve reflex and reaction time (Gualdi-Russo & Zaccagni, 2021). Additionally, it has psychological effects such as feeling well and happy, thinking positively, and improving the ability to cope with stress (Stanton, Happell, & Reaburn, 2014). Today, exercises such as brisk walking, jogging, cycling, swimming, aerobic dance, rowing, and skating are defined as aerobic exercises through which these benefits can be achieved (Erkkola, Vasankari, & Erkkola, 2021).

Aerobic exercise is a type of exercise that increases breathing rate by using large muscle groups regularly and at the same tempo, with 60-80% of the maximum number of heartbeats for a period of 15-20 minutes or longer. AASM defines aerobic exercise as a natural rhythm that can be maintained continuously in every activity in which large muscle groups are used (Li, Liu, Deng, & Wang, 2024). Fast, entertaining and various physical activities with music and rhythm make exercise enjoyable and long-term. Revealing different formats of aerobic exercises, which have induced great interest, also increases participation in these types of exercise (Sevinç & Tetik, 2018). The literature shows the effect of exercise training programs on healthy individuals and different disease groups in all periods of life (Chang, Wang, Chen, & Hu, 2017; Fisseha, Janakiraman, Yitayeh, & Ravichandran, 2017; Shigematsu, et al., 2008a; Shigematsu, Okura, Sakai, & Rantanen, 2008b; Teixeira, et al., 2013). Regularly performed aerobic exercises are found to have crucial health benefits. Aerobic exercises have a positive effect on health, coordination, body-fat ratio, muscle quality, muscle strength, flexibility, and endurance (On, Yıldız & Dündar, 2020; Yıldırım & Bozkuş, 2020; Unal, Altug, Tıkaç, & Altug, 2023).

Square-stepping exercises (SSE), developed by Shigematsu and Okura in 2006, is also a type of aerobic exercise that has positive effects on improving lower-extremity motor functions (Shigematsu & Okura, 2006). The literature reveals that SSE is employed for many purposes such as physical fitness, functionality, improvement of cognitive functions as well as for exemining its impact on the treatment of various diseases. This study investigates the effectiveness of square-stepping exercise training on lower-extremity motor performance, muscle strength, and muscle quality in healthy young people.

Methods

The study protocol was approved by the Pamukkale University Non-Invasive Clinical Research Medical Ethics Committee with the board decision dated June 11, 2019, and numbered 11. The clinical trial number of the study is NCT04910035.

Participants

The study was conducted between September 2019 and May 2020 in the Pamukkale University, Faculty of Physiotherapy and Rehabilitation, Department of Neurological Rehabilitation. One hundred and twenty participants, aged between 20-25 years, studying at the Pamukkale University, Faculty of Physiotherapy and Rehabilitation participated in the study.

The study was conducted with the participation of volunteers who met the inclusion criteria among the ones studying at Pamukkale University, Faculty of Physical Therapy and Rehabilitation. All volunteers were informed about the study and granted their written consent.

The participants were divided into two groups through block randomization in SPSS. A total of 12 sessions of SSE training were applied to the treatment group (Group 1, n=60) four days a week for three weeks and each session lasted 45 minutes. No exercise training was provided for the control group (Group 2, n=60).

Inclusion criteria

Treatment and control group:

- 20-25 years of age
- Not attending any exercise program for the last one year
- Not having a neurological, orthopedic disease or any disease affecting lower extremity functioning
- Having had no lower-extremity surgery
- No vision and/or hearing issues.

Exclusion criteria (before the study)

Treatment and control group:

- Having a vision and/or hearing problem
- Having neurological, psychiatric, and/or orthopedic problems that affect walking
- Having had lower-extremity surgery.

Exclusion criteria (during the study)

Participants who developed any pathology of the lower-extremity (sprain, fracture or development of a disease that might affect the lower extremity) during the training or evaluation weeks, those who in less than 75% of the exercise program, who were unable to complete the tests or unwilling to continue exercising at any stage of the study, and ones who joined any other aerobic exercise program were excluded from the study.

Outcome measures

The participants' demographic information was recorded in the registration form. Vertical jumping, side jumping, one-leg squat, and step-up tests were employed to identify the participants' levels of motor performance. The quadriceps muscle strength was identified through the hand-held dynamometer. Also, the Muscle Quality Index (MQI) was employed to determine the muscle quality of participants. All evaluation methods were applied to all

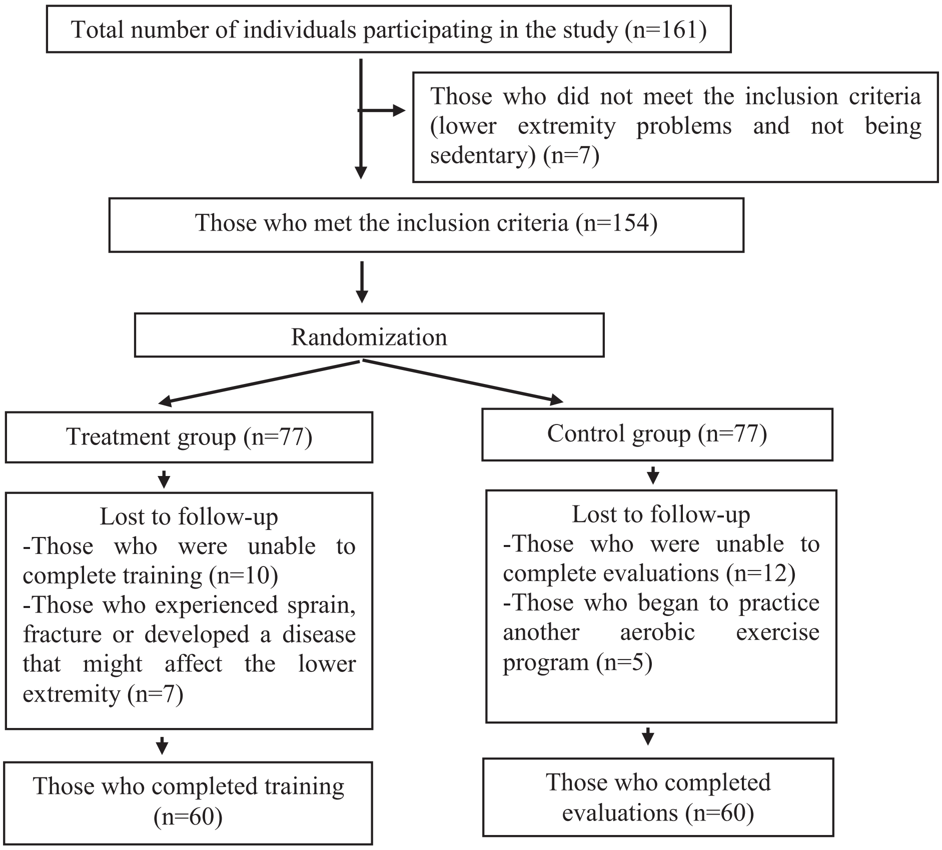

Figure 1. Flowchart of the study.

participants in Group 1 and Group 2 by a blinded physiotherapist in the pre and post 3-week training period.

Motor performance

Vertical jumping test. The vertical jumping test calculates the lower-extremity muscular workforce. Vertical jumping was first defined by Sargent in 1921. Participants stood sideways next to the measuring paper on the wall so that their dominant extremity would be on the measurement paper and touched the last point they could reach with their middle finger through bringing the dominant arm to 180 degrees of flexion and elbow extension. The participants then jumped up as high as they could by bringing their knees to a slight flexion and to mark again the last point they could reach. The distance between the two points determined was measured and recorded in centimeters. The test was repeated three times, and the best value was recorded (Anderson, et al., 1991; Östenberg, Roos, Ekdahll, & Roos, 1998; Reiman & Manske, 2009).

Side-jumping test. The side-jumping test is a valid and reliable test utilized to evaluate agility in aerobic work regimen. The test aims to evaluate individuals' lateral mobility. The individual's location was numbered as 1 at the beginning of the test; 75 cm apart the individual to the right and left were numbers 2 and 3. Along with the start command, the individual was required to complete a cycle by jumping first from number 1 to 2, from 2 to 1, then to 3 and again to number 1 (1→2, 2→1, 1→3, 3→1). The maximum number of cycles she/he managed to do in 20 seconds (s) was recorded as the participant's score (Safrit & Wood, 1995).

One-leg squat test. The one-leg squat test measures the extensor muscle strength of the extremity. Participants squatted on one leg and stood up repeatedly without touching the ground with their non-tested foot. The test was terminated when the individual became fatigued or if the non-tested foot touched the ground. The same measurement was repeated for the other leg. The results were recorded separately for each leg (Safrit & Wood, 1995).

Step-up test. The step-up test is a functional test that measures the lower-extremity muscle strength. Individuals stepped up and off the 45 cm high step using the same foot. Individuals first placed one foot on the step, climbed up, and then lowered the same foot to step down. Participants were instructed to continue the test until they became fatigued, and the number of repetitions was recorded. The dominant and non-dominant sides were evaluated separately (Von Bothmer & Fridlung, 2005).

Muscle strength

Analysis of muscle strength started with positioning the participant's hip at the edge of the bed and with the flexed at 90°. Participants brought their knees to full extension by performing a maximum voluntary contraction. Hand-held dynamometer (HHD) was placed in the distal part of the leg and resistance was provided. The participant was then required to hold this position for 4-5 seconds. The test was repeated three times and the highest power observed on the digital display was recorded in newtons (Bohannon, 2005; O'Sullivan, Schmitz, & Fulk, 2019). HHD's reliability has been proven (Martin, et al., 2006).

Muscle quality

Muscle quality was determined through Muscle Quality Index (MQI), which is a valid and reliable method developed by Takai et al. (2009). The MQI measures the duration of five repetitions of sit-to-stand test in seconds (s). MQI is calculated by measuring the 5-repetition sit-to-go test duration (s), body weight (kg), and leg length (L-m). In the calculation, the formula

$$(L-0.5)*5*weight*g/5$$

repetitions sit-to-stand test duration was employed.

To calculate length of the leg, individuals sit on the chair with the hip and knee flexed at 90 degrees and the feet in full contact with the floor. Thigh-length and knee height were added and recorded. Thigh-length is the length from the midpoint of the inguinal line to the midline of the patella along the midline of the thigh. Knee height is the distance from the lateral condyle of the femur to the heel. Body weight was recorded in kg by measuring the participant's weight without shoes. The expression g used in the calculation indicated the gravitational acceleration and was taken as $g = 9.8\ m/s^2$ in the measurement. For the 5-repetition sit-to-stand test, the time from the sitting position to return to the sitting position five times was recorded. Hands-on help was not allowed in the sit-to-stand test (Takai, et al., 2009).

Square-stepping exercise (SSE) protocol

The SSE is an aerobic exercise developed by Shigematsu and Okura in 2006 based on the fall mechanism for the elderly and ladder exercises for athletes (Shigematsu & Okura, 2006). Permission was obtained from Shigematsu for the exercise application, and the exercises to be performed were determined. Participants were introduced to certain step patterns and then repeated the same step pattern until they reached the end of the exercise mat. The pattern was repeated until all participants performed the pattern without errors (3-5 repetitions). After the pattern was performed, a mirror-image pattern of the same pattern was also performed. Examples of exercises are shown in Figure 2. Basically, a pattern was repeated 3-5 times and then the mirror-image pattern was repeated the same number of times. However, when participants had difficulty in applying the pattern, it was repeated until they learned it. Exercise training was performed by groups of 8-10 individuals and movement patterns were introduced by a physiotherapist. Participants executed the pattern introduced on the exercise mat, and they took turns at the head of the mat when they reached the end of the mat. (Shigematsu & Okura, 2006). In the study, SSE was applied four days a week for three weeks (a total of 12 sessions) and each session lasted 45 minutes.

Statistical analysis

The data were analyzed with SPSS Statistics 21.0 package program. Continuous variables were reported as mean ± standard deviation (Mean ± SD), and categorical variables as number (n) and percentage (%). The Kolmogorov-Smirnov test was employed to identify whether the data were distributed normally (Tabachnick & Fidell, 2013). When parametric test assumptions were provided, independent t-test for comparing differences between independent samples was used; when parametric test assumptions were not provided, the Mann-Whitney U-test was employed to compare independent group differences. In dependent group comparisons, the paired-sample t-test for parametric test assumptions and the Wilcoxon test for non-providing parametric test assumptions were utilized. A value of $p<.05$ was regarded as the level of significance. Cohen (d) calculation was applied to determine the effect size. In that regard, $d\geq1$ was considered a very large effect, $1>d\geq0.8$ a large effect, $0.8>d\geq0.5$ a moderate effect, and $0.5>d\geq0.2$ a small effect (Cohen, 1988).

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6	2	1	5
8	4	3	7
6	2	1	5
8	4	3	7
6	2	1	5

Figure 2. Square stepping exercise example steps.

Results

The 120 healthy young individuals were randomly divided into two groups. The treatment group (Group 1) included 60 individuals, 35 (58.3%) of which were female and 25 (41.7%) were male. The control group (Group 2) included 60 individuals, 35 (58.3%) of which were female and 25 (41.7%) were male. The demographic data of the groups are provided in Table 1. No statistically significant difference between the groups was observed in terms of demographic data (p>.05).

The motor performance levels of Group 1 and Group 2 showed no statistical difference in the pre-test (p>.05). All motor performance levels of Group 1 in the pre- and post-test showed a statistically significant difference, but a statistically significant difference was observed only in the one-leg squat-left leg value in Group 2 (p<.05). The comparisons of two groups' motor performance in the post-test revealed a significant difference in favor of Group 1 (p=.0001) in all motor performance parameters. The comparison of lower-extremity motor performance values within and between the groups is presented in Table 2.

The analysis of the muscular force of the groups in the pre-test showed no statistically significant

Table 1. Comparison of the demographic data of the groups

Variables	Group 1 (n=60) Mean±SD	Group 2 (n=60) Mean±SD	t/z	p
Age (year)	21.93±1.33	22.08±1.16	-0.654*	.514
Height (cm)	170.30±8.27	169.63±7.96	0.450*	.654
Body weight (kg)	67.53±13.09	64.18±12.75	1.420*	.158
BMI (kg/m²)	23.34±4.69	22.13±3.17	-1.483**	.138

Note. Group 1: exercise group, Group 2: control group, n: number of individuals, SD: standard deviation, cm: centimeter, kg: kilogram, kg / m²: kilogram / square meter, BMI: body mass index, t: independent groups t-test, z: Mann-Whitney U-test, * independent groups t-test, ** Mann Whitney U-test.

Table 2. Comparison of motor performance levels within and between the groups

Motor performance values	Pre-training Mean±SD	Post-training Mean±SD	p^2
Vertical jumping			
Group 1	29.28±8.20	33.46±8.35	.0001†
Group 2	30.46±7.92	31.26±6.55	.099†
p^1	0.423*	0.0001**	
Side jumping			
Group 1	5.98±1.34	7.65±1.19	.0001†
Group 2	6.40±1.42	6.61±1.16	.127†
p^1	0.102*	0.0001*	
One leg squat – right leg			
Group 1	39.65±29.32	73.16±51.21	.0001†
Group 2	35.40±26.95	37.35±31.05	.422†
p^1	0.410*	0.0001**	
One leg squat – left leg			
Group 1	41.61±38.44	85.13±98.98	.0001††
Group 2	32.93±25.99	35.86±26.23	.041††
p^1	0.330**	0.0001**	
Step up – right leg			
Group 1	41.11±19.14	62.16±55.48	.002†
Group 2	34.98±18.87	32.38±12.71	.166†
p^1	0.800*	0.0001**	
Step up – left leg			
Group 1	35.93±18.88	48.93±27.19	.0001††
Group 2	29.46±12.43	28.91±10.98	.825††
p^1	0.055**	0.0001**	

Note. Group 1: exercise group, Group 2: control group, * independent groups t-test, ** Mann Whitney U-test, † dependent groups t-test, †† Wilcoxon test, p^1: significance between the groups, p^2: intragroup significance level.

Table 3. Comparison of muscle strength within and between the groups

Muscle strenght	Pre-training Mean±SD	Post-training Mean±SD	p²
Quadriceps femoris – right leg			
Group 1	147.26±42.85	196.75±49.82	0.0001†
Group 2	156.91±68.11	167.82±64.58	0.025†
p¹	0.355*	0.0001*	
Quadriceps femoris – left leg			
Group 1	133.80±48.46	180.02±53.14	0.0001†
Group 2	152.28±70.28	156.89±69.41	0.258†
p¹	0.096*	0.0001*	

Note. Group 1: exercise group, Group 2: control group, * independent groups t-test, † dependent groups t-test, p¹: significance level between the groups, p²: significance level within the group.

Table 4. Comparison of muscle quality within and between the groups

Muscle quality	Pre-training Mean±SD	Post-training Mean±SD	p²
Group 1	44127.62±14115.01	54129.99±15217.68	0.0001††
Group 2	42555.87±18358.73	40739.84±14744.86	0.131††
p¹	0.223**	0.0001*	

Note. Group 1: exercise group, Group 2: control group, * independent groups t-test, ** Mann Whitney U-test, †† Wilcoxon test, p¹: significance between the groups, p²: intragroup significance level.

Table 5. Examining the success rates of the applied training

Variables	Group 1		Group 2	
	Success rate (%)	Cohen's d	Success rate (%)	Cohen's d
Motor performance				
Vertical jumping	16	1.11	5	0.21
Side jumping	31	1.60	6	0.20
One leg squat – right leg	161	0.83	19	0.10
One leg squat – left leg	142	0.58	48	0.17
Step up – right leg	52	0.42	1	0.18
Step up – left leg	45	0.75	26	0.05
Muscle strenght				
Qf right leg	37	1.52	14	0.29
Qf left leg	40	1.34	6	0.14
Muscle quality				
MQI	25	1.13	-1	0.24

Note. Group 1: exercise group, Group 2: control group, QF: quadriceps femoris, MQI: muscle quality index, Cohen's d: effect size.

difference (p>.05). The comparison of muscle strength in pre- and post-test revealed an increase in quadriceps femoris muscle strength of both legs in Group 1, but a statistically significant difference was observed in only the right-leg quadriceps femoris in Group 2 (p<.05). The comparisons of the muscle strength between the groups in the post-test revealed a statistically significant difference in favor of the treatment group (p=.0001).

The analysis of the groups' muscle quality in the pre-test showed no statistically significant difference between the groups (p>.05). A statistically significant difference was observed in only the treatment group when comparing the groups' muscle quality in the pre- and post-test (p<.05). The comparisons of muscle quality between the groups in the post-test revealed a statistically significant difference in favor of the treatment group (p=.0001).

The analysis of the effectiveness of SSE training in regard to motor performance revealed an improvement of 161% in one-leg squat – right leg value and 142% in one-leg squat – left leg value, 52% in step-up – right leg value and 45% in step-up – left leg value. Also, an improvement of 31% in the side jumping and 16% in the vertical jumping value was observed. The analysis of the effect level of SSE training in terms of motor performance showed a very large effect (d≥1) on vertical jumping and side jumping, a large effect (1>d≥0.8) on one-leg squat – right leg (1>d≥0.8), a moderate effect (0.8>d≥0.5) on one-leg squat – left leg and step-up – left leg, and a small effect (0.5>d≥0.2) on step-up – right leg in Group 1. On the other hand, a small effect (0.5>d≥0.2) was observed on all parameters in Group 2. The analysis of the effectiveness of SSE training in regard to quadriceps femoris muscle strength showed left-leg quadriceps femoris muscle strength increased by 40% and left-leg quadriceps femoris muscle strength increased by 37% in Group 1. The analysis of the effect level of SSE training in terms of quadriceps femoris muscle strength in Group 1 showed a very large effect (1>d≥0.8) on the right- and left-leg quadriceps femoris muscle strength. A small effect (0.5>d≥0.2) was noticed on the quadriceps femoris muscle strength in Group 2. The analysis of the effectiveness of SSE training in terms of muscle quality revealed a 25% increase in muscle quality level in Group 1. The analysis of the effect level of SSE training in terms of muscle quality showed a large effect (1>d≥0.8) of the training in Group 1. However, a small effect (0.5>d≥0.2) was observed on the muscle quality level in Group 2. The within-group efficiency and success rate of the training are presented in Table 5.

Discussion and conclusions

This study analyzed the effect of SSE on the lower-extremity motor performance, muscle quality, and muscle strength in healthy sedentary young individuals. In that regard, the study revealed a significant increase in the lower-extremity motor performance, muscle strength, and muscle quality in the treatment group. However, the control group was found to increase the performance of the one-leg squat – left leg and quadriceps femoris muscle strength – right leg.

The literature showed the positive effect of exercises with sufficient intensity, volume, and duration in various studies (Chan, et al., 2018; Zhou, Li, & Jiang, 2024). Also, the literature includes many studies reporting better values of individuals who do exercises than sedentary individuals in regard to physical fitness parameters such as balance and coordination, flexibility, endurance, and agility (Aslan, Eyuboğlu, & Koç, 2016; Chan, et al., 2018).

Along with the studies on the effect of aerobic exercise, studies on physical fitness factors such as general health, balance and coordination, flexibility and endurance, agility, body-fat ratio, muscle quality, and muscle strength take a large place in the literature (Li, et al., 2024; On, et al., 2020; Unal, Altug, Tıkac, & Altug, 2023; Yıldırım & Bozkuş, 2020). In a study with 60 females, aged 18-25, Saygın, Oktay, and Ceylan (2016) investigated participants' flexibility, aerobic fitness, muscular force and endurance, body composition, blood pressure (systolic, diastolic), and resting pulse. In that regard, an 8-week aerobics-based exercise was found to have a positive effect on flexibility, aerobic fitness, muscle strength and endurance, and body composition, but was found to not have a significant effect on blood pressure and resting pulse. Similar results were also observed in other studies (Li, et al., 2024; On, et al., 2020). In that similar vein, aerobic exercises were found to have a positive impact on motor performance, muscle strength, and muscle quality in the current study.

The literature also showed several studies on the effectiveness of SSE in geriatric age groups for various purposes. In that regard, studies focused more on ensuring physical fitness such as eliminating the problems of balance and falling, increasing strength, improving walking, increasing flexibility and speed of movement (Chang, et al., 2017; Fisseha, et al., 2017; Shigematsu, et al., 2008a, 2008b; Teixeira, et al., 2013). Investigating agility, flexibility, movement speed, leg strength, and balance parameters of 56 participants, whose age range was from 60 to 80, Shigematsu and Okura (2006) found significant changes in the participants who received SSE training. In that similar vein, the current study found a significant increase in agility, muscle strength, muscle strength in the lower-extremity motor performance, and muscle quality in favor of the SSE-training group.

In another study by Shigematsu et al. (2008a), 39 participants, aged 65-74 years, received SSE or strength-balance training. The analysis of particiipants' agility, flexibility, movement speed, leg strength, balance, and incidence of falling revealed SSE was as effective as strength-balance training on those parameters. Similar results were also noticed in other studies (Shigematsu, et al., 2008b; Teixeira, et al., 2013).

Combining SSE with a pedometer, Jindo et al. (2016) investigated 68 participants over 65 years of age in terms of the one-leg balance test, 5-repetition sit-to-stand test, timed up-and-go test, the performance of 5-m habitual walk, and timed reaction with their eyes open. The results indicated the benefits of SSE in terms of increasing the lower-extremity physical function of the participants who wore pedometer in addition to exercise.

Investigating the functional fitness of 102 individuals over 65 years of age, such as aerobic endurance, leg strength, flexibility, reaction time, static balance, and mobility, Chang et al. (2017) found positive improvements in aerobic endurance, leg muscle strength, and static balance in all groups; however, no significant difference was observed between the groups. Also, in mobility, SSE or ball games applied in addition to aerobic exercise were found to show a significant improvement compared to those who performed only aerobic exercise (Chang, et al., 2017).

The unexpected increase in one-leg squat performance (left leg) and quadriceps femoris muscle strength (right leg) in the control group, despite not receiving any training, may be attributed to several potential factors. Participants in the control group underwent baseline and post-test assessments. Repeated exposure to the testing procedures, especially for motor tasks like the one-leg squat test, could have led to performance improvements due to familiarization rather than actual physiological adaptation. Even though the control group did not participate in the SSE program, incidental physical activity in their daily lives (e.g., walking, stair climbing, standing up from a seated position) might have contributed to subtle neuromuscular adaptations, particularly in weight-bearing lower extremity muscles. Knowing they were part of a study, participants in the control group might have unconsciously exerted greater effort during post-testing compared to their initial performance. This could explain the improvements in the specific strength measures recorded.

The results of this study revealed the positive impact of SSE applied four days a week for three weeks on the lower-extremity motor performance, muscle strength, and muscle quality in healthy sedentary young individuals. The evaluation methods validated in the literature and implemented in objective ways, and study of healthy young individuals unlike the participant profiles in the literature are regarded as the significances of this study. Through developing a new point of view for SSE to be a new type of aerobic exercise that can be employed for the lower extremity, the widespread implementation of SSE was targeted in this study. However, not being conducted with different disease and age groups of participants, not being combined with different treatment methods, not keeping the exercise duration longer can be among the limitations of the study. Therefore, this study suggests the following studies to investigate SSE with different disease and age groups, integrate different treatment methods, make comparisons, and keep the exercise period longer.

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Correspondence to:
Assist. Prof. Asli Demirtas, P.T., Ph.D.
Nigde Omer Halisdemir University, Faculty of Bor Health Science, Department of Physiotherapy and Rehabilitation, 51200, Nigde, Türkiye.
Phone: 90 388 21 05/ 2093
E-mail: aslicelik@ohu.edu.tr / fztaslicelik@gmail.com

STRENGTH TRAINING TO REDUCE BIOMECHANICAL RISK FACTORS FOR ACL INJURIES IN ATHLETES: A SYSTEMATIC REVIEW AND META–ANALYSIS

Juliana Pennone[1,2], Kjell Nürnberger[3], Nelson Carvas Junior[4], and Luis Mochizuki[1,2]

[1]Department of Orthopedics and Traumatology, Hospital das Clínicas, Faculty of Medicine, University of São Paulo, Brazil
[2]School of Arts, Sciences and Humanities, University of Sao Paulo, Brazil
[3]Westfälische Wilhelms-Universität Münster, Germany
[4]Department of Evidence Based Health, Federal University of São Paulo, Brazil

Systematic review
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Abstract:

Anterior cruciate ligament (ACL) injuries can significantly affect an athlete's ability to participate in sport, emphasizing the importance of prevention strategies to mitigate knee impairments. Strength training has been shown to enhance landing mechanics during sidestepping and jumping, movements often linked to ACL injuries. This systematic review with meta-analysis investigated the effects of strength training on biomechanical risk factors for ACL injuries in athletes. After searching trials up to May 4, 2022, eight articles were included. The articles included in the study seemed to be limited to female athletes who participated in sports that required cutting, jumping, or pivoting. Due to the heterogeneity of the included studies, only three articles (78 participants) could be included in the meta-analysis. The results from the meta-analysis suggest that strength training may favor lower ACL stress as it is correlated with an increased landing knee flexion angle during drop vertical jump. The data are limited, however, and the literature remains sparce in quality and number. This review exposes the need for a deeper understanding of how strengthening influences landing mechanics, reduces knee overload, and decreases the risk of ACL injuries. Future research should focus on standardizing the evaluation of ACL injury-related movements, including the definition of biomechanical outcomes, training interventions, and functional tasks for measurements. Strengthening of pelvic, core and lower body muscles 2-3 times per week seems to lower the ACL injuries risk.

Keywords: *ACL injuries, strength training, biomechanical risk factors*

Introduction

Anterior cruciate ligament (ACL) injuries are prevalent among athletes who participate in landing, cutting and pivoting sports, such as soccer, volleyball or basketball (Dufek & Bates, 2012). It has been shown that 60% of ACL injuries occur in non-contact sidestepping and single sporting tasks (Cochrane, Lloyd, Buttfield, Seward, & McGivern, 2007). Key risk factors include dynamic knee valgus – a medial collapse of the knee during weight bearing caused by hip adduction and femoral internal rotation, combined with tibial abduction and external rotation (Paz, Maia, Farias, Miranda, & Lima, 2016; Pollard, Sigward, Ota, Langford, & Powers, 2006), as well as a reduced knee and hip flexion, which impairs shock attenuation during foot-ground contact (Hewett, Ford, & Hoogenboom, 2010; Sigward, Pollard, & Powers, 2012). These factors increase ACL strain and patellofemoral joint stress (Lee, Morris, & Csintalan, 2003; Markolf, Willems, Jackson, & Finerman, 1998). The most commom mechanism for non-contact ACL injuries is a deceleration event combined with a sudden change in direction while the foot is planted, known as a cutting maneuver (Renstrom, et al., 2008).

The ACL injuries lead to short-term impairments, i.e, joint effusion, muscle weakness, static and functional instability (Daniel, et al., 1994; Filbay & Grindem, 2019) and might induce long-term consequences, including premature development of osteoarthritis (Ireland, 2002; Pinczewski, et al., 2007; Wilk & Arrigo, 2017). While less than half of athletes who undergo ACL reconstruction return to pre-injury competitive levels one year after the surgery, more than half of them abandon their professional careers (Ardern, Taylor, Feller,

& Webster, 2014). ACL injury impairs and reduces participation in sports.

ACL injury prevention is the most effective way to avoid knee impairments. Despite the fact that ACL injury etiology is complex and multifactorial, involving non-modifiable risk factors such as anatomic, genetic and physiological, other risk factors are modifiable, such as the neuromuscular and biomechanical factors (Pfeifer, Beattie, Sacko, & Hand, 2018). These modifiable factors can be changed with training (Ferri-Caruana, Prades-Insa, & Serra-Añó, 2020; Herman, et al., 2008; Hewett, Myer, Ford, & Slauterbeck, 2007; Hopper, Haff, Joyce, Lloyd, & Haff, 2017; McCurdy, Walker, Saxe, & Woods, 2012; Myer, Ford, Brent, & Hewett, 2006, 2007; Zebis, et al., 2008). Protocols combining different types of exercise and fitness components have been shown to reduce incidence of ACL injuries, as well as improve jumping and side cutting techniques (Hewett, et al., 2005; Hewett, Stroupe, Nance, & Noyes, 1996; Meyer & Haut, 2008). Although several studies have reported improvement in landing mechanics after progressive strengthening and neuromuscular training, the injury rates have appeared to double in the past decade (Gianotti, Marshall, Hume, & Bunt, 2009; Janssen, Orchard, Driscoll, & van Mechelen, 2012).

There is a gap between scientific evidence and clinical practice regarding ACL injuries. The purpose of this systematic review was to analyze randomized controlled trials (RCT) that investigated the influence of strength training upon biomechanical risk factors in ACL injuries in athletes. The aim of this study was: 1) to evaluate the effects of strength training on biomechanical risk factors in ACL injuries, compared to no-intervention; 2) to suggest future directions of research to improve the knowledge of how muscle strengthening influences landing mechanics, reduces knee overload, and decreases the risk of these injuries.

Methods

Selection criteria

Types of studies. We included randomized controlled trials (RCT) that investigated the effects of strength training on biomechanical risk factors in ACL injuries of athletes of cutting, landing and pivoting sports compared to a control group (no additional training to a regular sport-specific training). The limitation to RCT aimed to provide reduced risk of bias (RoB) and balance participants between the groups (Hariton & Locascio, 2018). Assessment of RoB using Cochrane's RoB 2 tool (Sterne, et al., 2019) was used to inform meta-analytical comparisons, but not to exclude studies during the selection process.

Types of participants. We included athletes that participated in landing, pivoting and cutting sports in any age group and competitive level, with no history of serious knee injury or other lower extremity injury within the previous six months.

Types of intervention. Included studies should embrace trials including at least one experimental group in which low extremity strengthening exercises were performed, either body-weight exercises and/or resistance training with elastic bands or various types of loads.

Types of outcome measures. The included outcome measures were: 1) knee valgus occurrence on landing and/or cutting tasks; 2) various combinations of tibial movement on landing (e.g., anterior translation + abduction, anterior translation + external rotation); 3) hip internal and external rotation during active range of motion relative to body weight; 4) knee and hip peak flexion and peak ankle dorsiflexion on landing; 5) vertical component of the ground reaction force during landing; 6) EMG amplitude and pre-activity of lower extremity muscles during the landing and cutting task. These outcomes were obtained with kinematic motion analysis (e.g., Vicon system, isoinertial sensors), kinetic analysis on a force plate, and EMG analysis with surface electrodes.

Search methods for studies identification

Bibliographic databases. The following databases were screened up to May 4, 2022: the Cochrane Central Register of Controlled Trials, MEDLINE, EM-BASE, and Pubmed (see Appendix 1). Furthermore, ClinicalTrials.gov was checked to identify any possible trials that have not been published yet.

Other resources. Additionally, reference lists of included trials were checked for further relevant literature.

Data collection and analysis

Protocol registration. This systematic review and meta-analysis adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher, et al., 2015). Assessment of study quality was conducted in accordance with the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) (Guyatt, et al., 2011). Methods were defined and the protocol was pre-registered in PROSPERO with No. CRD42022289200 before commencing the search process. Registration number was attributed on February 12, 2022.

Selection of studies. After obtaining all articles from the aforementioned literature searches, two blinded review authors (JP and KJ) used the Rayyan software to independently screen the abstracts, keywords, and publication type. Any uncertainties or disagreements were solved by discussion between these two reviewers, and if the disagreement remained, the third author (LM) made the final decision. The full-text articles of all inclusion-eligible studies were obtained, following inclusion and exclusion criteria.

Data extraction. The two review authors (JP and KJ) independently extracted the necessary information (Table 1) and assessed the risk of bias of the included trials. As well as for the selection of studies, if there was any uncertainty or disagreement not solved by these two reviewers, the third author (LM) made the final decision. The pooled results have been analyzed using standardized mean difference (MD) values.

Risk of bias of independent individual studies. The revised Cochrane RoB tool for randomized trials (RoB 2) was applied (Sterne, et al., 2019) at the outcome level. All five RoB dimensions were assessed: i) randomization process; ii) deviations

Table 1. Characteristics of individual studies

Author (year)	Study design	Participants	Comparison group	Intervention protocol	Outcomes assessed
Ferri-Caruana, et al. (2020)	RCT	Adolescent female soccer players, 15-24 years old (16 intervention; 10 control)	No additional training beyond regular technical and tactical training	Pelvic and core strengthening with resistance bands. 2 sessions/week, 8 weeks. Session duration: 30 min. Participants performed repetitions until reaching a "very hard" intensity (7-8 on the modified Borg scale).	Bilateral drop vertical jump (DVJ): peak hip, knee, and ankle dorsiflexion at landing. Unilateral DVJ: knee frontal plane projection angle.
Hopper, et al. (2017)	RCT	Female netball athletes, 11-13 years old (13 intervention; 10 control)	No additional training beyond regular technical and tactical training	Neuromuscular training program with progressive plyometric and strength exercises, increasing intensity from easy (RPE 3-4) to moderate (RPE 5-6) to hard (RPE 7-8). 3 sessions/week, 6 weeks. Session duration: 60 min.	Unilateral DVJ: bilateral knee valgus at initial contact and maximum knee flexion-extension, vertical ground reaction force immediately after box drop and landing.
Zebis, et al. (2015)	RCT	Female soccer and handball players, 15-16 years old (20 intervention; 20 control)	No additional training beyond regular technical and tactical training	Neuromuscular training with wobble boards, balance mats, and balls to enhance body awareness and motor control at the hip, knees, and ankles during running, cutting, jumping, and landing. Progressively increasing difficulty. 3 sessions/week, 12 weeks. Session duration: 15 min.	Side cutting movement: maximal knee joint valgus moment, knee valgus angle at initial contact, EMG amplitude from vastus lateralis (VL), semitendinosus (ST), and biceps femoris 10 ms before initial contact, normalized to peak EMG during maximal voluntary isometric contraction.
McCurdy, et al. (2012)	RCT	Young adult females with high school athletic experience, 19-23 years old (13 intervention; 16 control)	No training	Resistance training with weight-bearing free weights using a repetition maximum (6-15 RM). 2 sessions/week, 8 weeks.	Bilateral DVJ and unilateral DVJ: maximum and mean knee valgus, knee flexion, and hip flexion angles.
Lim, et al. (2009)	RCT	Adolescent female basketball players, 15-18 years old (11 intervention; 11 control)	No additional training beyond regular technical and tactical training	Sports injury prevention training (warm-up, stretching, strengthening, plyometrics, and agility drills). 8 weeks. Session duration: 20 min.	Rebound jump: maximum knee flexion angle, minimum inter-knee distance, maximum knee internal rotation angle, maximum knee extension moment, and maximum knee valgus moment.
Herman, et al. (2008)	RCT	Female recreational athletes, 18-30 years old (33 intervention; 33 control)	No additional training beyond regular technical and tactical training	Strength training using resistance bands, targeting quadriceps, hamstrings, gluteus medius, and gluteus maximus. 3 sessions/week, 9 weeks.	Stop-jump task.
Grandstrand, et al. (2006)	RCT	Female youth soccer players, 9-11 years old (12 intervention; 9 control)	No additional training beyond regular technical and tactical training	Sportsmetrics Warm-Up for Injury Prevention and Performance (WIPP), including plyometrics, landings, and agility drills. 2 sessions/week, 8 weeks. Session duration: 20 min. Exercise duration was adjusted to ensure technical quality without fatigue.	Bilateral DVJ: knee abduction and adduction at pre-landing, landing, takeoff, and maximum height.
Chimera, et al. (2004)	RCT	Collegiate female soccer and field hockey players, 18-22 years old (9 intervention; 9 control)	No additional training beyond regular technical and tactical training	Sport-oriented plyometric training, with various jump types. 2 sessions/week, 6 weeks. Session duration: 15 min.	Bilateral DVJ: height, EMG amplitude (area, mean, peak) of vastus medialis, vastus lateralis, medial hamstrings, lateral hamstrings, abductor, and adductor muscles. 40-yard shuttle run: maximal sprint speed.

from intended interventions; iii) missing outcome data; iv) measurement of the outcome; and v) selection of the reported result.

Analysis and presentation. An overall analysis was performed for two outcomes: peak landing knee flexion angle during drop vertical jump and peak landing hip flexion angle during drop vertical jump.

Although there are many more biomechanical variables related to ACL injuries, as the ones mentioned in "types of outcome measures", they are either not investigated or they were analyzed on different tasks (see Table 1) in the included studies, which did not allow for their comparison and consequently, their meta-analyses.

Comparisons. The meta-analysis was made with at least two trials of comparable outcome measurements. Only two parameters that appeared in the three articles included were analyzed. Statistical analyses were made using RStudio.

Continuous outcomes. For the parameters that were meta-analyzed, a positive value indicated benefit of the intervention. Heterogeneity was assessed using the I2 statistic, with values of <25%, 25-75%, and >75% considered to represent low, moderate, and high levels of heterogeneity, respectively (Higgins, Thompson, Deeks, & Altman, 2003). Random-effects model was used in all analyses.

Summary of findings table. A 'summary of findings' table (Table 2) was created with the following outcomes: peak landing knee flexion angle during drop vertical jump and peak landing hip flexion angle during drop vertical jump. We used the five GRADE (Grades of Recommendation, Assessment, Development and Evaluation) considerations (study limitations, consistency of effect, imprecision, indirectness and publication bias) to assess the quality of a body of evidence for stated outcomes (Schünemann, et al., 2008).

Outcomes pooled using MDs were re-expressed as absolute mean differences (or changes) by multiplying by a representative control group baseline SD based on Scholten, de Beurs, and Bouter (1999).

Table 2. Summary of findings

Strength training compared to control for biomechanical risk factors for ACL injuries						
Patient or population: biomechanical risk factors for ACL injuries						
Setting:						
Intervention: Strength Training						
Comparison: Control						
Outcomes	**Anticipated absolute effects* [95% CI]**		**Relative effect (95% CI)**	**Number of studies**	**Certainty of the evidence (GRADE)**	**Comments**
	Risk with control	**Risk with strength traning**				
Lower limb kinematics. Peak knee flexion angle during drop vertical jump landing. Follow-up: from 6 to 8 weeks	The mean peak landing knee flexion angle during drop vertical jump was 0º	MD 13.92º, range: [9.31, 18.52]	-	78 (3 RCTs)	⊕⊕⊕⊕ High[a]	Strength training results in a larger peak knee flexion angle during drop vertical jump landing.
Lower limb kinematics. Peak hip flexion angle during drop vertical jump landing. Follow-up: from 6 to 8 weeks	The mean peak landing hip flexion angle during drop vertical jump was 0°	MD 3.81°, range [1.48, 6.14]	-	78 (3 RCTs)	⊕⊕◯◯ Low[a,b]	Strength training results in little to no difference in peak hip flexion angle during drop vertical jump landing.
*The risk in the intervention group (and its 95% confidence interval) is based on the assumed risk in the comparison group and the relative effect of the intervention (and its 95% CI). CI: confidence interval; MD: mean difference						
GRADE Working Group grades of evidence						
High certainty: we are very confident that the true effect lies close to that of the estimate of the effect.						
Moderate certainty: we are moderately confident in the effect estimate: the true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different.						
Low certainty: our confidence in the effect estimate is limited: the true effect may be substantially different from the estimate of the effect.						
Very low certainty: we have very little confidence in the effect estimate: the true effect is likely to be substantially different from the estimate of effect.						
Explanations: a. low number of studies and low total number of subjects; b. confidence interval ranging for relevant to clinically important clinically not						

Results

Description of the studies

Results of the search (Figure 1). Sixty-one articles were identified, and a record was found on ongoing trials (clinicaltrials.gov). After checking the references of the three articles included, five other articles met the inclusion criteria. Thirty-one duplicated records were removed, and 28 records were excluded after the title and abstract screening. Thus, finally eight studies were included.

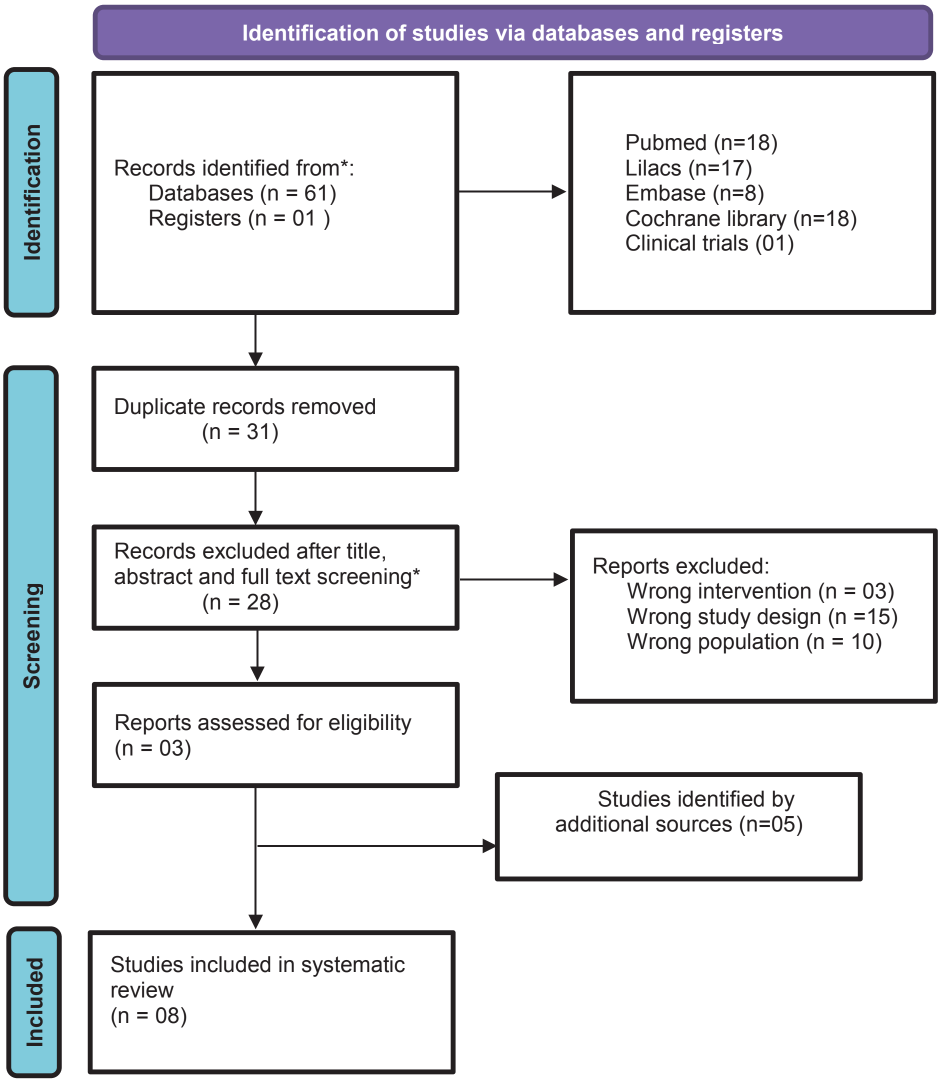
Included studies. The three included RCTs with a total of 78 participants met the inclusion criteria (Ferri-Caruana, et al., 2020 [n=26]; McCurdy, et al., 2012 [n=29]; Hopper, et al., 2017 [n=23]). See Table 1 (Characteristics of individual studies) for further information.

All participants were female (100%), with an average age of 16 years (range from 11 to 23 years). Their average body mass was 59.65 kg, and the range was 43.3 to 71.88 kg. Their average height was 1.65 m, and the range was 1.55 to 1.71 m. The strength training duration was 6-8 weeks. The mean adherence rate was 95% (SD 9.0%).

Risk of bias. In the risk of bias assessment, only one included trial presented some concerns (Grandstrand, Pfeiffer, Sabick, DeBeliso, & Shea, 2006), which did not describe the group allocation process. Other seven included trials were at a low risk of bias. In conclusion, the evidence presented in this review is based upon the low risk of bias of the included studies (Table 3 and Figure 2).

Effects of intervention

Effect of strength training on peak landing flexion angle during drop vertical (DPV) jump. For the three trials reporting the peak landing knee flexion angle during DPV (Ferri-Caruana, et al., 2020; Hopper, et al., 2017; McCurdy, et al., 2012), strength training significantly increased the peak landing knee flexion angle during DPV (MD 13.92 confidence interval [CI] 9.31 to 18.52) and moderate



* As there was a low number of studies, the authors chose to open the full texts when necessary, in the same phase of titles and abstract screening.

Figure 1. Identification of studies via databases and registers.

Table 3. Risk of bias within studies

	Bias arising from the randomization process	Bias due to deviations from intended interventions	Bias due to missing outcome data	Bias in measurement of the outcome	Bias in selection of the reported result	Overall risk of bias
Zebis et al. 2015	+	+	+	+	+	+
Mc Curdy et al. 2012	+	+	+	+	+	+
Lim et al. 2009	+	+	+	+	+	+
Hopper et al. 2017	+	+	+	+	+	+
Herman et al. 2008	+	+	+	+	+	+
Grandstrand et al. 2006	!	+	+	+	+	!
Chimera et al. 2004	+	+	+	+	+	+
Caruana et al. 2020	+	+	+	+	+	+

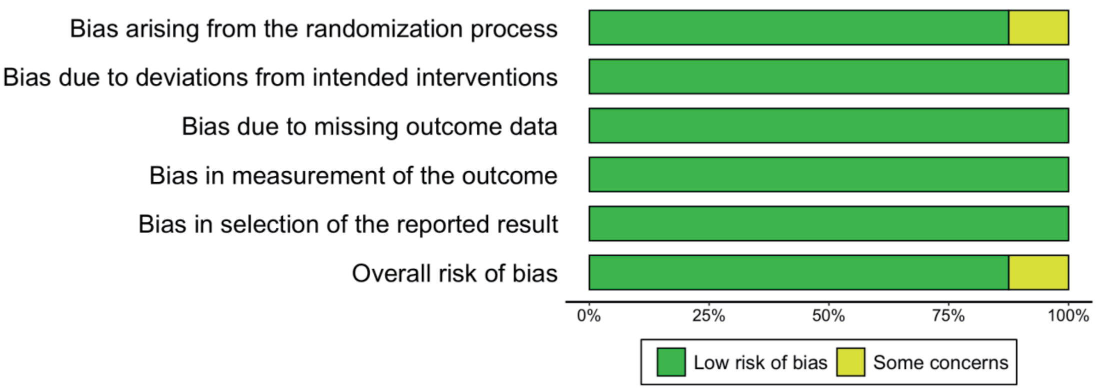


Figure 2. Risk of bias graph: review authors' judgements about each risk of bias item presented as percentages across all the included trials.

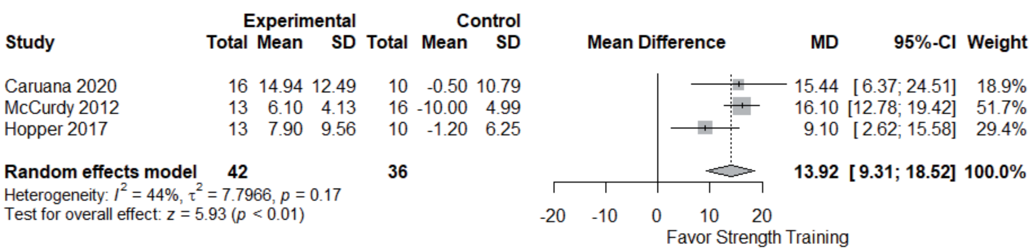


Figure 3. Peak landing knee flexion angle during drop vertical jump (DPV).

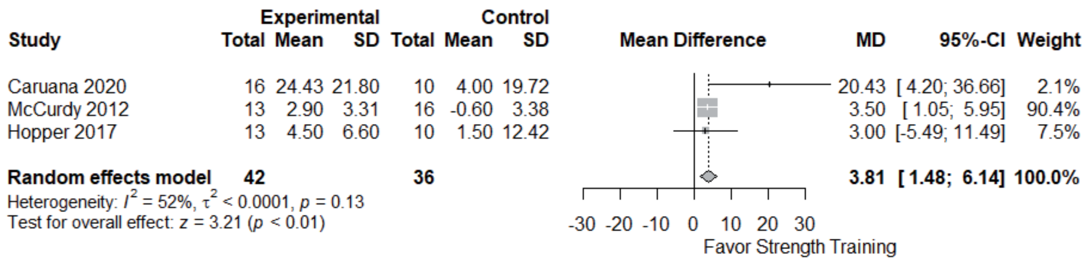


Figure 4. Peak landing hip flexion angle during drop vertical jump (DPV).

heterogeneity (Figure 3). This result has a clinically relevant effect.

On the other hand, the peak landing hip flexion angle during DPV (Ferri-Caruana, et al., 2020; Hopper, et al., 2017; McCurdy, et al., 2012) was not affected by strength training (MD 3.81, CI: 1.48 to 6.14) showing moderate heterogeneity (Figure 4). Hence, this result is not clinically relevant.

Discussion and conclusions

This systematic review with meta-analysis shows that strength training has a clinically relevant effect on peak landing knee flexion angle during DPV on athletes. Based on high quality of evidence, those who did strength training showed about 14º larger knee flexion during landing compared to the control group. On the other hand, despite a forest plot showing a tendency of strength training to increase the peak hip landing flexion angle during DPV, these results were not clinically relevant and were based on low quality of evidence.

Due to heterogeneity in study designs, only three out of the eight original articles met the inclusion criteria for this meta-analysis. The peak landing knee flexion angle during DPV has shown a significant change. Three studies (Ferri-Caruana, et al., 2020; Hopper, et al., 2017; McCurdy, et al., 2012) presented moderate heterogeneity and high effect, however, this clinically relevant result should be interpreted with caution because of the limited number of studies included. Even among the meta-analyzed studies, despite selecting the same outcomes, the frequency and type of training varied considerably. Ferri-Caruana et al. (2020) implemented core and pelvic strengthening exercises using resistance bands, performed twice a week for eight weeks. Similarly, McCurdy et al. (2012) applied the same training frequency and duration but focused on lower limb exercises using body weight. In contrast, Hopper et al. (2017) investigated a three-times-per-week regimen over six weeks, incorporating plyometric exercises for the lower limbs. Despite the high incidence and substantial costs generated by ACL injuries, few high-quality studies have investigated its prevention, making it challenging to meta-analyze them and synthesize robust evidence. In fact, current literature lacks standardization in terms of intervention type, volume, intensity, population and outcomes measures.

Sex significantly influences the risk for ACL injuries in athletes, with female athletes being 2-8 times more likely to sustain an ACL injury compared to their male counterparts in the same sport (Arendt-Nielsen, Graven-Nielsen, Svarrer, & Svensson, 1996; Hewett, et al., 2005; Myklebust, et al., 2003). A meta-analysis examining ACL tear incidence by gender and sport reported female-to-male injury ratios of 2.67 in soccer, 3.5 in basketball and 4.05 in wrestling (Prodromos, Han, Rogowski, Joyce, & Shi, 2007). This disparity likely explains why all articles included in our study focused exclusively on female athletes as participants. The notion that higher injury rates among females are due to a lack of experience in sports has been disproved (Sutton & Bullock, 2013). Instead, unique anatomical factors in females, such as a greater Q angle, smaller ACL size, narrower intercondylar notch, and increased medial posterior tibial slope (PTS) are among the potential static contributors to their higher injury rates (Sutton & Bullock, 2013). Biomechanicaly, women tend to land with less knee and hip flexion compared to men (Hewett, et al., 2005; Salci, Kentel, Heycan, Akin, & Korkusuz, 2004). Although this is not the only biomechanical risk factor in ACL injury, greater lower limb joint flexion promotes softer landings, reduces ground reaction forces, enhances energy absorption by muscles and lowers stress on the ACL (McCurdy, et al., 2012). Our findings indicate that strength training effectively increases knee flexion during landing, supporting its potential for mitigating ACL injury risk.

Considering the increase in knee flexion in our meta-analysis, the next question is how this change relates to an increase in quadriceps force for impact absorption during DPV and its potential for lowering the risk of an ACL injury. However, on a broader scale, hip flexion did not change significantly, with the examined subjects maintaining an upright landing posture—a position already associated with higher ground reaction force and increased quadriceps electromyographic activity and elevated risk factor of ACL injury (Blackburn

& Padua, 2009). These findings suggest that the load on the ACL is unlikely to have changed significantly following strength training.

The main finding of this study is that one of the most serious and common sports injuries remains not only understudied but also characterized by sparse and inconsistent literature, highlighting how little is known about such an important topic. This systematic review exposed the limited number and the methodological fragility of studies investigating strength training aiming to prevent ACL injuries. The diversity of biomechanical parameters analyzed in the included articles allowed us to do the meta-analysis of only three of them. While the number of studies is small, the moderate heterogeneity and high quality of these studies point to strength training as a promising tool in ACL injury prevention.

Based on these results, strength training should be further investigated as a contributor to reducing the risk of ACL injury, a present, harmful and costly issue for athletes. Articles published in peer-reviewed journals have demonstrated favorable results of strength training lowering the ACL injury risk but significant differences among experimental designs, volume and intensity of interventions, population and outcomes do not allow a better understanding on how strengthening influences landing mechanics, reduces knee overload, and decreases the risk of these injuries.

Evaluating sports programs in scientific studies presents several challenges due to the complexity and variability inherent to sports settings. Firstly, sports environments are dynamic, with multiple factors such as team dynamics, individual performance, and coaching strategies influencing outcomes, making it difficult to isolate the effects of a specific program. Secondly, adherence and compliance to intervention protocols can vary widely among athletes and teams, impacting the consistency and reliability of the data collected.

Another significant challenge is that sports clubs often have their own agendas and pre-established training programs. These programs are meticulously planned to optimize performance, leaving little room for external modifications or experimental interventions. This lack of receptiveness to changes in their schedules and methods can hinder the implementation of scientifically designed programs within real-world settings.

We suggest that future studies should analyze more ACL injury-related movements in a more standardized way, i.e., using comparable biomechanical outcomes, as well as training interventions of comparable intensity and volume. Biomechanical factors related to injury risk also deserve greater attention. Addressing these challenges requires innovative study designs (which may facilitate adherence and implementation in competitive teams), standardized evaluation frameworks (which will increase generalizability and study reproducibility), and collaboration between researchers, coaches, and sports organizations to bridge the gap between science and practice.

This systematic review and meta-analysis showed that strength training results in an increase in peak landing knee flexion angle during drop vertical jump, a change that can be seen as optimistic to lower ACL stress.

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Correspondence to:
Juliana Pennone, M.Sc.
School of Arts, Sciences and Humanities,
University of Sao Paulo
Rua Arlindo Bétio, 1000, Sao Paulo, SP,
Brazil 03828-000
Email: juliana.pennone@gmail.com

VERTICAL OR HORIZONTAL FORCE–VELOCITY PROFILE: WHICH ONE IS MORE SENSITIVE TO DETECT THE FATIGUE INDUCED BY A BASKETBALL-SPECIFIC PROTOCOL?

Zhaoqian Li[1], Linna Gao[2], Xing Zhang[1], Kuiying Deng[3], Yaodong Gu[2,4], Danica Janicijevic[2,4], and Amador García-Ramos[1,5]

[1]*Department of Physical Education and Sport, Faculty of Sport Sciences, University of Granada, Spain*
[2]*Faculty of Sports Science, Ningbo University, Ningbo, China*
[3]*School of Sports Engineering, Beijing Sport University, Beijing, China*
[4]*Department of Radiology, Ningbo No. 2 Hospital, Ningbo, Chin*
[5]*Department of Sports Sciences and Physical Conditioning, Faculty of Education, Universidad Católica de la Santísima Concepción, Concepción, Chile*

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Abstract:

This study aimed to determine which task (jumping or sprinting) and which force-velocity (F-V) relationship parameter (maximal force [F_0], maximal velocity [v_0], or maximal power [P_{max}]) is the most sensitive indicator of fatigue induced by a basketball-specific protocol. Following a familiarization session, 19 junior male basketball players completed an experimental session in which both vertical (jumping) and horizontal (sprinting) F-V profiles were measured before, during and after undergoing a basketball-specific fatigue protocol (modified version of the Loughborough Intermittent Shuttle Test). All F-V relationship parameters, except horizontal F_0 (p = .328), were significantly reduced after fatigue (p ≤ .042). The vertical P_{max} (ES = -0.48 to -0.80), horizontal P_{max} (ES = -0.58 to -1.28), and horizontal v_0 (ES = -0.81 to -0.98) showed larger reductions compared to the pre-fatigue assessment than the vertical v_0 (ES = -0.19 to -0.27), vertical F_0 (ES = -0.16 to -0.25), and horizontal F_0 (ES = -0.11 to -0.30). When the percentage changes with respect to the pre-fatigue assessment were compared between the jumping and sprinting tasks, no significant differences in their magnitude (p ≥ .364) and trivial to small correlations (-0.23 ≤ *r* ≤ 0.19) were detected. The results suggest that P_{max} is the most suitable parameter to detect fatigue following a basketball-specific fatigue protocol, while the lack of significant correlations for the changes in F-V relationship parameters highlight the importance of measuring both the vertical and horizontal F-V profiles to gain comprehensive understanding of the changes in the mechanical properties of lower-body muscles following fatigue protocols.

Keywords: *jump, monitoring, sprint, team sport, testing*

Introduction

Basketball is one of the most popular team sports worldwide and has captivated both players and spectators with its dynamic characteristics (B. Li & Xu, 2021). Time-motion analysis reveals that the majority of actions in basketball are of short duration and high intensity (McInnes, Carlson, Jones, & McKenna, 1995). For example, modern competitive basketball demands that players perform repeated high-intensity actions such as accelerations, decelerations, vertical jumps, and quick changes of direction, which are especially important during key moments like shooting, rebounding, or dribbling (García, Castellano, Reche, & Vázquez-Guerrero, 2021). The use of novel technologies has provided a better understanding of the physical demands in elite basketball, showing that players run an average of approximately 80 meters per minute, with peak speeds exceeding 18 km/h (Puente, Abián-Vicén, Areces, López & Del Coso, 2017). Sprinting and jumping abilities not only influence players' physical fitness but also exhibit a strong association with basketball-specific technical skills (Pliauga, et al., 2015). For instance, enhancing jump ability increases the likelihood of securing rebounds, while increasing speed ensures players can swiftly reach offensive and defensive positions during quick transitions (Asadi, 2016). Another important factor to consider is that the repetition of high-intensity actions in basketball exposes players to fatigue, impairing sports performance and increasing the risk of injury during the game (Scanlan, et al., 2017). Basketball-specific fatigue protocols have been shown to compromise both technical elements performance, such as dribbling and shooting velocity and accuracy (F. Li, Rupčić, & Knjaz, 2021; Lyons, Al-Nakeeb, & Nevill, 2006; Mulazimoglu, Yanar, Evcil, & Duvan, 2017), and physical components, including jumping and sprint performance, as well as landing technique (Liveris, et al., 2021; Pliauga, et al., 2015). Given a significant impact of jumping and sprinting on basketball performance and their susceptibility to fatigue, monitoring their performance holds potential value for basketball players.

The assessment of the force-velocity (F-V) profile in jumping and sprinting tasks has recently seen a surge in popularity among strength and conditioning coaches (Morin & Samozino, 2016). This growing interest can be attributed to two key factors: (i) the comprehensive insights their parameters provide into the maximal capabilities of the neuromuscular system for generating force (F_0), velocity (v_0), and power (P_{max}), and (ii) the straightforward and inexpensive nature of this testing method, which primarily involves measuring kinematic variables such as flight time or displacement-time data (Haugen, Breitschädel, & Samozino, 2020; Z. Li, Zhi, Yuan, García-Ramos, & King, 2024). The insights gained from F-V profile assessments have been utilized to tailor individualized training programs with the dual goals of enhancing ballistic performance and reducing the risk of injury (Jiménez-Reyes, Samozino, Brughelli, & Morin, 2017; Mendiguchia, et al., 2016). In addition, F-V profiles have been recently used to assess the acute fatigue induced by different physical protocols (García-Ramos, et al., 2018; Z. Li, et al., 2024). Its application is recommended because the same decrement in P_{max}, indicative of overall fatigue originated from the physical protocol, can result from varying decreases in F_0 and v_0 (Hermosilla-Palma, et al., 2023; Jiménez-Reyes, Cross, et al., 2018; Z. Li, et al., 2024). Regarding the sensitivity of horizontal (sprint) F-V profiles to detect fatigue, it has been shown that repeated sprint protocols compromise v_0 more than F_0 (Hermosilla-Palma, et al., 2023; Jiménez-Reyes, Cross, et al., 2018). On the other hand, vertical (jump) F-V profiles were sensitive enough to detect a greater decrement in F_0 compared to v_0 following a heavy-load squat protocol, and a greater impairment in v_0 compared to F_0 after a light-load ballistic squat protocol (Z. Li, et al., 2024). Considering the significant involvement of the lower limbs in basketball, it is important to investigate whether vertical and horizontal F-V profiles can be utilized to monitor the specific fatigue impact of this more comprehensive task on F_0, v_0, and P_{max}.

Research has consistently demonstrated a strong correlation between jump height and sprint time (Köklü, Alemdaroğlu, Özkan, Koz, & Ersöz, 2015; Washif & Kok, 2022). Likewise, Jiménez-Reyes et al. (2019) observed similar decreases in jump height and sprint velocity following a repeated sprint training protocol. This suggests that jumping and sprinting abilities may share common physiological and biomechanical underpinnings (Köklü, et al., 2015). However, Jiménez-Reyes, Samozino, et al. (2018) also found generally weaker correlations for F-V relationship parameters (F_0 and v_0) than for performance variables (jump height and sprint time) in jumping and sprinting tasks. Consequently, it becomes critical to ascertain whether vertical and horizontal F-V profiles are sensitive equally for detecting fatigue caused by a basketball-specific protocol. This area of research is groundbreaking, as no previous research has concurrently investigated sensitivity of both the vertical and horizontal F-V profiles in the context of fatigue monitoring.

To address the questions, we measured the vertical and horizontal F-V profiles at three time points: before (pre), during (mid) and after (post) undergoing a basketball-specific fatigue protocol. The main objective of the present study was to determine which task (jumping or sprinting) and which F-V relationship parameter (F_0, v_0, or P_{max}) was the most sensitive indicator of fatigue induced by the basketball-specific protocol. It was hypothesized that (i) both vertical and horizontal F-V profiles would be decreased during and after the basketball-specific fatigue protocol, but (ii) low correlations were expected for the percentage changes in the F-V relationship parameters between the jumping and sprinting tasks.

Materials and methods

Subjects

Nineteen junior male basketball players (mean ± standard deviation [SD]; age = 16.0 ± 0.6 years, height: 178.4 ± 4.2 cm, body mass: 71.2 ± 9.8 kg) participated in this study. All subjects had at least one year of resistance training experience and had not sustained any musculoskeletal injuries for at least the past year. Subjects were also advised to refrain from engaging in any vigorous physical activity for at least 48 hours before each testing session. They and their legal guardians were informed about the study's purpose and procedures and they both gave their consent by signing an informed consent form before participating. The study protocol adhered to the tenets of the Declaration of Helsinki and was approved by the Ningbo University Institutional Review Board.

Study design

The subjects completed two sessions separated by at least 72 hours of rest. The first visit was designed to assess body composition (body mass and body height), push-off distance, and the load that enabled a squat jump (SJ) height of 12 cm. The push-off distance was determined as the difference between the extended lower limb length (perpendicular distance from the iliac crest to the toes with the three lower-limb joints fully extended) and the vertical distance between the iliac crest and the ground with knees flexed at 90º (Janicijevic, et al., 2020). An incremental loading test was implemented to determine the load that allowed a SJ height of 12 cm (63.7 ± 11.2 kg). The push-off distance was used in the second session when assessing the vertical F-V relationship, while the load that allowed a SJ height of 12 cm represented the heavy load used in the second session for the application of the two-point method (Janicijevic, et al., 2020)

The second session represented the main experimental session in which both the vertical and horizontal F-V profiles were measured at three time points: before (pre), during (mid) and after (post) undergoing a basketball-specific fatigue protocol. The warm-up routine for both sessions included 5-minute jogging, dynamic stretching exercises, three progressively faster 30-meter sprints, and five maximal unloaded and 20-kg loaded SJ. Both sessions were performed at the same time (± 1 hour) of the day for each participant and under similar environmental conditions.

Basketball-specific fatigue protocol

We used a modified version of the Loughborough Intermittent Shuttle Test (LIST) (Nicholas, Nuttall, &Williams, 2000), a protocol frequently employed in basketball fatigue studies (Afman, et al., 2014; Ansdell & Dekerle, 2020) (Figure 1). To mimic the four quarters of a basketball game, the exercise was structured into four blocks, with each block consisting of 11 cycles. Each cycle was composed of three sequences of 20-m walking at ≈ 1.54 $m \cdot s^{-1}$, running at ≈ 3.49 $m \cdot s^{-1}$, jogging at ≈ 2.79 $m \cdot s^{-1}$, one 15-m maximum-effort sprint, and a basketball lay-up. After the first and third blocks, participants had a 2-minute rest period to simulate the break between quarters in basketball. A 10-minute rest, representing the half time interval, was provided immediately after the second (mid) assessment of the F-V profiles. Sprint times for each cycle were recorded using timing gates (Smart Speed, Fusion Sport, Australia), and the experimenter kept track of the number of successful lay-ups.

Vertical F-V profile modelling

The specific warm-up consisted of four progressive sets until reaching the heavy load used for the application of the two-point method. The two-point method has demonstrated a high validity for the assessment of the vertical F-V relationship (García-Ramos, Pérez-Castilla, & Jaric, 2021). Subjects performed two SJs with a plastic barbell of 0.5 kg and two SJs with the load associated with a jump height of ≈ 12 cm (63.7 ± 11.2 kg). A rest period of

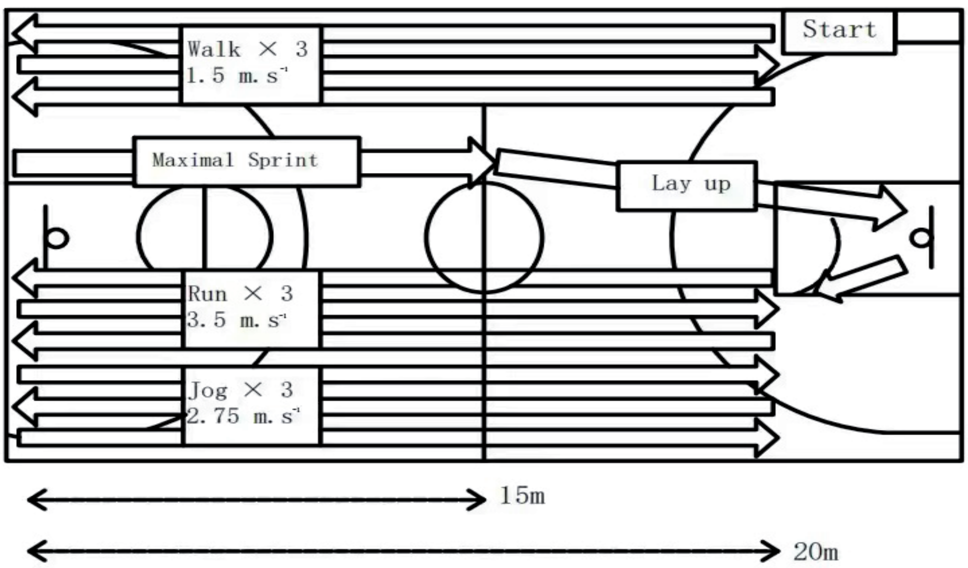

Figure 1. Modified version of the Loughborough Intermittent Shuttle Test (LIST).

one minute was implemented between successive jumps. Jump height was estimated by the flight time method at 240 frames per second using the validated My Jump 2 app on an iPhone 13 (Apple Inc., USA) (Bogataj, Pajek, Andrašić, & Trajković, 2020; Yingling, et al., 2018). The mean values of force and velocity were calculated using the simple method proposed by Samozino, Morin, Hintzy, and Belli (2008) considering three input variables: system mass, jump height and push-off distance. The mean values of force and velocity obtained under two loading conditions were used for the assessment of the F-V relationship through a linear model: $F(\mathrm{V}) = F_0 - aV$, in which F_0 represented the force-intercept and a was the slope of the F-V relationship. The maximal theoretical velocity (v_0) corresponds to F_0/a. Finally, maximum power (P_{max}) was calculated as $P_{max} = F_0 \cdot v_0/4$. F_0 and P_{max} were normalized to body mass. Only the trial with the highest jump height of each load was used for the F-V relationship modelling.

Before each jump, subjects were instructed to stand upright and motionless in the center of the jumping area. To ensure a consistent knee angle of approximately 90º and control the push-off distance, a small chair was placed behind each subject (Z. Li, et al., 2024). Subjects were required to hold this initial position for about two seconds before starting the jump. Any countermovement was not allowed, and we strictly monitored to enforce this rule. Subjects were instructed to jump as high as possible during all trials.

Horizontal F-V profile modelling

Subjects were asked to execute two all-out 30-meter sprints separated by three minutes of rest. The sprints were initiated using a three-point stance. Timing gates were positioned at 0, 10, 20, and 30 meters along the sprint path. Subjects started with their heads 5-cm from the first beam and the front foot's toe 50 cm behind the starting line. The sprint with the shortest 30-meter time was used to assess the F-V profiles. A purpose-built Excel spreadsheet created by Morin and Samozino (2016) was used to calculate the parameters of the horizontal F-V profiles, including maximal theoretical force (F_0), maximal theoretical velocity (v_0), and maximal power output (P_{max}). This spreadsheet requires input of the sprint times recorded at each gate, along with the athlete's height, body mass, and the temperature and air pressure of the testing environment. F_0 and P_{max} were normalized to each participant's body mass.

Statistical analysis

Descriptive data are presented through means and SDs. The Shapiro-Wilk test confirmed the normal distribution of all vertical F-V relationship parameters (F_0, v_0, P_{max}) and the horizontal F_0 parameter ($p > .05$), but the rest of the horizontal F-V relationship parameters (v_0 and P_{max}) were not normally distributed ($p < .05$). In order to assess the effects of the basketball-specific fatigue protocol on the F-V relationship parameters, a one-way repeated-measures analysis of variance (ANOVA) (pre-fatigue *vs.* mid-fatigue *vs.* post-fatigue) with Bonferroni *post-hoc* corrections was applied to the normally distributed variables (vertical F_0, v_0, P_{max} and horizontal F_0), while the Friedman's test was applied to the variables which were not normally distributed (horizontal v_0 and P_{max}). When sphericity was violated ($p < .05$), the Greenhouse-Geisser correction was applied. The Cohen's d effect size (ES) was calculated to quantify the magnitude of the differences, and it was interpreted according to the scale proposed by Hopkins, Marshall, Batterham, and Hanin (2009): trivial (< 0.20), small (0.20-59), moderate (0.60-1.19), large (1.20-1.99) and very large (≥ 2.00).

Additionally, percentage differences of mid- and post-fatigue assessments with respect to the pre-fatigue assessment were calculated for different dependent variables ($\%\Delta = [\text{mid/post} - \text{pre}] / \text{pre} \times 100$). Paired samples t-tests and the Pearson's correlation coefficient (r) were used to compare the percentage differences between the jumping and sprinting tasks separately for each F-V relationship parameter (F_0, v_0, P_{max}). The magnitude of the r coefficient was interpreted according to the scale proposed by Hopkins et al. (2009): trivial (< 0.10), small (0.10-0.29), moderate (0.30-0.49), large (0.50-0.69), very large (0.70-0.89), and nearly perfect (≥ 0.90). All statistical analyses were performed using SPSS software version 22.0 (SPSS Inc., Chicago, IL, USA) and statistical significance was set at an alpha level of 0.05.

Results

All F-V relationship parameters, with the exception of the horizontal F_0, were significantly reduced compared to the pre-fatigue assessment (Table 1). Vertical P_{max} (ES = -0.48 to -0.80), horizontal P_{max} (ES = -0.58 to -1.28) and horizontal v_0 (ES = -0.81 to -0.98) showed larger reductions compared to the pre-fatigue assessment than vertical v_0 (ES = -0.19 to -0.27), vertical F_0 (ES = -0.16 to -0.25), and horizontal F_0 (ES = -0.11 to -0.30) (Figure 2). The differences between the mid- and post-fatigue assessment were negligible for vertical v_0, vertical F_0, and horizontal F_0 (ES < 0.20), but small differences in favor of the mid-fatigue assessment was observed for vertical P_{max}, horizontal P_{max}, and horizontal v_0 (ES = 0.30 to 0.49)

The percentage changes with respect to the pre-fatigue assessment did not significantly differ between the jumping and sprinting tasks for any F-V relationship parameter ($p \geq .364$). However, trivial to small correlations ($-0.23 \leq r \leq 0.19$) were

Table 1. Comparison of the force-velocity (F-V) relationship parameters obtained during the jumping and sprinting tasks before, during, and after undergoing a basketball-specific fatigue protocol

Task	Parameter	Time of assessment			ANOVA or Friedman test
		Pre-fatigue	Mid-fatigue	Post-fatigue	
Vertical F-V profile	F_0 (N·kg^{-1})	35.8 ± 6.0	34.9 ± 5.9	34.2 ± 7.0	F = 7.6; ***p* = .013**
	v_0 (m·s^{-1})	3.33 ± 0.87	3.17 ± 0.88	3.09 ± 0.90	F = 4.8; ***p* = .042**
	P_{max} (W·kg^{-1})	28.9 ± 4.5	26.7 ± 4.4	25.4 ± 4.3	F = 23.4; ***p* < .001**
Horizontal F-V profile	F_0 (N·kg^{-1})	7.58 ± 1.19	7.41 ± 1.78	7.17 ± 1.49	F = 1.0; *p* = .328
	v_0 (m·s^{-1})	8.82 ± 0.65	8.25 ± 0.76	7.97 ± 1.08	χ^2 = 8.3; ***p* = .016**
	P_{max} (W·kg^{-1})	16.6 ± 2.5	15.1 ± 2.9	14.0 ± 1.7	χ^2 = 19.9; ***p* < .001**

Note. ANOVA – analysis of variance; F_0 – maximal theoretical force; v_0 – maximal theoretical velocity, P_{max} – maximal power. Significant differences are emphasized in bold.

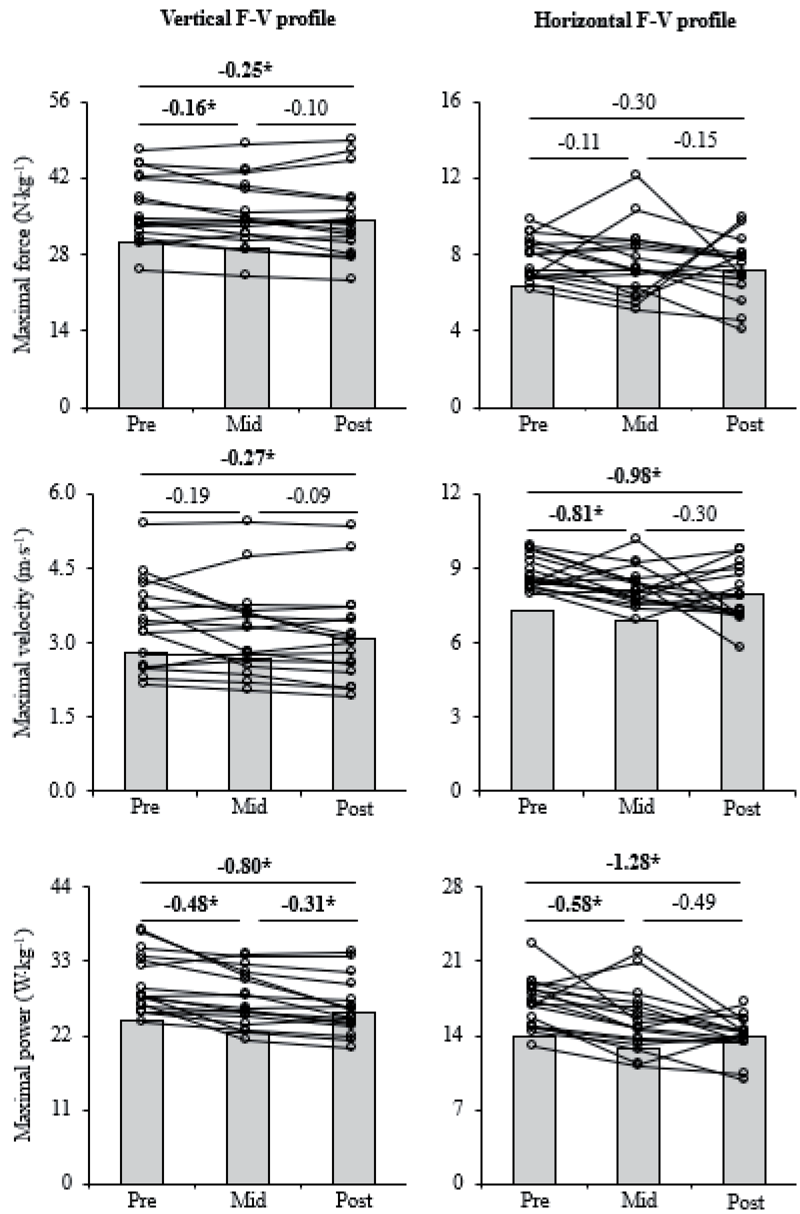

*Figure 2. Comparison of the force-velocity (F-V) relationship parameters collected during the jumping (left panels) and sprinting (right panels) tasks between the assessments performed before (pre), during (mid) and after (post) undergoing a basketball-specific fatigue protocol. Numbers represent the Cohen's d effect size. * – significant differences (p < .05).*

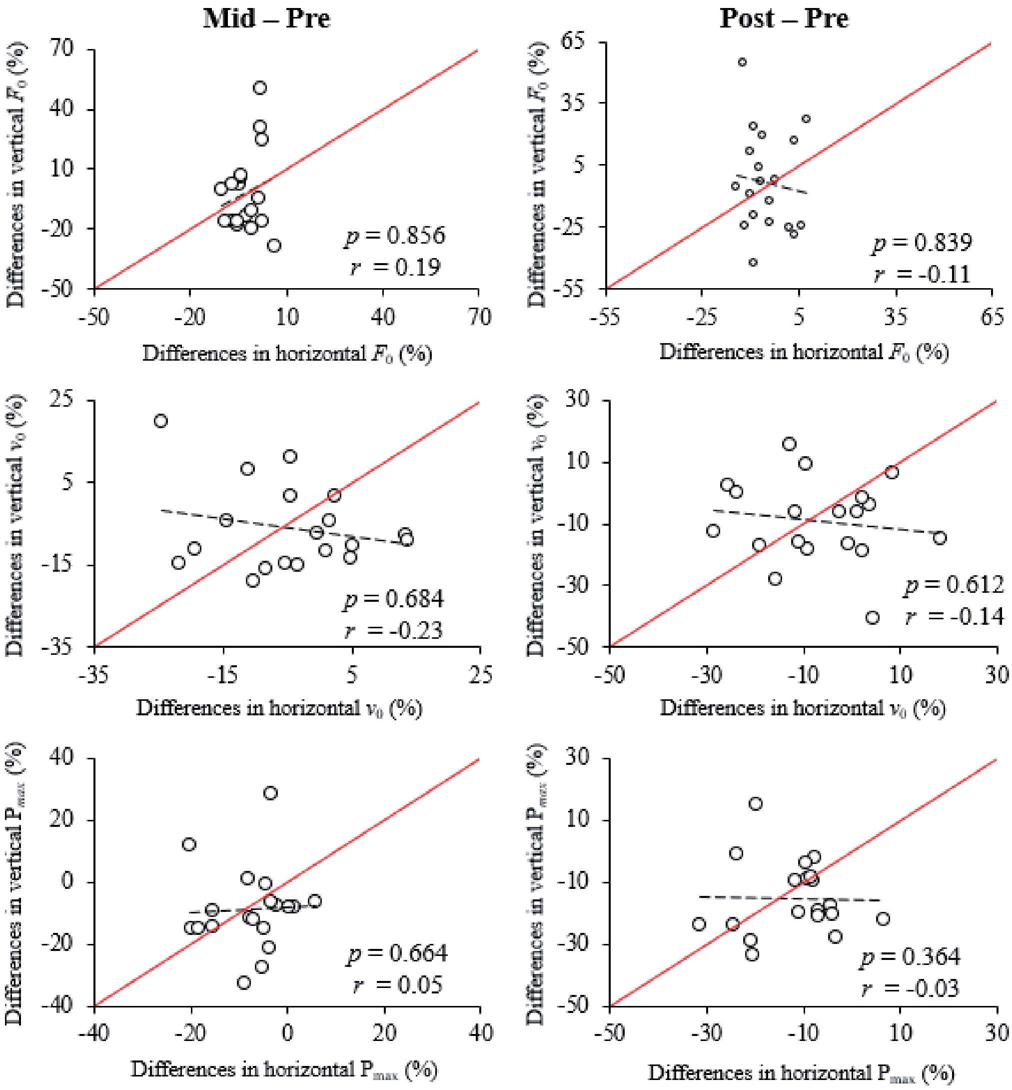

Figure 3. Comparison and association between the jumping and sprinting tasks for the percentage differences with respect to the pre-fatigue assessment in maximum force (F_0; upper panels), maximum velocity (v_0; middle panels) and maximum power (P_{max}; lower panels) at mid-fatigue (left panels) and post-fatigue (right panels) assessments. p – p-value obtained from paired sample's t tests; r – Pearson's correlation coefficient. The regression (dashed line) and identity (straight line) lines are depicted.

obtained for the percentage changes in the same F-V relationship parameters between the jumping and sprinting tasks (Figure 3).

Discussion and conclusions

This research was designed to determine the effects of a basketball-specific fatigue protocol on the changes in vertical and horizontal F-V profiles. All F-V parameters, except horizontal F_0, decreased significantly after the fatigue protocol. Vertical P_{max}, horizontal P_{max}, and horizontal v_0 showed the largest decrements. Regarding the comparison of the percentage change for the same F-V parameters obtained through the jumping and sprinting tasks, non-significant differences and trivial to small correlations were found. The results suggest that P_{max} should be the preferred parameter to detect fatigue after a basketball-specific fatigue protocol and emphasize the importance of assessing both jumping and sprinting tasks to gain a comprehensive understanding of the alterations in the lower-body muscle function after fatigue protocols.

Previous studies have indicated that P_{max} stands out as the most sensitive parameter for discerning the fatigue level induced by a particular task, as it encompasses variations in both F_0 and v_0 (García-Ramos, et al., 2018; Jiménez-Reyes, Cross, et al., 2018; Z. Li, et al., 2024). However, these findings have predominantly been documented within the context of resistance training and sprinting movements, leaving us uncertain about their applicability to the nuances of basketball matches. To generalize previous findings, this research compared the horizontal and vertical F-V profiles after a modified version of the LIST protocol. P_{max} also proved to be the most sensitive parameter in detecting the fatigue level caused by a basketball-specific fatigue protocol as it showed moderate to large decrements in both horizontal and vertical directions. Horizontal F_0 was the only variable that failed to detect fatigue induced by the LIST protocol, whereas the sensitivity of v_0 differed between the jumping and sprinting tasks, with moderate reductions for horizontal v_0 and trivial to small reductions for vertical v_0.

Although F_0 and v_0 were not as sensitive as P_{max} to reveal fatigue levels, previous studies found that F_0 and v_0 were capable of detecting selective fatigue under specific circumstances. For example, Z. Li et al. (2024) found that vertical v_0 had a considerable decrease, but not vertical F_0, after five repetitions of light-load ballistic squats. Additionally, a repeated sprint protocol impaired horizontal v_0 more than horizontal F_0 (Jiménez-Reyes, Cross, et al., 2018). Our findings are somewhat similar to the obtained in previous studies (Jiménez-Reyes, Cross, et al., 2018; Z. Li, et al., 2024). Due to the characteristics of the LIST protocol, it was expected that v_0 would experience greater decrements compared to F_0. This expectation was confirmed as no significant change was observed for horizontal F_0, whereas horizontal v_0 exhibited a moderate and significant decrement. Similarly, vertical F_0 showed a lesser decline compared to vertical v_0. The composition of the modified LIST, which primarily consisted of high repetitions of low-resistance movements like vertical jumping, horizontal running, and sprinting, likely contributed to these differences.

Several studies have explored the sprinting and jumping performance after different fatigue situations such as a match or Yo-Yo test (Fry, et al., 2024; Gathercole, Sporer, Stellingwerff, & Sleivert, et al., 2015; Janicijevic, et al., 2024; Pliauga, et al., 2015; Spillets, 2017). However, no study has directly compared in the same study the changes in F-V relationship parameters obtained through jumping and sprinting tasks. No significant differences were reported for the percentage changes with respect to the pre-fatigue assessment between jumping and sprinting tasks for any F-V parameter. This result suggests that the modified version of the LIST protocol led to similar fatigue in the horizontal and vertical directions of force application, which might be somewhat expected because the LIST protocol included a similar volume of high-intensity movements in both horizontal and vertical directions (15m sprint in the horizontal direction and lay-up in both the horizontal and vertical direction).

When compared to conventional fatigue monitoring tools such as heart rate and biochemical markers, what sets vertical jump height and sprinting time apart is their dual role in both sports performance and fatigue assessment (Edwards, et al., 2018). Additionally, several studies reported a high correlation between sprinting time and jumping height under fatigued and non-fatigued situations (Jiménez-Reyes, et al., 2019; Jiménez-Reyes, Samozino, et al., 2018; Lin, Shen, Zhang, Zhou, & Guo, 2023) Jiménez-Reyes et al. (2019) used countermovement jump (CMJ) height as a marker of fatigue during repeated sprint training and they found strong correlations of the decrement in CMJ height with lactate and ammonia concentrations. However, it is important to note that while CMJ height and sprint time are generally significantly correlated, the F-V relationship parameters derived from the jumping and sprinting tasks present weaker correlations (Jiménez-Reyes, Samozino, et al., 2018). In line with the findings by Jiménez-Reyes, Samozino, et al. (2018), we also found trivial to low correlations for the changes in the same F-V parameters after the modified LIST protocol. The different mechanisms involved in jumping and sprinting likely promote that their F-V parameters do not behave similarly under non-fatigue and fatigue situations. In line with our findings, sprinting performance and related variables, such as step length and step frequency, have shown significant correlations with unilateral jumping kinematics but not with bilateral vertical jumping kinematics (Mccurdy, et al., 2010). Therefore, to gain a more comprehensive understanding of players' fatigue levels, it is advisable to measure both vertical and horizontal F-V profiles in fatigue-inducing conditions.

Finally, some limitations should be acknowledged. Firstly, vertical and horizontal F-V profiles were tested using validated simple measurements and procedures, but direct force recordings were not obtained in this study. The reliability of the two-point method for evaluating vertical F-V profiles has not been evaluated in amateur youth athletes. However, it is worth noting that these athletes demonstrated sufficient strength, with an average vertical jump of at least 12 cm while carrying an external load exceeding 60 kg, thereby ensuring an adequate distance between the experimental points (García-Ramos, 2023). Horizontal F_0 was reported to be higher when assessed by the timing gate method (Haugen, et al., 2020). Additionally, although the participants were classified as junior players, their age range places them closer to cadet-level athletes. This may limit the generalizability of the findings to older juniors, young seniors, or adult athletes. Finally, the LIST protocol's limited inclusion of ball-handling movements, such as passing and change of direction, raised a concern as it could not fully replicate the demands of basketball games and accurately reflect their mechanical requirements

Both vertical and horizontal F-V profiles are effective in tracking fatigue resulting from a basketball-specific fatigue protocol. We discovered that P_{max}, a parameter combining F_0 and v_0 capacities, is the most sensitive indicator of fatigue levels. When we used vertical jumps for measurement, both F_0 and v_0 showed similar declines. However, in linear sprints, only v_0, not F_0, exhibited a significant decrease. This larger drop in horizontal v_0 compared to horizontal F_0 might be due to the protocol's emphasis on low-resistance, high-repetition tasks. Despite the overall reduction in F-V parameters (F_0, v_0, and P_{max}) being similar for both jumping and sprinting, the changes were not significantly correlated between both tasks. Therefore, practitioners are encouraged to assess F-V relationships during both jumping and sprinting to comprehensively monitor lower-body adaptations resulting from basketball training routines.

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Correspondence to:
Danica Janicijevic
E mail: janicijevic@nbu.edu.cn

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ATHLETICS COACHES EXPERIENCING COOPERATIVE LEARNING FOR THE FIRST TIME: A QUALITATIVE STUDY

Lea Železnik Mežan and Saša Cecić Erpič

Faculty of Sport, University of Ljubljana, Slovenia

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Abstract:

As cooperative learning (CL) is not yet well researched and widely used in competitive youth sport, we aimed to gather coaches' experiences of CL to evaluate and promote its suitability for use in kids' athletics. Four track-and-field coaches from Slovenia who coached mixed youth athletics groups were interviewed after conducting 30 training sessions with CL according to the experimental programme. In addition, the coaches wrote a reflective analysis after each session. The coaches' responses from the interview and the reflections were analysed using thematic analysis and constant comparison. Three themes were identified: (a) *roles in the pedagogical process*, (b) *interpersonal and small-group skills*, and (c) *transition to CL and related challenges*. The coaches developed very positive attitude towards CL and group work in general. They reported that children acquired various interpersonal and small-group skills, which helped them in peer teaching and learning. The most difficult part was the beginning, as the children were not able to cooperate with their peers. Later on, the athletes were active learners and very confident in taking on different roles, including the role of the tutor. Because of this, the coaches' role changed tremendously. Nevertheless, the coaches felt important in guiding the learners to the desired knowledge. CL is very effective in improving children's learning in kids' athletics and is also well accepted by Slovenian track-and-field coaches. However, we would suggest combining it with other pedagogical models. In addition, coaches would need additional training in CL to be able to decide which learning objectives should be targeted with which approach.

Keywords: *pedagogical model, roles, peer teaching, autonomy, youth sport*

Introduction

The effects of cooperative learning (CL) in youth athletics' motivational climate, peer relationships and self-concept (Železnik Mežan, Škof, Leskošek, & Cecić Erpič, 2023) and the effects of CL on children's motor learning (Železnik Mežan & Škof, 2023) have been empirically investigated. Although statistics confirm the effectiveness of CL on some psychosocial and cognitive variables, the success and usefulness of the model for coaching young athletes depends heavily on the participants' experiences with it. Although the study focuses on youth sport, CL was developed and initially used in an educational setting, which is why the terms *students* and *teachers* are also used in the following sections.

"…in CL, teachers need to promote students' ability to cooperate and deal with potential conflicts and divergent ideas. This requires teachers to abandon traditional and authoritative roles, in which the teacher is the full instructional leader, and start acting as facilitators of student-centred learning." (Silva, Farias, & Mesquita, 2021: 2). While the focus of CL is indeed on students learning to cooperate with their peers, and the theme is *students learning with, by, and for each other* (Gurvitch & Metzler, 2013), is it necessary for a teacher or a coach to relinquish all of their traditional responsibilities? What does it mean to take on the role of a facilitator and what should it look like? Should modern approaches such as CL really only be student-centred?

Student-centred learning has its origins in constructivist learning theory, which recognises the active role of the learner (Zhu, Ennis, & Chen, 2011). Rather than delivering content so that the learner passively absorbs the information, a constructivist paradigm gives the learner ample opportunity to actively engage in linking his/her prior experiences to new knowledge in order to build personally meaningful understanding. This approach is often considered good, whereas teacher-centred direct instruction (DI) is now mostly considered bad (Hattie, 2009). Nevertheless, it is still one of the most commonly used pedagogical models (Guzmán & Payá, 2020). In this type of learning process, the teacher leads the process, makes decisions independently (about the content, class management, student participation), controls all group interactions, introduces tasks, determines their progression, evaluates the achievement of objectives, etc. (Metzler, 2011; Pereira, Araújo, Farias, & Mesquita, 2016).

CL has developed on the basis of the constructivist paradigm, which is why it places the student at the centre of the pedagogical process and assigns the teacher the role of a facilitator. However, this does not necessarily mean that the teacher has to stand on the sidelines and should only interact when asked to do so by the students (García-González, Santed, Escolano-Pérez, & Fernández-Río, 2023). The role of the teacher as a facilitator in CL is usually misunderstood. For this reason, Biesta (2012) warns against the disappearance of teaching (by the teacher). The representative of relational pedagogy fears that a teacher and his or her basic function will no longer be needed over time. The disappearance could be caused by the newer theories of teaching and learning, which place the teacher alongside the learning process. This is as extreme a view as that of the constructivists. Rather, the pedagogical process should be centred on both the student and the teacher.

Visible teaching and learning encompass a teacher-centred and a student-centred approach (Hattie, 2009). The concept represents a combination of extreme perspectives. It is characterised by the active participation of both actors in the pedagogical process. According to the concept of visible learning, students should be encouraged to learn actively by testing optimal learning paths, looking for clues to help them learn, etc., until they become their own teachers. Then they are able to set appropriate learning goals and reflect on their own success. It is very important that the learning goals challenge the students to an appropriate degree (Hattie, 2009). Creating an appropriate learning environment requires a dedicated and passionate teacher. He/she must know which teaching strategies work well and which do not; he/she must understand the students (at least try to); a teacher must be willing to adapt the learning process to the students and the context; he/she should share his/her experiences with the students… Creating a warm socio-emotional group climate is one of the steps a teacher must take to invest in students' learning. In addition, it is important for the teacher to ensure that all students are included, to be open to students' experiences and feedback, to expect that every student can make progress, to encourage students to make an effort to learn, etc.

While in DI the teacher is the only person who supports the students in their learning, the interaction between the teacher and each student is only emphasised. In CL, however, the teacher should be responsible for teaching students interpersonal and small-group skills that enable them to successfully interact and cooperate with each other. Explicitly teaching the latter is one of the most important CL features that promises improvements in interpersonal relationships (Grineski, 1996; Jacobs, Teh, & Spencer, 2017; Železnik Mežan, et al., 2023). For this reason, a student- and teacher-centred pedagogical process with CL should have the potential to improve students' learning and promote the development of interpersonal relationships between all those involved in the pedagogical process.

Previous studies on CL in Physical Education (PE) (Dyson, Howley, & Shen, 2021; García-González, et al., 2023; Liu & Lipowski, 2021; Yang, Chen, R., Chen, X., & Lu, 2021) and in youth sport (Železnik Mežan & Škof, 2023; Železnik Mežan, et al., 2023) have mainly focused on the impact of CL on students' outcomes, but rarely on the impact on teachers/coaches who have introduced CL (Cochon Drouet, Fargier, Margas, & Lentillon-Kaestner, 2023). In order to implement CL in either PE or youth sport, teachers/coaches' attitudes towards this model need to be well researched. Qualitative methods are needed to analyse the teachers/coaches' implementation strategies in more detail (Schulze & Huth, 2023). Research has shown that teachers appreciate the fact that CL is less directive and therefore more engaging for students (Casey, 2014; Casey, Dyson, & Campbell, 2009). On the other hand, teachers do not feel comfortable being left out of the learning process. This paper adds to the existing literature describing coaches' experiences with CL in youth sport and emphasises the importance of both children and coaches being at the centre of the learning process. The aim was to analyse coaches' perceptions of their involvement and engagement of children with CL and its suitability for coaching young athletes. Coaches' experiences with CL have not yet been researched.

Methods

Participants

The participants in this study were four track-and-field coaches who trained three mixed youth athletics groups from Slovenia. The average age of the coaches was 34.50 years (SD=8.43; min=26 and max=44). On average, they had been working as coaches for 10.25 years (SD=6.60; min=3 and max=18). Further demographic data can be found in Table 1. Coaches were assigned identification codes (Table 1), used in the interpretation of the results (section Results).

Procedure

The study was approved by the Committee on Ethical Issues in Sport (University of Ljubljana, Faculty of Sport, Ljubljana, Slovenia) in February 2021 (number: 033-1/2021-2). Shortly afterwards,

Table 1. Demographic information of the groups

Club (group)	1	2	3
Coach's identification code	E	F	G, H
Number of sessions per week	2	2	3
Length of a session [min]	90	60	60
Coach's gender	F	F	F
Coach's age	39	44	29, 26
Coach's education/qualification	PE teacher[a]	Q. – 2nd level	Sports coaching graduates[a]
Coach – professional/amateur	A	P	P, A
Coach's experience coaching athletics [years]	13	18	7, 3
Male athletes [number]	11	9	8
Female athletes [number]	15	8	16
Athletes' age [Mean±SD]	9,45±0,60	8,60±0,83	9,20±0,56

Note. Group 3 had two coaches (G and H) because of the size of the group.
[a]Educated personnel (PE teachers, sports coaches) does not need a qualification to coach.

an introductory meeting was held for coaches and parents to inform them about the study and give them the opportunity to ask questions. The coaches, children and their parents then signed a consent form. From March to October 2021, the coaches participated in the CL training (see section Model fidelity).

The coaches conducted 30 consecutive training sessions following the experimental programme based on CL. The experiment lasted from November 2021 to April 2022 (the groups did not end at exactly the same time due to the different training conditions [see Table 1] and the COVID-19 pandemic). During that time, the coaches performed a reflective analysis after each training session and wrote it down. A semi-structured interview with each coach took place directly after the last training session of their athletics group.

Data collection

Qualitative data were collected to report on the children's and coaches' perceptions of CL: semi-structured interview with the coaches and *Post-Coaching Reflective Analysis* (PCRA). Quantitative data were collected using the *Cooperative Learning Validation Tool* (CLVT; Casey, Goodyear, & Dyson, 2015) to report on fidelity to the CL (see section Model fidelity).

Semi-structured interview. To investigate the coaches' attitude towards the CL and its actual implementation, we interviewed the coaches individually immediately after the last training session analysed. The cloud-based video conferencing service Zoom was used for this purpose. Each interview lasted between 20 and 30 minutes. We asked the coaches eight semi-structured questions related to: the idea of CL implementation in kids' athletics (*Present your view of CL implementation in kids' athletics.*); the differences between CL and DI (which they used before the study); how they experienced the CL training sessions; how CL influenced their pedagogical practice; the suitability of CL for coaching 9-11 year olds; the children's reaction to the new learning approach. The whole set of questions is available from the first author.

Post-coaching reflective analysis. The coaches were asked to answer five questions after each training session. The set of questions is a translated and modified version of the Post-Teaching Reflective Analysis (Dyson, 1994, quoted in Casey, et al., 2009: 422). It is available from the first author. We wanted to gain a deeper insight into the achievement of goals in different categories (*Did you achieve the learning goals you set? How do you know this? Explain using specific observations.*) that indicated the effectiveness of the CL and the most positive and negative things that happened during the training sessions from the coaches' perspective. The coaches answered five questions.

Data analysis

The coaches' responses from the interview and the PCRA were analysed using thematic analysis and constant comparison (Braun & Clarke, 2006). The interviews were recorded and transcribed verbatim. The responses from the interviews were carefully read through several times to get a sense of their meaning as a whole. The analysis continued with the coding of the data. Each relevant thought from the coaches was labelled with a composite marker (coach identification code and a sequential number) and a code. The codes were then sorted into nine categories so that six themes and three sub-themes could be identified.

The responses from the PCRAs were also read several times, but the analysis was slightly different. The categories were predetermined, according to the themes from the interviews. The coaches' thoughts were coded and assigned to the categories at the same time.

At this stage, the authors discussed the identified themes and tried to refine them accordingly. Finally, all analyses were merged and three main themes were identified: (a) *roles in the pedagogical process*, (b) *interpersonal and small-group skills*, and (c) *transition to CL and related challenges*.

Trustworthiness

Dependability of the results was enhanced by the involvement of an expert in qualitative methods who is familiar with this research but not directly involved in it (the second author). She scrutinised the logic behind the results and interpretations of the first author. We have attempted to fulfil Braun and Clarke's (2006) criterion of confirmability by producing a reflective, self-critical account. To meet the criterion of credibility, the interviewer tried to have an open and free dialogue with the coaches so that they could tell her how they actually experienced the learning journey through CL. During the experiment, we were in constant contact with the coaches. We met regularly remotely and communicated by phone and email to resolve various dilemmas, deepened the coaches' knowledge of CL and adapted the plan according to the circumstances. To support credibility, two member checks were also conducted (Bjørke, Standal, & Mordal Moen, 2021). In the first, the coaches received the interview transcripts back and had the opportunity to change or clarify various parts of the interviews. In the second member check, the coaches read a draft of the manuscript to verify the interpretations. They did not suggest any significant changes. Finally, we provided a detailed description of the programme context to ensure transferability (section Model fidelity).

Model fidelity

For the results of this study to be valid, it was necessary to demonstrate that the CL implementation met the standards for this model. To adequately understand the results, we reported on all three elements of model fidelity that should be considered when exploring educational approaches (Casey, et al., 2015; Hastie & Casey, 2014).

A rich description of the curricular elements of the unit. The first author prepared a thorough intervention programme. It started with the Introduction to CL, as coaches and children had to get used to their new roles (Casey, et al., 2015). The first unit started with cooperation games (icebreakers) that did not yet contain all the key elements of CL. The coaches added them gradually, in line with the programme (see Appendix A). In the second and third units, the coaches had to form permanent, heterogeneous (by gender, abilities, knowledge, psychosocial characteristics, friendships) groups of four (±1). The organization of the learning process was based on cooperative structures that determined how the children worked together and what their learning objectives were. Pairs-check-perform (Grineski, 1996; based on Kagan, 1992) was introduced first because learning in pairs is much easier than working in larger groups. Peer teaching was also promoted through learning teams (Johnson & Johnson 1994). Coaches had to assign specific roles to children (e.g., performer, tutor, timekeeper, referee, etc.) so that they learnt to take responsibility for part of a group task. Jigsaw (Grineski, 1996) was also frequently used for learning basic track-and-field skills, which were broken down into parts (subtasks). With *performer and coach earn rewards* (PACER; Kane & Kane Jr., 2004) we focused on improving running technique. Student teams-achievement divisions (STAD; Slavin, 1995) was the most complicated of all the structures used. Learners tried to make the most progress as a group, so they taught the other group members the correct technique. Collective score (Orlick, 1982) was mainly used to develop movement skills for sports skill learning (Kane & Kane Jr., 2004). Each structure was adapted for 8-11-year olds and used several times with different track-and-field skills. Only six different structures were used because the learners needed to become well acquainted with each of them before a new one was to be added (Grineski, 1996).

The cooperative structures promoted peer teaching and all five CL non-negotiables. The children were provided with learning materials, e.g., special flashcards with coordination exercises (PACER), so that face-to-face promotive interaction was encouraged. Positive interdependence and individual accountability were promoted by giving each member of a jigsaw group only one piece of information needed to complete a group task. PACER also emphasised positive interdependence, by requiring all members to reach a certain level of competence in coordination exercises before the group (consisting of two pairs) could play a game. Individual accountability was also promoted by publicly presenting both the group's progress and individual results (posters). As part of the affective goals, the interpersonal and small-group skills were defined separately for each training session (Appendix A). The coaches presented each skill to the children and they wrote it together on a special poster that accompanied them throughout the experiment. Group processing took place at the end of each session. It evolved from a coach-led discussion in the whole group to an independent debate in fixed groups.

A detailed validation of model implementation. To determine model fidelity, we recorded four randomly selected training sessions from each athletics group (Polvi & Telama, 2000; Zach, Cohen, & Arnon, 2020). Data were collected through systematic event coding of the 17 categories of the CLVT (Casey, et al., 2015) (see Appendix B). The observations were conducted by the first author. In the quantitative analysis of the CLVT data, the average percentages of each coded category were calculated.

The CLVT results showed that we achieved a satisfactory degree of CL model fidelity (Appendix B). All critical elements of CL were used in 75% of the sessions, but group processing was done in all sessions. Other key concepts of CL beyond the five non-negotiables (categories 2-6 in Appendix B) were also observed in about three-quarters of the recorded training sessions. We found that the percentage of the observed CL key elements would be even higher if the structures and non-negotiables were not gradually added. Student learning was assessed in each session and improvements were made in 92% of the sessions, reflecting high student engagement. The number of learning assessments and improvements observed was highest in the social or emotional domain. The CLVT revealed that social/emotional and cognitive goals were observed in 75% of the recorded sessions. However, physical goals were observed in every training session. We cannot claim that full fidelity was achieved in every session, and there are certainly examples highlighted by the CLVT that show variation in the degree of fidelity achieved. However, this moderate-to-high degree of fidelity to CL ensures an appropriate interpretation of the qualitative data collected in the study (Bjørke & Mordal Moen, 2020; Casey, et al., 2015).

A detailed description of the programme context that includes the previous experiences of the coaches and children with the model. The study was carried out in the Republic of Slovenia, a small country in central-southeast Europe with a population of 2.052 million. On 31st December 2021, 6534 young athletes, born in 2009, were registered at the Olympic Committee of Slovenia – Association of Sports Federations (OCS-ASF, 2022), 388 of them with the Slovenian Athletic Federation. The official language is Slovenian.

All coaches (except the first author) had only used the traditional approach (DI) before the study, so their athletes had no experience with CL. Prior to the first training session, a coach training for CL was conducted. We met five times from March to October and held two lectures and three workshops, totalling 20 hours. In the lectures, the coaches received a theoretical introduction to CL with its non-negotiables and structures. In the workshops, the coaches were given an initial insight into the intervention programme. The cooperative structures with athletic content were presented in practice. To check whether the learning had taken place, the coaches themselves tried to teach according to CL.

Results

To assess the suitability of CL for use in kids' athletics, we analysed coaches' experiences with CL and identified three main themes: (a) *roles in the pedagogical process*, (b) *interpersonal and small-group skills*, and (c) *transition to CL and related challenges*. The second theme is mainly concerned with the impact of CL on children's social learning.

Roles in the pedagogical process

The coaches talked about the roles in the training process more in the interviews. They all noted that the children had become much more independent in preparing the equipment, performing the exercises and learning with the help of peers and different learning materials. The coaches repeatedly emphasised the importance of involving the children in the organization of the training sessions: *The children took responsibility as they did the time keeping and recording of the results themselves… the most positive thing about this training was that the children learned how to use the stopwatch. I think it was a great achievement that the children read the instructions themselves and prepared the necessary equipment themselves.* (PCRA)

The coaches found the role of the child as tutor particularly interesting. They realised that the children came up with very good drills, for example to train the block start (PCRA). The coaches developed a positive attitude towards peer teaching because: *The pair work went smoothly most of the time. Before, I was the only person who corrected… in the CL, I also demonstrated occasionally, but giving feedback was mostly up to the children.* (PCRA, interview) The coaches also found peer teaching effective: … *the children gave each other feedback on their execution of the scissors, which was reflected in their technique*. (PCRA) Working together encouraged rational learning, which enabled children to recognise mistakes for themselves: *Through CL, where the children worked alone most of the time, they learned a lot… including what to look for when observing a performance of their partners.* (interview)

The active involvement of children in teaching and learning proved to be very useful in several ways: *Children who were present at the last session explained and demonstrated exercises for the members of the group who might have been absent last time.* (PCRA) The coaches reported that the children were very realistic when assessing each other. Independent learning also encouraged the children's creativity.

In CL I gave the children a free hand… I gave instructions and then they worked independently

– some of them better, others worse… (interview) The coaches have recognised that their role in the learning process has changed. They have become learning facilitators. This change in role was the most difficult thing for some of them. In the beginning, they had to hold back from directly instructing the children, but rather guiding them in the right direction. *Initially, I wanted to correct the children subconsciously. I had to hold back…* (interview) *When the children had difficulties and/or asked for help, it was very difficult not to immediately rush to their aid. I had to be patient because children learn more slowly...* (interview)

Interpersonal and small-group skills

Not only did *the young athletes significantly improve their understanding of CL over time*, but they also began to realise that *mutual help and cooperation are very important* – coach F noted this as early as the fifth training session. Another coach noted her observation: *The children realised that without the help and feedback of their partner(s) it is difficult to do an exercise correctly... or you just don't know if you have done it right* (PCRA). The coaches noted improvements in many interpersonal and small-group skills, e.g., cooperating with all peers, helping and respecting each other, communicating appropriately, giving feedback, contributing ideas and opinions, giving praise, etc. The coaches also observed that the children were friendlier to each other and that *they no longer despised their less skilful peers* (interview). As a result, they felt more comfortable in the athletics group than before the intervention. The coaches found that CL enabled all the children to be included: *I thought it was great that nobody was lonely. Now they all had to be active, but the traditional coaching method allowed individuals to be passive and skip...* (PCRA, interview) The coaches also noted that all conflicts were resolved cooperatively, which they really liked. *Before the experiment started, I eliminated disruptive children, but now we all confront each other and discuss what went wrong and how we can improve the situation…* (interview).

The coaches thus recognised positive effects of CL on the group climate, which they liked very much: *The collective score structure has strengthened cohesion… everyone was aware of their tasks and wanted improvements in the team, so the group members really helped each other...* (PCRA). One coach told us in the interview that she would recommend the CL to any coach, who felt that the climate in their group was not so good. The coaches saw better group cohesion compared to the traditional coaching approach: *It's useful because the children are more peer orientated… At the beginning of the experiment, for example, they didn't even know the names of the other group members… now they at least seem to know the names… it seems that they have mingled with the others.* (interview)

Transition to cooperative learning and associated challenges

The coaches had a positive attitude towards the chosen pedagogical model. They found it interesting and useful for their future coaching activities. What they particularly appreciated was the feeling of trust: *I think it's wonderful that I can trust the children when they work independently.* (PCRA) However, coach E noted that a large number of young athletes occasionally caused her problems with control: *I did not have as much control as I would have liked*. The coaches felt that the children enjoyed the CL training sessions, had fun, *generally did not get bored* (PCRA) and that they were interested (*Although some of them have a lot of energy, the activities seemed to interest them, otherwise they would not be so focused on the tasks*...).

Although the coaches recognised many positive aspects of CL, they stated that the implementation brought many concerns and difficulties in the transition to the new form of teaching (interviews). According to the coaches' comments, the children were not able to cooperate with their peers before the experiment began. *At home, at school and during leisure activities, the children were constantly guided by adults. Not only were they used to certain warm-up protocols, games, etc., but they also knew that a coach was the only one giving instructions, demonstrating, helping, giving feedback, controlling... Before the experiment began, the children were not used to taking on roles other than that of the performer. As a result, some children were at the beginning of the study extremely dependent and had difficulty putting themselves in the role of a coach; they felt uncomfortable when they had to observe their partner and give him/her feedback. They felt the same way during the group processing.* Considering that communication among peers is usually forbidden during the educational process, regardless of the setting, the children found it completely alienating at the beginning of the experiment, when the coach started to encourage communication among them about the learning activities. The coaches admitted that the Introduction to CL (the first unit) was necessary and very useful: *It seemed indispensable to have these ten training sessions that allowed us and the children to familiarise ourselves with the concept.* They reported that they needed time to adjust to a different way of thinking about teaching and learning.

On the other hand, as the children's initial curiosity waned over time, some of them showed a desire to return to the traditional approach. Some children were saturated with cooperation (and only cooperation) at every training session for more than three months.

Discussion and conclusions

The aim of our study was to use qualitative data to discuss the perspectives of athletics coaches who were confronted with CL for the first time. The coaches described their experiences and those of the children as predominantly positive. These results confirm the findings from a study by Velázquez Callado (2012). The children developed a positive attitude towards working in groups and cooperating. Goudas and Magotsiou (2009) and Bjørke and Mordal Moen (2020) also found greater affection for collaboration and less discomfort when working in groups.

CL helped to develop autonomous individuals. The coaches praised the division of roles, which influenced the acceptance of responsibility among all young athletes. However, by sharing responsibility, coaches recognised that their role in the learning process had changed. It is very important that children develop into autonomous individuals, but there should always be a teacher/coach to guide learners towards universal knowledge, even if the children follow their own learning paths (Biesta, 2012). The teacher/coach should also play a very important role in modern learning approaches. The coaches in our study perceived the changes in their role as very big, but they did not feel that it would become less important (interviews). Although each pedagogical model is based on a theoretical foundation, it can be applied in different ways (Casey, 2016). Considering that the Slovenian athletics coaches did not feel neglected, the learning was both athlete-centred and coach-centred (Hattie, 2009). This type of CL implementation improves the attitude of all participants towards the pedagogical model and the training process and has a positive effect on the group climate (Železnik Mežan, et al., 2023).

Although it appears that the coaches in our study view the children's autonomy as positive, one coach perceived control issues. The feeling of losing control over the children has its origins in old habits. By introducing CL methods, teachers and coaches need to change their attitudes and habits in teaching practice and transfer responsibility to the learners. Cochon Drouet and colleagues (2023) have also found that this can lead to a sense of loss of control and work overload. Therefore, training coaches in the use of cooperative methods is essential to support them in making these changes in practise.

The coaches reported that the children learnt many interpersonal and small-group skills. However, they had to work hard initially to teach these skills to the young athletes. As a result, the coaches noted improvements in group climate, which they felt was very positive. Although athletics is an individual sport, every athlete needs companions to help each other, celebrate successes, and comfort each other when things do not go as planned. Achieving positive interdependence is very complicated or even impossible in some cases. Silva and colleagues (2021) reported improvements in giving feedback among peers as a result of CL, but students did not trust and accept everyone.

According to the coaches' comments, the children were not used to cooperate with their peers before the experiment began. Similar findings were observed and reported by a teacher-as-researcher (Casey, et al., 2015) who admitted that things did not go as planned, especially at the beginning of the implementation. In the initial stages, groups were not focused and students had difficulty taking on different roles and cooperating with other group members. Silva and colleagues (2021) found that during the first AR-cycle, students were not able to use appropriate social skills, they had difficulty accepting others' opinions, and they were not able to resolve conflicts. Casey and colleagues (2009) also reported a difficult transition to CL, but from the students' perspective. The main reason why the children had difficulties with the transition to CL and sometimes expressed their unwillingness to cooperate could be the traditional, teacher-centred approach to which they are accustomed. It encourages competition and direct comparison between peers (Grineski, 1996). The success of CL could be related to the motivational climate of an environment that includes a teacher/coach (Zach, et al., 2020).

The willingness to cooperate, observe peers, give feedback, share ideas, etc., is also determined by the personality of the individual. In order to maintain a cooperative climate, some character adjustments of the learners are necessary. And these take time. CL is a complex model that needs time to be implemented effectively and allow students to realise its potential. Goodyear's findings (2017) suggest that initial difficulties can be overcome with time, experience and support if teachers gradually adapt CL methods to students' learning needs.

The coaches found the idea of introducing CL in kids' athletics very good and useful. They told us that they would definitely use CL in the future. However, they agreed not to use it in every training session. These findings seem to be very important for the development of CL and coaching approaches in youth sport in general. Even if a particular coaching approach proves to be effective – through its impact on athletes' learning and development – this does not mean that coaches will use it.

Therefore, we can conclude that CL is a suitable pedagogical model that can also be used in youth sport, but we would suggest combining it with other pedagogical models. The coach should judge for themselves which learning objectives and content are suitable for this type of delivery and which can be learnt in the old way (or using another approach). Furthermore, coaches should undergo additional training for CL so that they fully understand their role in the pedagogical process and can counteract the feeling of loss of control.

This study makes an important scientific contribution, whereas previously there was only one study dealing with CL in sport (Železnik Mežan, et al., 2023). The results proved the effectiveness of the model and also brought in the coaches' experiences with CL, which should be taken into account when implementing the model. In the future, it would be very useful to repeat the study with other coaches to investigate whether the experiences are consistent with those presented. It would also be interesting to measure retention. Next time, we would analyse the PCRAs regularly to adjust the training process accordingly. Future research should also focus on other sports.

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Correspondence to:
Lea Železnik Mežan, Ph.D.
University of Ljubljana, Faculty of Sport
Gortanova 22, 1000 Ljubljana
Phone: 00386-40-653-665
E-mail: lea.zeleznik@fsp.uni-lj.si

MATCH PEAK SPEED ACROSS A SOCCER SEASON: THE INFLUENCE OF PLAYING POSITION, COMPETITION, MATCH OUTCOME, AND MATCH LOCATION

Hugo Silva[1,2], Fábio Yuzo Nakamura[1,2], António Gómez-Diaz[3,4], Pedro Menezes[3], and Rui Marcelino[1,2,5]

[1]*Research Center in Sports Sciences, Health Sciences and Human Development—CIDESD, University of Maia, Maia, Portugal*
[2]*University of Maia, Maia, Portugal*
[3]*Clube de Regatas do Flamengo, Rio de Janeiro, Brazil*
[4]*Spanish Football Federation (RFEF), Madrid, Spain*
[5]*Portugal Football School, Portuguese Football Federation, Oeiras, Portugal*

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Abstract:

This study compared match peak speeds (MPS) across a full season considering different playing positions, competitions, match outcomes, and match locations. Thirty-one elite male soccer players were monitored during matches using global navigation satellite system devices. Independent mean differences [95% confidence intervals] were calculated for the investigated variable (MPS). Fullbacks reached higher MPS than central defenders (CD) (d=0.78 [0.56, 1.00]), central midfielders (CM) (d=-0.75 [-0.93, -0.57]) and forwards (d=-0.32 [-0.55, -0.08]); wide midfielders reached higher MPS than CD (d=0.66 [0.43, 0.90]) and CM (d=0.64 [0.45, 0.84]); and forwards reached higher MPS than CD (d=0.46 [0.22, 0.71]) and CM (d=0.41 [0.21, 0.62]). Higher MPS were reached during the National League than the National Cup (d=-0.38 [-0.58, -0.19]) and the Supercup (d=-0.57 [-1.09, -0.06]); higher MPS were reached during the State Cup than the National Cup (d=-0.32 [-0.55, -0.09]) and the Supercup (d=-0.57 [-1.12, -0.05]); and higher MPS were reached during the International Cup than the National Cup (d=0.26 [0.04, 0.48]). Higher MPS were reached during matches lost than won (d=0.19 [0.03, 0.35]). Playing position was the highest differentiator of MPS across a soccer season, underlining the importance of players' individualization when assessing MPS or when calculating normalized speed thresholds. MPS can also vary between competitions, especially if teams face lower division teams.

Keywords: *contextual factors, football, outcome, sprint, velocity*

Introduction

Soccer match performance is usually assessed using various variables, such as global positioning system (GPS) data, including total distance, high-intensity and sprint distances, as well as acceleration and deceleration, each providing information on different aspects of locomotor performance. Among these variables, high-speed movements are increasingly receiving attention from both practitioners and researchers (Gualtieri, Rampinini, Dello Iacono, & Beato, 2023). First, high-speed movements might create goal-scoring opportunities (Faude, Koch, & Meyer, 2012) and second, these efforts might place players at higher risk of muscle injuries (Gregson, et al., 2020). To measure these efforts, practitioners usually apply absolute and arbitrary thresholds disregarding player's individuality (Sweeting, Cormack, Morgan, & Aughey, 2017). That is, when a player surpasses a specific threshold (such as > 25.2 km/h), practitioners usually assess the load as the number of actions, or the distance covered above that threshold (Gualtieri, et al., 2023). This strategy is replicated for all players, regardless of their different capacities.

To address this issue, authors have proposed relative thresholds (i.e., distance covered above a pre-established threshold, which refers to a percentage of the individual maximal effort), by considering players' maximum speeds obtained in field conditions (Gualtieri, Rampinini, Sassi, & Beato, 2020; Hennessy & Jeffreys, 2018). Briefly, practitioners can choose to classify efforts based on the maximum speed obtained during standardized field sprint (Hennessy & Jeffreys, 2018), or based on the match peak speed (Gualtieri, et al., 2020). The first strategy can raise one additional concern since players rarely replicate the maximal field tests' speeds during matches (Buchheit, Simpson, Hader, & Lacome, 2021). However, using match peak speed as reference to calculate a normalized threshold (calculated as a percentage of the individual match peak speed) raises the question regarding intra-individual and inter-match variability. For instance, while the match peak speed appears to remain stable across a full season (1.5% between-match, 2.8% between-player, 3.0% between-position, and 4.9% within-player) (Oliva-Lozano, Muyor, Fortes, & McLaren, 2021), previous research has highlighted differences between playing positions, with wide positions and forwards reaching higher speeds (Aquino, et al., 2017).

Of note, across a soccer season, players face different contextual variations which can influence the measured load. For example, previous studies have reported that players differ their intense displacements according to the match outcome and location (Chmura, et al., 2018; Morgans, et al., 2025; Nobari, Banoocy, Oliveira, & Pérez-Gómez, 2021). However, higher distances during won matches may be covered with ball possession, while teams that are losing may cover higher distances at high speeds without ball possession, in an attempt to recover from the negative result (Trewin, Meylan, Varley, & Cronin, 2017). Importantly, these reported differences between contexts use absolute and arbitrary thresholds which can limit the individualization (Gualtieri, et al., 2023). Therefore, if practitioners apply normalized thresholds with the match peak speed as the reference value, different findings may arise. For instance, one study has recently reported no significant differences in match peak speed while comparing the same players in different competitions (Freire, et al., 2022). Increasingly, previous research reported that external midfielders (30.4±2.3 km/h), forwards (30.4±3.7 km/h), and external defenders (29.9±2.2 km/h) reached higher match peak speed than central defenders (27.1±3.2 km/h) and central midfielders (26.8±4.0 km/h) (Aquino, et al., 2017). By knowing what contextual factors may impact the expression of the match peak speed, practitioners can therefore consider if applying the match peak speed as a reference to classify high-speed efforts intensity is indeed adequate. Therefore, this study has two main objectives: a) to analyze intra-individual and inter-match variability in peak match speeds across a full season, considering players' positions in relation to the type of competition, match outcome, and match location; and b) to compare differences in peak match speeds based on these same contextual factors.

Methods

Participants

From an initial sample of forty-four (*n*=44) male players, thirty-one (*n*=31) elite players (McKay, et al., 2022) were selected to participate in this study. As for inclusion criteria, a minimum of five matches and playing at least 10 minutes per match were required. These inclusion criteria were established to avoid the inclusion of sporadic participation of young players in the senior team (minimum of five matches), and to exclude short match-participations that can limit the opportunity of players to reach higher speeds (≥ 10 minutes). Goalkeepers were excluded due to the particularities of their position. Mean ± standard deviation (M±SD) age, body height and weight was 27.6±5.2 years, 180.5±6.2 cm, and 74.6±6.7 kg, respectively. Players were divided by their playing position as central defenders (CD; *n*=6), fullbacks (FB; *n*=6), central midfielders (CM; *n*=11), wide midfielders (WM; *n*=5), and forwards (FW; *n*=3). From the 77 matches disputed by the team, participants participation ranged from 5 to 59 matches, with M±SD of 31.9±15.9. An *a priori* analysis was conducted with G*Power 3.1, requiring a minimum of 400 observations. From the retrieved files, 989 observations (match peak speeds) were considered. Total observations were 989 files. Ethics Committee clearance was obtained (35/2021) and the study was conducted in accordance with the Declaration of Helsinki.

Procedures

One top-level Brazilian team was monitored during the full 2022 season, from January to November. During this period, the club competed in five competitions: the State Cup (Carioca), the National League (Brasileirão), the National Cup (Copa do Brazil), the National Supercup (Supercopa do Brazil), and an International Cup (Libertadores da América). Across the season, all players were monitored with a 10 Hz global positioning system (WIMU PRO™ – Realtrack Systems) that encompassed a double constellation system (Global navigation satellite system [GNSS] and global positioning system [GPS]) and included triaxial high-resolution accelerometers (1,000 Hz), as a standard procedure. This device was certified by Federation Internationale de Football Association (FIFA) (Certification number: 1004497) and previously considered valid (Gómez-Carmona, Bastida-Castillo, García-Rubio, Ibáñez, & Pino-Ortega, 2019) and reliable for sprint monitoring (intra-class correlation coefficient [ICC]: 0.935) (Bastida Castillo, Gómez Carmona, De la Cruz Sánchez, & Pino Ortega, 2018). Devices (dimensions: 81x45x16 mm) were secured between the upper scapulae, at approximately the T3-T4 junction in a pocket of a specific chest vest and were activated 15 minutes before use, in accordance with the manufacturer's instructions. To avoid interunit errors, each player used the same WIMU device throughout the data collection period. Match data were retrieved from the GPS software (WIMU SPRO) as speed (km/h), with the match peak speeds being selected as the highest speed achieved for each player and during each match.

Four variables were selected to investigate potential differences in match peak speeds: differences between playing positions (CD, FB, CM, WM, FW), differences between competitions disputed by the team (National League [matches: *n* = 33; observations: *n* = 474], State Cup [matches: *n* = 12; observations: *n* = 139], National Cup [matches: *n* = 10; observations: *n* = 139], Supercup [matches: *n* = 1; observations: *n* = 15], and International Cup [matches: *n* = 13; observations: *n* = 190]), differences between matches outcomes (wins [matches: *n* = 42; observations: *n* = 608], draws [matches: *n* = 13; observations: *n* = 187] or losses [matches: *n* = 14; observations: *n* = 194]), and differences between match locations (home [matches: *n* = 35; observations: *n* = 504], neutral [matches: *n* = 3; observations: *n* = 43] or away [matches: *n* = 31; observations: *n* = 442]).

Statistical analysis

All analyses were performed with Microsoft Excel (Microsoft Corporation; Version 16.68) and jamovi (The jamovi project, 2022, version 2.3). Means ± SDs were calculated for each variable, considering the possible contexts or playing positions. For example, match peak speed means ± SDs were calculated for wins, draws and losses, within the match outcome variable. Additionally, coefficients of variance (CV) were calculated individually for all players (intra-individually), and for all variables (playing position, competition, match outcome, and match location) by using the formula:

Coefficient of Variation = (SD / Mean) * 100.

Potential differences within each variable (playing position, competition, match outcome, and match location) were estimated with an independent groups design (Cumming & Calin-Jageman, 2016), using independent mean differences with 95% confidence intervals. Here, the match peak speed was categorized as the dependent variable while the grouping variable was used for each variable. Cohen's *d* with 95% CI was established as trivial (<0.2), small (0.2<0.6), moderate (0.6<1.2), large (1.2<2.0), very large (2.0<4.0), extremely large (>4.0), and unclear (when CI crossed both positive and negative values; p>.05) (Batterham & Hopkins, 2006). Significance was established at p<.05.

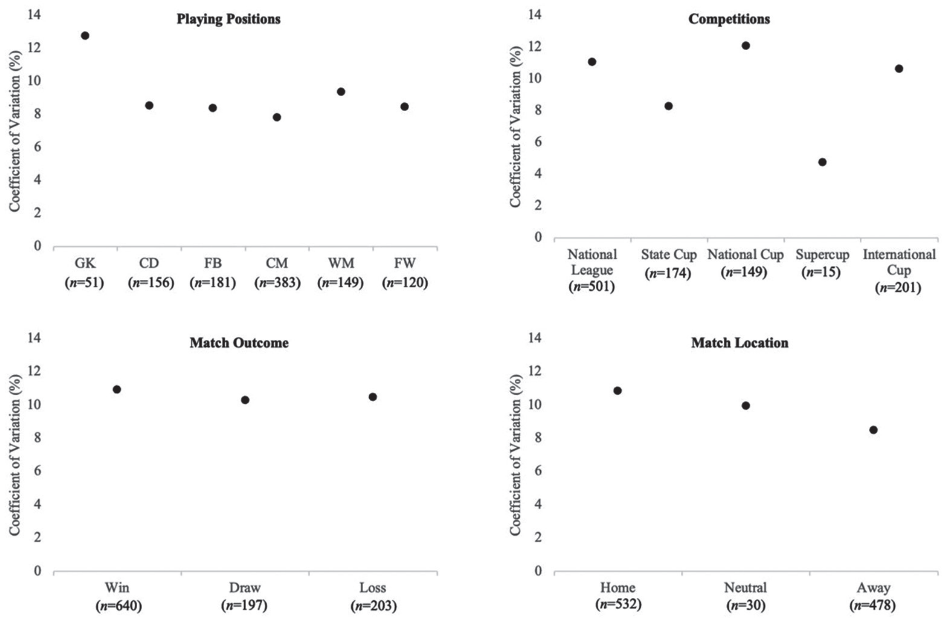
Results

In Table 1, M±SD of match peak speeds are presented, according to the specific variable (playing position, competition, match outcome, and match location). Intra-individual CV ranged from 4 to 12% (Figure 1). Comparisons of the achieved match peak speeds within each variable presented clear differences (p<.05), which are presented in Table 2, and represented—with the effect sizes of the differences—in Figure 2. Except for match location, differences were found in all the variables. Specifically, regarding playing positions, FB reached higher match peak speeds than CD (d=0.78 [0.56, 1.00], moderate effect size, p<.001), CM (d=-0.75 [-0.93, -0.57], moderate effect size, p<.001) and FW (d=-0.32 [-0.55, -0.08], small effect size, p=.008); WM reached higher match peak speeds than CD (d=0.66 [0.43, 0.90], moderate effect size, p<.001) and CM (d=0.64 [0.45, 0.84], moderate effect size, p<.001); and FW reached higher match peak speeds than CD (d=0.46 [0.22, 0.71], small effect size, p<.001) and CM (d=0.41 [0.21, 0.62], small effect size, p<.001). Regarding competitions,

Table 1. Match peak speeds (km/h) according to the analyzed variables (playing position, competition, match outcome, and match location)

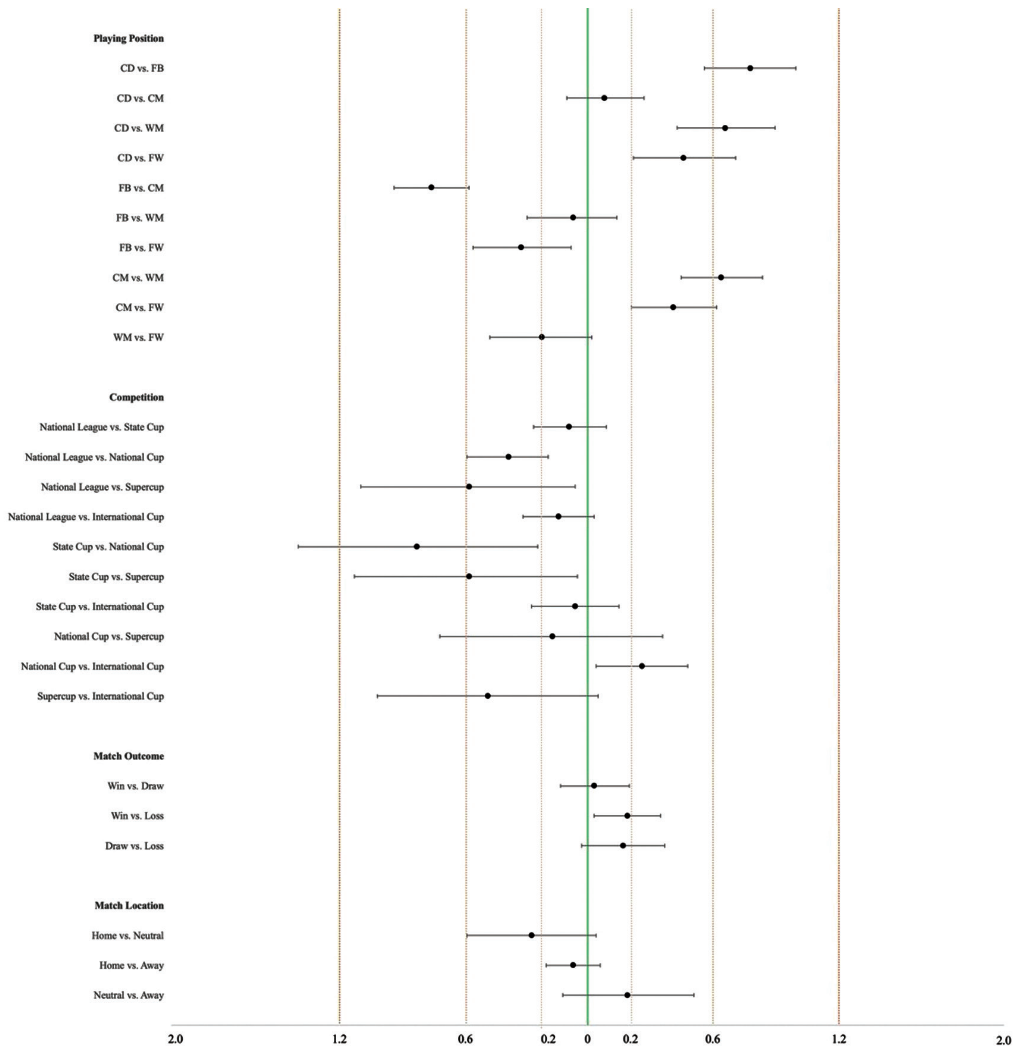
Variable	Means ± SD				
Playing position	CD (*n*=156)	FB (*n*=181)	CM (*n*=383)	WM (*n*=149)	FW (*n*=120)
	28.70±2.46	30.66±2.58	28.90±2.26	30.46±2.85	29.86±2.53
Competition	National League (*n*=474)	State Cup (*n*=171)	National Cup (*n*=139)	Supercup (*n*=15)	Int. Cup (*n*=190)
	29.82±2.67	29.60±2.29	28.78±2.83	28.31±1.39	29.45±2.45
Match outcome	Win (*n*=608)	Draw (*n*=187)	Loss (*n*=194)		
	29.43±2.65	29.51±2.43	29.93±2.59		
Match location	Home (*n*=504)	Neutral (*n*=43)	Away (*n*=442)		
	29.65±2.55	28.97±2.24	29.47±2.69		

Note. CD=central defenders; FB=fullbacks; CM=central midfielders; WM=wide midfielders; FW=forwards; Int=International. *n*=number of files.



Note. CD=central defenders; FB=fullbacks; CM=central midfielders; WM=wide midfielders; FW=forwards.

Figure 1. Individual coefficient of variation (%) of match peak speeds across the season, for each variable.



Note. CD=central defenders; FB=fullbacks; CM=central midfielders; WM=wide midfielders; FW=forwards.

Figure 2. Effect sizes [95%] of independent mean differences according to the analyzed variables (playing positions, competitions, match outcome, and match location).

Table 2. Independent mean differences [95% CI] with effect sizes (d) [95% CI]) within the analyzed variables (playing position, competition, match ooutcome, and match location).

Playing position	CD (*n*=156)	FB (*n*=181)	CM (*n*=383)	WM (*n*=149)	FW (*n*=120)
CD	-	1.96 [1.42, 2.50] *d*=0.78 [0.56, 1.00] *p*<.001	0.19 [-0.24, 0.63] *d*=0.08 [-0.10, 0.27] *p*=.378	1.76 [1.16, 2.36] *d*=0.66 [0.43, 0.90] *p*<.001	1.15 [0.56, 1.75] *d*=0.46 [0.22, 0.71] *p*<.001
FB			-1.77 [-2.19, -1.35] *d*=-0.75 [-0.93, -0.57] *p*<.001	-0.20 [-0.79, 0.39] *d*=-0.07 [-0.29, 0.14] *p*<.502	-0.81 [-1.40, -0.22] *d*=-0.32 [-0.55, -0.08] *p*=.008
CM				1.56 [1.10, 2.03] *d*=0.64 [0.45, 0.84] *p*<.001	0.96 [0.48, 1.44] *d*=0.41 [0.21, 0.62] *p*<.001
WM					-0.61 [-1.26, 0.05] *d*=-0.22 [-0.47, 0.02] *p*=.069
Competition	**National League (*n*=474)**	**State Cup (*n*=171)**	**National Cup (*n*=139)**	**Supercup (*n*=15)**	**International Cup (*n*=190)**
National League	-	-0.22 [-0.68, 0.23] (*d*=-0.09 [-0.26, 0.09]) *p*=.330	-1.04 [-1.55, -0.53] (*d*=-0.38 [-0.58, -0.19] *p*<.001	-1.51 [-2.88, -0.15] *d*=-0.57 [-1.09, -0.06] *p*=.029	-0.37 [-0.81, 0.07] *d*=-0.14 [-0.31, 0.03] *p*=.100
State Cup		-	-0.82 [-1.39, -0.24] *d*=-0.32 [-0.55, -0.09] *p*=.005	-1.29 [-2.48, 0.10] *d*=-0.57 [-1.12, -0.05] *p*=.034	-0.15 [-0.64, 0.35] *d*=-0.06 [-0.27, 0.15] *p*=.565
National Cup			-	-0.47 [-1.94, 0.99] *d*=-0.17 [-0.71, 0.36] *p*=.524	0.67 [0.10, 1.25] *d*=0.26 [0.04, 0.48] *p*=.022
Supercup				-	-1.15 [-2.41, 0.12] *d*=-0.48 [-1.01, 0.05] *p*=.076
Match outcome	**Win (*n*=608)**	**Draw (*n*=187)**	**Loss (*n*=194)**		
Win	-	0.08 [-0.34, 0.51] *d*=0.03 [-0.13, 0.20] *p*=.706	0.50 [0.08, 0.93] *d*=0.19 [0.03, 0.35] *p*=.021		
Draw		-	0.42 [-0.09, 0.93] *d*=0.17 [-0.03, 0.37] *p*=.103		
Match location	**Home (*n*=504)**	**Neutral (*n*=43)**	**Away (*n*=442)**		
Home	-	-0.68 [-1.47, 0.11] *d*=-0.27 [-0.58, 0.04] *p*=.089	-0.18 [-0.51, 0.16] *d*=-0.07 [-0.20, 0.06] *p*=.298		
Neutral		-	0.51 [-0.33, 1.34] *d*= 0.19 [-0.12, 0.51] *p*=.233		

Note. CD=central defenders; FB=fullbacks; CM=central midfielders; WM=wide midfielders; FW=forwards; *n*=number of files.

higher match peak speeds were reached during the National League in comparison with the National Cup (*d*=-0.38 [-0.58, -0.19], small effect size, *p*<.001) and with the Supercup (*d*=-0.57 [-1.09, -0.06], small effect size, *p*=.029); higher match peak speeds were reached during the State Cup in comparison with the National Cup (*d*=-0.32 [-0.55, -0.09], small effect size, *p*=.005) and with the Supercup (*d*=-0.57 [-1.12, -0.05], small effect size, *p*=.034); and higher match peak speeds were reached during the International Cup in comparison with the National Cup (*d*=0.26 [0.04, 0.48], small effect size, *p*=.022). Finally, higher match peak speeds were reached when the team lost in comparison with matches won (*d*=0.19 [0.03, 0.35], trivial effect size, *p*=.021).

Discussion and conclusions

This study compared match peak speeds across a full season regarding four variables: playing positions (central defenders [CD], fullbacks [FB], central midfielders [CM], wide midfielders [WM], and forwards [FW]), the different competitions disputed by the team (National League, State Cup, National Cup, Supercup, and International Cup), match outcomes (wins, draws or losses), and match locations (home, neutral or away). The main findings of this study were that match peak speeds presented a coefficient of variation (CV) between 4% and 12% and match peak speeds mostly differed between playing positions and competitions than between match outcomes (only one difference with trivial effect size) and match locations (no differences).

Intra-individual CV ranged from 4 to 12%, with most players (90%, *n*=28) showing variations <10%. Although our CV range surpassed previous research reports of 4.9% within-players (Oliva-Lozano, Muyor, et al., 2021), it is closer to the CV range that accounts for players' positions (3-10%) (Al Haddad, Méndez-Villanueva, Torreño, Munguía-Izquierdo, & Suárez-Arrones, 2018). In the latter study, second strikers and fullbacks reported the lowest and highest CV, respectively, although the authors divided the CV for each part of the match. However, both studies presented the CV from all players or from all players for each playing position. Although there is no golden standard regarding CV, it is important to notice that this value is highly dependent on the sample size (Bedeian & Mossholder, 2000), which was partially seen in the data of this study (Figure 1). This means that match peak speeds remained fairly regular throughout the full season.

Match peak speeds have been brought to attention by recent research as a potential tool to apply normalized thresholds in order to classify high-speed displacements (Aiello, et al., 2023; Gualtieri, et al., 2023; Silva, Nakamura, Loturco, Ribeiro, & Marcelino, 2024). Notwithstanding, while sprint tests can provide important information, referring to peak speeds registered during tests can fail to consider the context (Kyprianou, et al., 2022) and displacement dynamics (Silva, et al., 2025). The current study contributes to this debate by highlighting specific variables that impact the match peak speed, with a special reference to playing positions and competitions. Differences between playing positions have been widely investigated with wide positions reaching higher match peak speeds than their teammates (Aquino, et al., 2017; Djaoui, Chamari, Owen, & Dellal, 2017; Massard, Eggers, & Lovell, 2018), which aligns with the findings of this study (Table 2). The reasoning for this is based on the players' capacities and the context. For instance, Djaoui et al. (2017) compared peak speeds achieved during sprint tests and competition, according to the players' positions. In that study, the authors reported higher peak speeds reached by FB, WM and FW in both scenarios, which highlights that the players' capacities were replicated, even with lower speeds, during competition. However, matches can also impact how players can expose their capabilities as shown by Al Haddad et al. (2015), where youth players decreased their relative peak speed (i.e., match peak speed as a percentage of the tested peak speed) as they approached adulthood. This highlights the importance of match context, which is analyzed in this study with competition, outcome, and location.

Regarding the different competitions, lower match peak speeds were found during the National Cup matches in comparison with the National League, State Cup, and International Cup matches (Table 2). The current findings differ from the findings reported by Freire et al. (2022), which considered the same competitions (except for the Supercup) in the same country. In the latter study, the authors reported non-significant differences (p=.408) of match peak speeds registered during the different competitions. Although team differences could explain our different findings, it is important to notice that, contrary to other competitions, the National Cup enables elite teams to face lower division teams, which occurred with the monitored team in this study. Considering that facing high-level opponents increase the high-intensity demands (Folgado, Duarte, Fernandes, & Sampaio, 2014), players may play matches against lower-level opponents with lower intensities, thus lowering the values of those matches' peak speeds. Nevertheless, all differences presented small effect sizes. Of note, caution is needed when extrapolating findings from the Supercup, due to the small sample size (as seen by the confidence intervals). This type of competition is usually played as an isolated match during the season, between the winners of the national leagues and cups, making the sample enlargement difficult. Moreover, since teams can change from season to season, researchers could potentially need to monitor several teams across different seasons to achieve a larger sample size. However, since comparisons between competitions were made individually (i.e., without an overall analysis such as an analysis of variance), this limitation is specific to the comparisons with this competition. The decision to include this competition allows for further comparisons since it is played in a neutral location.

Interestingly, similarities were found between peak speeds achieved during matches played at different locations. Previously, Oliva-Lozano, Rojas-Valverde, Gómez-Carmona, Fortes, and Pino-Ortega (2021) reported no differences of match peak speeds when comparing matches outcomes (wins, draws and losses) and match locations (home and away) of a Spanish first division team. Increasingly, Nassis (2013) also reported similar match peak speeds recorded during the FIFA World Cup 2010, where players competed at sea-level and altitude (up to 1753m). The current study presents a novel finding by reporting similarities with neutral location.

Regarding the match outcome, only one difference was registered, although with a trivial effect size: players achieved higher peak speeds during matches they lost in comparison with the matches won. This aligns with previous research (Oliva-Lozano, Rojas-Valverde, et al., 2021), and is probably explained with the match variability of high-speed displacements (Gregson, Drust, Atkinson, & Salvo, 2010). Notwithstanding, while it would be possible to speculate that players would achieve higher speeds to counter a disadvantage outcome, or to regain ball possession, previous research has reported similar peak speeds between teams with high or low percentages of ball possessions, including comparisons within playing positions (Bradley, Lago-Peñas, Rey, & Gomez Diaz, 2013). Although peak speeds are lower if players sprint with the ball (Carling, 2010), ball possession appears not to be the reason to justify potential differences of match peak speeds (Bradley, et al., 2013).

Importantly, three main limitations of this study should be addressed. First, and as previously mentioned, the number of observations of the Supercup matches prevented definite conclusions, or assessing the interaction between different variables, and an extended monitoring period or merging different teams could ensure more observations. Secondly, although practitioners can always collect the match peak speed from competition (as the highest speed achieved), players rarely achieve their tested maximal speeds (Buchheit, et al., 2021; Djaoui, et al., 2017), showing that this analysis should include tactical approaches and the effort dynamics. And finally, this study analyzed one team that reached later stages of all competition disputed, thereby translating to a specific scenario. Future studies should assess potential variations in match peak speeds in different contexts, including different competitions and considering national teams. For the latter, this could be of major importance, as final phases of the major competitions are disputed in a specific location.

According to the findings of this study, practitioners can use the match peak speed as a reference value to calculate a normalized displacement threshold. This would consider the differences in match peak speed found between playing positions. Importantly, this strategy would benefit match load monitoring by providing data that account for players' individuality and the real scenario, instead of unique situations registered during field tests. While soccer matches also present an absolute component, (i.e., coaches want their players reaching the ball before the opposition) (Hunter, et al., 2015) and practitioners can assess if training sessions are eliciting maximal speeds developments (Haugen, Seiler, Sandbakk, & Tønnessen, 2019), monitoring match load exclusively with the absolute approach would result in different intensities for different players (Sweeting, et al., 2017). Importantly, achieving high-speed efforts—such as exceeding 90% or 95% of an individual's absolute peak speed—during training may play a key role in reducing the risk of hamstring injuries (Gómez-Piqueras & Alcaraz, 2024). While normalized thresholds can provide a more accurate representation of match loads based on individual movement profiles, absolute peak speeds remain essential for the broader operationalization and monitoring of physical capacities in soccer.

However, practitioners should consider that match peak speeds can also differ during matches of National Cups, as teams can face opposition from lower divisions, and if their team wins or loses. Therefore, match peak speeds should periodically be assessed to ensure that the reference value was not exceptionally different due to the competition or the outcome. Therefore, when calculating normalized thresholds, practitioners should account for the context. According to the current findings, while the differences between playing positions would be accounted for with an individualized approach, practitioners should also consider that the reference value can change according to the competitions. For example, if practitioners choose a normalized threshold of 80% of players' match peak speed (Aiello, et al., 2023; Silva, et al., 2024), that value could differ if it is collected during the national league or the national cup matches. Accounting for the match peak speeds here reported, an 80% relative threshold for the national league would be 23.9 km/h (i.e., 80% of 29.82 km/h), while for the national cup it would be 23.0 km/h (i.e., 80% of 28.78 km/h). Increasingly, by acknowledging these differences, the coaching staff can prepare tactical strategies according to the expected peak speeds according to each context.

In conclusion, players' position is the highest differentiator of match peak speeds throughout a soccer season, which underlines the importance of players' individualization when assessing match load. Although competitions and outcomes resulted in small and trivial differences in match peak speeds, respectively, that could be related to the possibility of teams to face lower-league opponents. The findings of this study support the idea that match peak speeds can be used as a reference to establish normalized and individualized thresholds, as playing positions were the main reason for the reported differences in match peak speeds, which means that an absolute threshold would represent a different effort for each playing position.

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Correspondence to:
Hugo Silva, Ph.D.
Department of Physical Education and Sports Sciences, University of Maia
Av. Carlos de Oliveira Campos, 4475-690 Maia, Portugal
Email: hugorodriguessilva.35@gmail.com

EFFECTS OF TWO PSYCHOMOTOR PROGRAMMES BASED ON DIFFERENT LEARNING ENVIRONMENTS ON CHILD DEVELOPMENT

Yulmis Isabel Rodríguez-Guerrero[1], Pedro Gil-Madrona[1], Luz Marina Méndez-Hinojosa[2], Carlos Montoya-Fernández[1], and Teresa Rodríguez-Martínez[1]

[1]*Faculty of Education of Albacete, University of Castilla-La Mancha, Spain*
[2]*The Autonomous University of Nuevo León, Monterrey, Mexico*

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Abstract:

The aim of the study was to analyse the effect of two motor intervention programmes, based on two different learning environments, on relevant dimensions in early childhood education: motor development, language development, mathematical thinking, motivation, and character. The research was conducted as a pilot study with children aged 4-5 years, based on a quasi-experimental group comparison design with pretest and post-test. The learning environment of the first group (n = 26) was based on Colombian legends, while the learning environment of the second group (n = 18) was based on the teacher's playful pedagogical project. For data collection a sociodemographic data record sheet, the Utrecht and TEPSI tests, and the EMAPI were used. The results showed improvements in both groups in the explored dimensions, with the most significant changes occurring in the group whose learning environment was based on the teacher's playful pedagogical project. These results confirm that motor intervention programmes in Physical Education have a positive impact on child development in early childhood education.

Keywords: *Physical Education, language development, mathematical thinking development, motivation, early childhood education*

Introduction

The importance of development during early childhood (prenatal stage up to eight years of age) is crucial for optimal physical and mental growth and well-being (WHO & UNICEF, 2012). During the last decades, the school environment has prioritized motor activities as a scenario for the promotion of different social skills and emotional competencies, i.e., linking motor development with the different dimensions that make up the infant stage. Thus, numerous studies highlight the importance of motor development in the maturation processes of the infant stage (Cuesta, Prieto-Ayuso, Gómez-Barreto, Barrera, & Gil-Madrona, 2016; Madrid, Prieto-Ayuso, Samalot, & Gil-Madrona, 2016; Saiz, Prieto-Ayuso, Gutiérrez, & Gil-Madrona, 2016).

Accordingly, the development of motor skills is a fundamental tool by which infants develop holistically and can express, integrate, communicate, and live different experiences that will allow them to learn more deeply the world around them, achieving independence and emotional stability, allowing them to discover their own abilities, as well as developing the motor, personal, social, and cultural skills (Gutiérrez, Fontela, Cons, & Rodríguez, 2017).

Studies such as Bodrova, Leong, and Yudina (2023) parameterizes play as a fundamental element in the progress of children's psychomotor, socioemotional and cognitive skills. Additionally, it contributes to the pedagogical practice of teachers and gives the necessary value to playful and corporal learning in a joint way. Therefore, it is important to promote positive physical activity habits from early education, which stimulate motor development and different movements, benefiting the child in the process of their life, and motivating them to be physically active during their life (Stodden, et al., 2008). Hence, the activity from Physical Education in the early childhood education stage becomes a key element for the improvement of children's relationships with the external world (Teixeira, Abelairas, Arufe, & Pazos, 2015).

In this context, the design and implementation of a motor intervention programme can favour the development of children's physical and academic abilities, as teachers can plan, adopt protocols and generate intervention strategies, both individual and collective, that can enable better motor and academic performance in their students (Vidarte-Claros, Vélez, & Parra-Sánchez, 2018). Following this trend, studies such as those by Cárdenas, Burbano, and Valdivieso (2019) show the positive and significant effects of a motor intervention programme on the coordination skills of preschool children.

Thus, countries such as Spain attach great importance to motor, affective, and social development during the early childhood stage, as stated in the *Decree 80/2022, of July 12, establishing the organization and curriculum of early childhood education in the autonomous community of Castilla-La Mancha* (Department of Education, Culture and Sports of Castilla-La Mancha, 2022). However, in countries such as Colombia and Brazil, despite all the epistemological and legal advances obtained by the reflection on early childhood education in the last decades, it is difficult to recognize the distinctiveness of Physical Education in early childhood education, which discipline is non-existent in the state policies aimed at the subject. Its legality, guaranteed by the legislation in Brazil and Colombia, is not sufficient for its recognition in institutions related to early childhood education (Almeida, da Silva, & Eusse, 2018). Consequently, motor experiences in early childhood education must be firmly grounded, and it is imperative to justify their inclusion in school education, especially during the early years (Gil-Madrona, Contreras, Díaz, & Lera, 2006).

In this regard, Piña, Ochoa, and Sáenz-López (2020) recently demonstrated a positive influence of a Physical Education programme at moderate intensity on motor development improvement in preschool children. Osorio, Piquer, Bartoll, and Capella-Peris (2019) determined the impact of a comprehensive physical activity programme on the gross motor skills of children with functional diversity. The statistical test results showed an improvement in the gross motor skills of the children and highlighted the benefits in cognitive function and learning. Beyond the psychomotor domain, different studies have demonstrated the interrelation between motor and cognitive development, alluding to the systematisation of motor activity as a means of favouring cognitive processes, such as mathematical thinking and language (Macdonald, Milne, Pope, & Orr, 2021; Mas, Jiménez, & Riera, 2018; Zeng, et al., 2017). In relation to the beforementioned, other studies refer to the promotion of psychomotor activities to stimulate active learning and teamwork (Aristizabal-Almanza, Arcelia Ramos-Monobe, & Chirino-Barceló, 2018).

On the other hand, Gil-Madrona (2004) notes that the evaluation in Physical Education can contribute as a preventive element, with the purpose of achieving the most exhaustive knowledge possible of the student's evolution and, therefore, enables adapting the educational process to the child. There is a growing interest in a better understanding of the relationship between psychomotor development and the infant, thus the evaluation of psychomotor skills is a priority in early childhood education because it represents a valuable tool for the teacher to guide relevant and direct lines of action based on the results obtained. Likewise, a motor intervention programme in Physical Education would mitigate risk factors in infants, and for some reasons the adequate development of motor skills provides a way for their adequate intellectual development (Da Fonseca, 1984), facilitating the development of their cognitive and learning competencies. In this context, in a proper integral development of the infant, a good motor assessment is crucial, which involves the implementation of intervention programmes that allow the teacher to design activities that favour the development of skills and attitudes in the students of early childhood education (Monge & Meneses, 2002).

Methods

The methodology used for the current study is based on a quantitative approach. Regarding the research design, it is a pilot study based on a quasi-experimental design of group comparison, with pretest and post-test measurement in two experimental groups.

Objectives and hypothesis

General objective was to analyse the effects of two psychomotor intervention programmes based on different learning environments in the context of children's Physical Education.

Hypothesis was as follows: The psychomotor intervention programmes would produce significant and positive changes in children's motor development, language proficiency, mathematical thinking, motivation, and character.

Sample of participants

The research sample of the study consisted of 44 students, distributed in two natural groups or classrooms in the last year of early childhood education in a public school in the town of Soledad, Atlantic Department, in the Colombian Caribbean. Group 1 (G1) consisted of 26 students, 50% were boys (n = 13) and the other 50% were girls (n = 13). In turn, group 2 (G2) consisted of 18 students, 50% boys (n = 9) and 50% girls (n = 9). The participants' age ranged from four years and eight months to five years and nine months. The homogeneous distribution of each group was due to circumstantial factors. The sample was a convenient one in terms of access and availability of time, space, and permissions.

Instruments

Motivation Scale to Children's Learning EMAPI. The EMAPI questionnaire (Blanco, 2014, 2017) consists of 22 items, which are distributed as follows: seven items of beliefs and expectations, four items of value, three items of levels of demand, and eight items of attributions. The items are arranged using different pictograms, a resource widely used in early childhood education, since at this stage images have a lot of meaning for the students, making them understand better what is expressed.

The items are answered with different emoticons like smiley faces and sad faces, to specify the agreement or disagreement with what is expressed in the item, or only with smiley faces in the items where they must choose between different suggested options. Likewise, all the items provided to the students are formulated in a positive way, to make it easier to understand and thus to answer. Therefore, the questionnaire is easy to adapt according to the age of the child population. It is administered individually, with an approximate duration of 30 to 45 minutes.

Character Rubric K-2. The Character Rubric K-2, which assesses the affective domain through six categories, was used for character assessment. Its use is endorsed by the American Association for Health, Physical Education, Recreation and Dance (AAHPERD), and a professor of kinesiology at the New York University oversaw the translation. For each of the categories, the level in which is the child is selected from five options, with the highest frequency being "consistently" and the lowest frequency being "never". The six categories are: respect, cooperation, sensitivity, leadership, teamwork, and self-control. The score obtained from this test was quantitative, through a 4-point Likert scale, administered individually with an approximate duration of 30 to 45 minutes.

Psychomotor Development Test (TEPSI). The TEPSI (Haeussler & Marchant, 2002) is aimed at a child population aged 2-5 years. This instrument was used to evaluate psychomotor development in the population under study. It consists of 52 items or tasks, which in turn are distributed into three subtests: coordination, language, and motor skills. The coordination subtest, consisting of 16 items, evaluates the child's ability to manipulate objects and draw, through behaviours such as building towers with cubes, threading a needle, and recognizing and copying geometric figures. The language subtest, consisting of 24 items, evaluates aspects of language comprehension and expression through tasks such as naming objects, defining words, and verbalizing actions. The motor subtest (12 items) evaluates children's ability to control their own body through behaviours such as hopping on one foot, picking up a ball or walking on tiptoe. The test is administered individually in an average time span of 30 to 45 minutes, and each response is scored with 0 or 1, depending on whether it is executed incorrectly or correctly, respectively.

Utrecht Test. To assess the development of mathematical processes, the Utrecht Test (Van de Rijt, Van Luit, & Pennings, 1999) was used, aimed at the population of children 4-7 years of age. It has three parallel versions of 40 items each. It consists of eight tasks, divided into groups of five. It has a maximum score of 40 points (one for each correct item). It must be administered individually, and its duration ranges between 20 and 30 minutes.

The instrument's dimensions focus on various aspects, such as relational and numerical aspects, which in turn contain four subtests each, assessing various areas such as: comparison, classification, correspondence, and seriation, as well as verbal counting, structured counting, resultant counting, and general number counting. Each of the eight components of the test has five items. Each correct answer is scored with 1 and errors with 0. The maximum score that can be obtained is 40.

The first four subtests (relational: items 1 to 20) evaluate Piagetian-type skills and the last four (numerical: items 21 to 40) estimate numerical skills of a cognitive nature. In this study only the relational aspects were assessed because they are part of the activities that make up the intervention programme. The subtest are comparison, classification, one-to-one correspondence, and seriation.

Procedure

Before the data collection, the institution ethics and social coexistence committee approved the study. The families signed the informed consent form, indicating the voluntary nature of their children's participation in the study and the confidentiality of the data, in compliance with the necessary ethical requirements.

The implementation of the Physical Education programme for children in G1, called *Se vive la leyenda*, provides a focus and a learning environment inspired by the traditional legends of the different regions that shape Colombia, such us: *el hombre caiman*, *el Sombrerón*, *el tesoro del pirata Morgan*, *la madre monte*, *el Yacuruna*, and *el silbón*. Each region has a variety of stories, therefore, the legend is chosen as a narrative resource to adapt the activities aimed at a child population, to turn them into allied agents in the creation of learning environments for the activities in Physical Education at the early childhood education stage. This motor games intervention programme aimed to promote children's development in the areas of language, motor skills, coordination, relational aspects of mathematical thinking (comparison, classification, seriation, and correspondence), motivation towards learning and character. The motor games programme for G2 provides its focus on the teacher's pedagogical recreational project. The teacher had four days of pedagogical training, dealing with the importance of motor intervention programmes, sharing material for their implementation, and advising on their possible implementation.

The programmes consisted of 14 sessions and a repeating cycle, i.e., 28 classes, which are implemented over four weeks, with a 50-minute session per day. Similarly, the objectives and contents of the programmes were based on the knowledge areas that constitute early childhood education (see Appendix 1), such as self-knowledge, interaction with others and the environment, and communication and representation. These contents were worked on systematically and transversally throughout the sessions that made up the programmes, in accordance with the curricular guidelines and coinciding with the pedagogical approach in the infant education stage. Thus, the contents are aimed at developing mathematical, perceptual, motor, emotional, sensory-motor, communication, and language skills in the students through the proposed motor tasks, as well as to improve motor skills in early childhood education, such as body control and awareness, locomotion (crawling, rolling, walking, running, jumping, climbing), manipulation and coordination (global, segmental, and dissociated) through motor activities designed for this purpose.

Data analysis

In this study, as statistical technical references, non-parametric tests were used due to the number of participants in both groups. However, when considering a non-parametric sample, the Hedges' G estimator was applied, since the groups were differently sized, thus, by using this estimator, the standard deviation could be weighted by the number of participants in each group.

As a starting point, a descriptive statistical analysis of the groups and the analyses with the range tests were carried out, followed by comparisons between the two groups. The IBM SPSS statistical program was used for computer processing of the data.

Regarding the effect size (ES), to interpret the result, Cohen (1988) proposed quantifying the magnitude of the effect in three classifications: small (d = 0.20-0.30), medium (d= 0.50-0.80) and high (d= > 0.80). It should be noted that this index can be applied in any estimation to evaluate ES. In this way, ES were explored in each group, in order to evaluate the changes in each subdimension of the scales applied.

Results

Results for Group 1

In G1, changes within the EMAPI scale were evaluated (see Table 1). Thereby, in the dimension Beliefs and expectations (Z = - 1.39; p = .165; g = .562) the ES was medium. In the dimension Task value (Z = -.447; p = .655; g = .191) the ES was low. In the dimension Demand values (Z = -2.213; p = .027; g = .054) the ES was low. Finally, in the dimension Attributions factor (Z = -1.085; p = .278; g = .561) the ES was medium.

In the CR scale (see Table 2) changes in each dimension were observed. In the dimension Respect character (1) (Z = -.577; p = .564; g = .153) the ES was low. In the dimension Respect character (2) (Z = .000; p = 1; g = 0) the ES was low. In the dimension Cooperation (Z = -1.414; p = .157; g = .377) the ES was low. In the dimension Sensitivity (Z = -3.217; p = .001; g = 1.095) the ES was high. In the dimension Leadership (Z = -4.472; p = .000; g = 2.226) the ES was high. In the dimension Teamwork (Z = -1.190; p = .234; g = .224) the ES was low. In the dimension Self-control (1) (Z = -3.127; p = .002; g = 1.029) the ES was high. In the dimension Self-control (2) (Z = -2.814; p = .005; g = .877) the ES was high.

In the TEPSI scale (see Table 3) results in the dimensions of the scale were obtained. In the dimension Coordination (Z = -3.547; p = .000; g = 1.305) the ES was high. In the dimension Language (Z = -4.362; p = .000; g = 1.448) the ES was high. In the dimension Motor skills (Z = -4.391; p = .000; g = 1.843) the ES was high.

Table 1. Effect size of the EMAPI scale dimensions

	N	Average	SD	Z	p	Hedges' g
Believes and expectations	26	6.0085	.42937	-1.389	.165	.562
Believes and expectations (POST)	26	5.5769	.93327			
Task value	26	3.2404	.04903	-.447	.655	.191
Task value (POST)	26	3.2115	.19612			
Demand values	26	2.2915	.19612	-2.213	.027	.054
Demand values (POST)	26	2.2821	.12265			
Attributions factor	26	5.4377	.92819	-1.085	.278	.561
Attributions factor (POST)	26	5.9663	.84525			

Table 2. Effect size of the CR scale dimensions (G1)

	N	Average	SD	Z	p	Hedges' g
Character respect (1)	26	3.9231	0.27175	-.577	.564	.153
Character respect (1) (POST)	26	3.9615	0.19612			
Character respect (2)	26	4.0000	0.00000	.000	1	.000
Character respect (2) (POST)	26	4.0000	0.00000			
Cooperation	26	4.0000	0.00000	-1.414	.157	.377
Cooperation (POST)	26	3.9231	0.27175			
Sensitivity	26	3.4231	0.70274	-3.217	.001	1.095
Sensitivity (POST)	26	4.0000	0.00000			
Leadership	26	3.1154	.32581	-4.472	.000	2.226
Leadership (POST)	26	3.8846	.32581			
Teamwork	26	3.6923	.67937	-1.190	.234	.224
Teamwork (POST)	26	3.8462	.61269			
Self-control (1)	26	3.5000	.64807	-3.127	.002	1.029
Self-control (1) (POST)	26	4.000	.000000			
Self-control (2)	26	3.4615	.64689	-2.814	.005	.877
Self-control (2) (POST)	26	3.9231	.27175			

Table 3. Effect size of the TEPSI scale dimensions

	N	Average	SD	Z	p	Hedges' g
Coordination	26	11.4808	2.98262	-3.547	.000	1.305
Coordination (POST)	26	14.5192	0.86508			
Language	26	18.7554	3.29478	-4.362	.000	1.448
Language (POST)	26	22.5032	1.02882			
Motor skills	26	8.0538	1.89142	-4.391	.000	1.843
Motor skills (POST)	26	10.7756	0.54913			

Table 4. Effect size in the UTRECH scale dimensions

	N	Average	SD	Z	p	Hedges' g
Comparison	26	3.6385	1.01826	-1.279	.201	.330
Comparison (POST)	26	3.9231	0.53089			
Classification	26	3.4160	1.31899	-1.548	.122	.587
Classification (POST)	26	4.0231	0.40527			
Seriation	26	3.5615	1.04922	-2.029	.042	.572
Seriation (POST)	26	4.0385	0.36669			
Correspondence	26	3.1692	1.15474	-3.208	.001	.940
Correspondence (POST)	26	4.0231	0.36366			

In the UTRECH scale (see Table 4), changes were obtained in the dimensions. Thus, in the dimension Comparison (Z = -1.279; p = .201; g = .330) the ES was low. In the dimension Classification (Z = -1.548; p = .122; g = .587) the ES was medium. In the dimension Seriation (Z = -2.029; p = .042; g = .572) the ES was medium. In the dimension Correspondence (Z = -3.208; p = .001; g = .940) the ES was high.

Results for Group 2

In G2, the following results were obtained from the EMAPI scale (see Table 5). Thus, in the dimension Beliefs and expectations (Z = - 1.925; p = .054; g = .696) the ES was medium. In the dimension Task value (Z = -.816; p = .414; g = .247) the ES was low. In the dimension Demand values (Z = -2.267; p = .023; g = .663) the ES was medium. Finally, in the dimension Attributions factor (Z = -3.179; p = .001; g = .561) the ES was high.

In the CR scale (see Table 6) changes were observed in each dimension. In the dimension Character respect (1) (Z = -.812; p = .417; g = .261) the ES was low. In the dimension Character respect (2) (Z = -1.530; p = .126; g = .499) the ES was medium. In the dimension Cooperation (Z = -2.556; p = .011; g = .909) the ES was high. In the dimension Sensitivity (Z = -3.134; p = .002; g = 1.132) the ES was high. In the dimension Leadership (Z = -2.915; p = .004; g = .992) the ES was high. In the dimension Teamwork (Z = -2.345; p = .019; g = .776) the ES was medium. In the dimension Self-control (1) (Z = -2.859; p = .004; g = 1.000) the ES was high. In the dimension Self-control (2) (Z = -1.671; p = .095; g = .539) the ES was medium.

In the TEPSI scale (see Table 7) results were obtained in the scale dimensions. In the dimension Coordination (Z = -3.080; p = .002; g = 1.130) the ES was high. In the Language dimension (Z = -3.7272; p = .000; g = 2.405) the ES was high. In the dimen-

Table 5. Effect size of the EMAPI scale dimensions

	N	Average	SD	Z	p	Hedges' g
Believes and expectations	18	5.3254	1.15415	-1.925	.054	.696
Believes and expectations (POST)	18	4.1746	1.87711			
Task value	18	3.0833	0.38348	-.816	.414	.247
Task value (POST)	18	2.9722	0.46089			
Demand values	18	2.1852	0.38301	-2.267	.023	.663
Demand values (POST)	18	1.8148	0.63885			
Attributions factor	18	4.5069	1.04007	-3.179	.001	1.102
Attributions factor (POST)	18	2.7639	1.83456			

Table 6. Effect size in the CR scale dimensions

	N	Average	SD	Z	p	Hedges' g
Character respect (1)	18	3.1667	0.92355	-.812	.417	.261
Character respect (1) (POST)	18	2.8889	1.07861			
Character respect (2)	18	3.0556	1.16175	-1.530	.126	.499
Character respect (2) (POST)	18	2.5000	0.92355			
Cooperation	18	3.1111	0.90025	-2.556	.011	.909
Cooperation (POST)	18	2.2222	0.94281			
Sensitivity	18	3.3889	0.77754	-3.134	.002	1.132
Sensitivity (POST)	18	2.3333	0.97014			
Leadership	18	2.7222	1.22741	-2.915	.004	.992
Leadership (POST)	18	1.6111	.84984			
Teamwork	18	2.7222	1.22741	-2.345	.019	.776
Teamwork (POST)	18	1.7778	1.06027			
Self-control (1)	18	2.9444	0.93760	-2.859	.004	1.000
Self-control (1) (POST)	18	2.0556	0.72536			
Self-control (2)	18	2.8333	0.98518	-1.671	.095	.539
Self-control (2) (POST)	18	2.2778	0.95828			

Table 7. Effect size in the TEPSI scale dimensions

	N	Average	SD	Z	p	Hedges' g
Coordination	18	11.1111	3.49866	-3.080	.002	1.130
Coordination (POST)	18	7.3194	2.79006			
Language	18	19.3079	2.97605	-3.727	.000	2.405
Language (POST)	18	12.3565	2.44925			
Motor skills	18	8.0926	1.94384	-2.928	.003	.936
Motor skills (POST)	18	6.0880	2.09213			

Table 8. Effect size in the UTRECHT scale dimensions

	N	Average	SD	Z	p	Hedges' g
Comparison	18	2.6444	1.66706	-.035	.972	.014
Comparison (POST)	18	2.6667	1.23669			
Classification	18	3.0556	1.31383	-2.683	.007	.813
Classification (POST)	18	1.8778	1.41611			
Seriation	18	2.9529	1.32765	-1.567	.117	.491
Seriation (POST)	18	2.2556	1.34917			
Correspondence	18	2.6444	1.39841	-1.260	.207	.427
Correspondence (POST)	18	2.0706	1.12237			

sion Motor skills (Z = -2.928; p = .003; g = .936) the ES was high.

In the UTRECH scale (see Table 8), changes were obtained in the dimensions. Hence, in the dimension Comparison (Z = -.035; p = .972; g = .014) the ES was low. In the dimension Classification (Z = -2.683; p = .007; g = .813) the ES was high. In the dimension Seriation (Z = -1.567; p = .117; g = .491) the ES was medium. In the dimension Correspondence (Z = -1.260; p = .207; g = .427) the ES was medium.

Discussion and conclusions

The data analysis carried out allows us to respond to the objective of this study, which is focused on analysing the effects of the motor intervention programmes on the motor development of children aged 4 to 5 years; specifically, on the aspects of child development such as language, relational aspects of mathematical thinking (seriation, classification, correspondence and comparison), motivation towards learning and character.

The results show that the programme in G1, in general, produced significant improvements in 12 out of the 20 aspects evaluated. However, the programme did not produce greater improvements than the Physical Education classes programmed by the teacher of G2, since in the latter programme improvements were produced in 16 out of the 20 aspects evaluated, and the significance in 14 of them was greater than in G1.

When examining whether the motor intervention programme *Se vive la leyenda* improved some aspects of motivation towards learning, considering the analysis carried out and the evaluation of each of the components that structured the test, it can be concluded that there was an improvement in two out of the four dimensions, being beliefs and expectations and attributions factor. In contrast, in G2, the motor programme based on the teacher's pedagogical recreational project resulted in improvements in the dimensions beliefs and expectations, demand values and attributions factor. Moreover, these improvements were more significant than those produced in G1.

The low effect on components such as task value and demand values in G1 is recognized, implying the need for revision of the contents and the little promotion of these components in the activities carried out. In this line, Blanco (2014) mentions that motivational patterns are established at an early age and the first years of life are crucial for the establishment of solid intrinsic motivational orientations that will last for a lifetime. The findings also highlight the role of the school as a promoter of motivating motor scenarios that stimulate the practice of physical activity in early childhood education (Hernández-Martínez, González-Martí, Sánchez-Matas, & Carrión-Olivares, 2020).

Inquiring whether the effects of the motor intervention programmes improve motor development in terms of some components of character, it was concluded that in G2 there were more significant effects than in G1, with the former showing improvements in the components of character, cooperation, sensitivity, leadership, teamwork, and self-control, while in the latter there was only a high and direct effect on the components of sensitivity, leadership, and self-control. It should be noted that in the self-control component, the improvements were greater in G1.

Accordingly, Aldana Sánchez (2020) points to the promotion of programmes aimed at strengthening well-being within school contexts, based on the development of skills and character strengths, thus suggesting the need for school intervention in these early stages of personal development. In other words, the execution of motor intervention activities improves some aspects of emotional self-regulation in childhood. All this partially validates the hypothesis presented in this study that there are significant and positive changes in motor development depending on some aspects of character. However, it can be concluded that properly planned, conducted and developed physical activity has a positive influence on the components of character, which can have an impact on health and well-being (Klavestrand & Vingård, 2009; Ohrberg, 2013; Warburton, Nicol, & Bredin, 2006).

Furthermore, when verifying whether the motor intervention programmes improve language, the results show that both groups achieved a highly significant improvement. This means that motor interventions have an impact on child's development, causing significant and positive changes in language.

Meanwhile, several investigations agree on stating that the psychomotor system positively influences the development of language and its production (Gonzales-Remigio, 2022; Kiat-Hui & Ee-Lynn, 2021; Mendiara, 2008; Teixeira, et al., 2015). This is how Physical Education meets the required characteristics to be a good educational resource where movement and language become the essential tools for a good development of skills at school age that should serve in adult life (Cañabate, Colomer, & Olivera, 2018). Therefore, collaboration from Physical Education to produce improvements not only in motor skills but also in language, implies that children's intervention programmes should emphasize combining different play strategies that incorporate movement, in order to enhance the proper development of motor skills (Vargas-Vitoria, et al., 2021).

When testing whether the intervention programmes have an impact on the improvement of mathematical development and relational aspects (such as seriation, classification, correspondence, and comparison), it should be noted that in G1 low scores were obtained in the comparison aspect, as opposed to medium scores in the classification and seriation aspects, and high results in correspondence. In this sense, the effects in G2 were similar, where low scores were obtained in the comparison aspect, high scores in classification, and medium scores in seriation and correspondence. Similarly, although in G2 there was a greater effect in the classification aspect, in G1 there was a greater effect in the correspondence aspect. This means that some progress was found in the relational aspects of mathematical development.

It is therefore noted that there is a positive effect on the improvement of mathematical development in G1. However, it is important to examine the proposed activities oriented to the comparison component in the improvement of the programme and future applications. In accordance with the foregoing, motor activities provide great help in the development of maturity, acquisition, and rehabilitation in the area of calculation, as stated by Hernández, de los Ángeles, and Vilugrón (2019). In addition, recent studies show that there is a direct, positive, and highly significant relationship between psychomotor development and basic mathematical notions (Quispe, 2021). Alonso and Pazos (2020) reveal the importance of motor practice in the integral education of the infant, further ratifying the need for the implementation of motor programmes due to their effects on the development of children as a complement and follow-up to the results of this research.

To conclude, the limitations of this study include the sample size, the convenience sampling method and the absence of a control group, which could limit the generalisability of the study results. However, this study supposes the beginning of a line of research poorly studied, given the scarce research linking the variables of motor intervention, motor development, coordination, motivation towards learning, character, language and relational aspects of mathematical development in early childhood education through the region's own cultural heritage. In this regard, Blanco (2017) highlights the precariousness of studies linked to motor skills, determinants of motivation and different aspects in early childhood education. Therefore, this study could serve as a foundation for future studies linking these variables.

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Correspondence to:
Carlos Montoya-Fernández
Department of Pedagogy,
Faculty of Education of Albacete
Plaza de la Universidad 3, 02071 Albacete, Spain
E-mail address: Carlos.Montoya@uclm.es

Appendix 1.

Table 9. Structure of the programmes

Transversal curricular contents		
Area	**Block**	**Content**
Area of self-awareness and personal autonomy	Block 1. The body: image and health	Body knowledge: parts of the body, identity, exploration of one's own body and others, care and hygiene habits. Postural control of the body and movement, coordination, balance and breathing. Identification and management of emotions, own and others' feelings.
	Block 2. Play and daily activity	Play: construction of and respect for rules and norms, initiative and personal effort, non-discriminatory attitudes. Activities of daily life; habits and behavioural patterns, conflict resolution, social relations and positive attitudes, coexistence.
Area of knowledge and interaction with the environment	Block 1. The approach to the natural environment	Moving and exploring, objects and their manipulation, both with care and protection orientations
	Block 2. Participation in cultural and social life	Social groups, school. Behavioural patterns. Culture and oral tradition. Dialogue as a conflict mediator.
Language area: Communication and representation	Block 1. Verbal language	Communication skills, speaking and listening Comprehension of the spoken word Participation in and use of language exchange norms.
	Block 2. Creative languages	Physical-motor expression. Body resources, Expression of emotions and feelings Legends, rhythms and dances, Spontaneous representation and symbolic play. Fine motor work techniques. Logical-mathematical thinking
	Block 3. The language of information and communication technologies	Audiovisual productions

ASSOCIATION BETWEEN LOWER EXTREMITY KINEMATICS AND HORIZONTAL JUMP PERFORMANCE IN HEALTHY YOUNG ADULTS

Tufan Ulcay[1], Nurseli Ekici Özdemir[1], Özkan Görgülü[2], Muhammed Fırat Aladağ[1], Emre Uğuz[1], Ruken Öncü[1], Mehmet Kutlu[1], Esra Bayramoğlu Demirdöğen[3], Burcu Kamaşak Arpaçay[1], and Kenan Aycan[1]

[1]Kırşehir Ahi Evran University, Faculty of Medicine, Department of Anatomy, Kırşehir, Türkiye
[2]Kırşehir Ahi Evran University, Faculty of Medicine, Department of Biostatistics and Medical Information, Kırşehir, Türkiye
[3]Kırşehir Ahi Evran University, Department of Pilot University Coordinatorship of Health Rectorship, Kırşehir, Türkiye

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Abstract:

This study investigates the correlation between lower extremity anthropometric parameters and the quadriceps angle in relation to horizontal jump performance in healthy young adults. Ninety-six healthy young adults (52 females and 44 males, aged 18-30 years), participating in no regular sports activity, were included. Measurements of lower extremity length, thigh length, leg length, foot length, hip circumference, and waist circumference were taken in centimeters using a non-elastic tape measure in an upright position. The quadriceps angle was measured with a goniometer, and horizontal jump performance was assessed via the standing broad jump test. Data were analyzed using SPSS version 29.00. A significant negative correlation was found between the quadriceps angle (both legs) and hip circumference, waist circumference, foot length, and horizontal jump distance. The quadriceps angle of the right leg also negatively correlated with lower extremity, thigh, and leg lengths. Horizontal jump distance positively correlated with lower extremity, thigh, leg, and foot lengths. Longer lower extremity, thigh, leg, and foot lengths enhance horizontal jump performance, while an increased quadriceps angle reduces it. These results highlight the quadriceps angle as a critical factor in horizontal jump performance, warranting further research.

Keywords: *anthropometry, quadriceps angle, standing broad jump test*

Introductıon

Anthropometric measurements encompass a wide array of parameters, including circumferential dimensions, linear lengths, diameters, and assessments of adipose tissue, with circumference measurements being the most commonly utilized among these. The quantitative data obtained from these anthropometric evaluations can be effectively correlated with individual's motor capabilities and overall performance outcomes. For example, the relationship between children's somatic growth, developmental trajectory, and kinetic output is significantly influenced by their anthropometric characteristics (Pekel, Balcı, Bağcı, Pepe, & Güzel, 2004; Yıldırım & Özdemir, 2010a,b).

The quadriceps (Q) angle, a crucial biomechanical parameter, is defined as the acute angle formed between two axes: one extending from the anterior superior iliac spine to the midpoint of the patella, and the other from the midpoint of the patella to the tibial tuberosity (Figure 1) (Raveendranath, Nachiket, Sujatha, Priya, & Rema, 1995). Although there is variation in the literature regarding normative Q angle values, Schulthies, Francis, Fisher, and Van de Graaff (1995) synthesized existing data to conclude that typical values range from 10.00º-14.00º in males and 14.50º-17.00º in females. The Q angle is an important measurement used to assess knee joint function, detect lower limb misalignment, and evaluate the health of the patellofemoral joint. It also helps estimate the risk of lower limb injuries (Raveendranath, et al., 1995; Schulthies, et al., 1995). Orsi et al. (2016) found that when the knee is bent at a 25° angle, a combination of knee valgus and internal rotation of the thigh bone significantly increases the stress on the anterior cruciate ligament. Similarly, Homyk et al. (2012) studied the effects of thigh bone rotation and valgus forces under the same knee angle and found that valgus forces pose a greater risk for anterior cruciate ligament injury than rotation alone. The Q angle has also received attention for its role in jump performance (Taş, Ok, Akdeniz, & Bingül, 2024). Daneshmandi, Saki, Shahheidari, and Khoori (2011) showed that people with a smaller Q angle could produce more force, which might help them perform better in jumping. Chester et al. (2008) added that a larger Q angle was linked to slower muscle responses in the quadriceps, the main muscle group used during jumps. Daugherty, Weiss, Paquette, Powell, and Allison (2021) also found that a smaller Q angle was connected to better jump performance, suggesting that proper alignment affects athletic ability. In line with this, Caia et al. (2016) found a strong connection between Q angle and jumping ability, emphasizing its importance in jump efficiency and performance.

The current body of literature underscores the significance of Q angle in jump performance given its association with superior force generation, faster neuromuscular activation, and overall biomechanical advantage. The Q angle thus emerges as a key factor in the complex interplay of variables that govern jumping efficacy.

Jumping represents a fundamental form of human movement that is intricately modulated by a multitude of biomechanical and physiological factors, including body anthropometry, muscular strength, explosive power, flexibility, and motor coordination. These interrelated components collectively enable an individual to generate sufficient force to overcome gravity and propel the body upwards. Proficiency in diverse types of jumping is not only critical for athletic success across numerous disciplines but also plays an essential role in specific aspects of daily motor tasks (Ugarkovic, Matavulj, Kukolj, & Jaric, 2002). Jumping is recognized as a key biomechanical determinant in the etiology of sports-related injuries (Milić, et al., 2025). Beyond their role in injury mechanisms, biomechanical variables have also been shown to significantly influence the phases of gait in activities of daily living. Although the biomechanics of fundamental motor tasks such as jumping, walking, running, rising from a seated position, and stair climbing have been well documented as discrete functional activities, methodological inconsistencies, variability in measurement techniques, and heterogeneity in study populations make data synthesis challenging (Khajooei, Quarmby, Kaplick, Mayer, & Engel, 2022; Reznick, et al., 2021).

Horizontal jumping specifically refers to the forward propulsion of the body from a vertical to a horizontal plane, executed either bilaterally or unilaterally (Yıldırım & Özdemir, 2010a). As a multifactorial motor skill, performance in horizontal jumping is contingent upon an array of biomechanical and physiological parameters that together determine the maximal jump distance. Existing literature predominantly emphasizes elite athletic populations and investigates determinants such as plyometric training, neuromuscular coordination, sport-specific skill acquisition (e.g., soccer), the role of a double-arm swing, lower limb kinematics, functional training regimens, muscular strength of the lower extremities, anthropometric factors, and flexibility (Ulusu, Keser, & Gündüz, 2018; Usgu, Yakut, & Kudaş, 2020; Vazini Taher, Pavlović, Ahanjan, Skrypchenko, & Joksimović, 2021; Zileli, & Söyler, 2021). Nevertheless, there exists a notable gap in the literature regarding the potential correlation between the Q angle and horizontal jump performance.

The objective of the present study is to identify the correlation between lower extremity anthropometric measurements and the Q angle in relation to horizontal jump performance among healthy young adults. Furthermore, this study aims to enrich the existing body of knowledge by providing data-driven insights and contributing empirical evidence to the current literature through the findings of our research.

Methods

A total of 96 volunteer participants, 52 females and 44 males, aged between 18 and 30 years and not professionally involved in athletic activities, were selected for this study. The exclusion criteria encompassed individuals younger than 18 years of age, those who had sustained any lower extremity trauma within the preceding six months, and individuals diagnosed with neurological, cardiovascular, vestibular, or rheumatic disorders. Additionally, participants with lower limb amputations or prostheses, those utilizing walking aids or other assistive devices, and individuals with a history of lower extremity fractures were excluded. Prior to enrollment, the study protocol was thoroughly explained to all participants, and informed consent was duly obtained in accordance with the established ethical standards.

The study proposal was approved by the local ethics committee (Decision No: 2022-23/203, Date: 20/12/2022), and conducted in accordance with the principles of the Declaration of Helsinki. This study was conducted between January and April 2023.

Anthropometric measurements

Anthropometric assessments were meticulously conducted by a single examiner to ensure measurement consistency across all voluntary participants. Each measurement was performed twice, and the mean of the two readings was subsequently

Figure 1. The reference points of the measurement of Q angle.

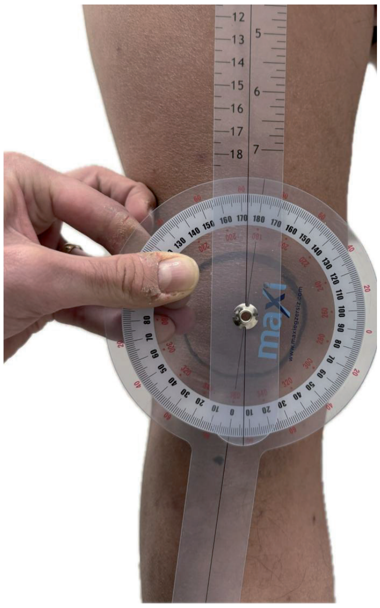

Figure 2. The measurement of Q angle.

recorded for analysis to enhance data accuracy. The anthropometric parameters evaluated included lower extremity length, thigh length, leg length, foot length, hip circumference, and waist circumference. Specifically, lower extremity length was measured as the distance from the anterior superior iliac spine to the medial malleolus with the participant in a standing posture. Thigh length was determined from the midpoint of the inguinal ligament to the proximal patella while the participant was seated with legs freely suspended over the edge of a chair. Leg length was quantified as the distance between the tibial plateau and the medial malleolus with the participant seated in a cross-legged position. Foot length was measured from the heel to the tip of the longest toe in a standing posture. Hip circumference was assessed at the broadest point of the gluteal region, and waist circumference was measured at the level of the umbilicus, both with the participant standing and the measurements taken parallel to the ground (Otman, Demirel, & Sade, 2014).

Q angle measurement

The Q angle was measured using a goniometer, with the participant in a supine position to ensure accurate anatomical alignment. The center of the goniometer was placed at the midpoint of the patella, with the fixed arm directed towards the tibial tuberosity and the movable arm aligned with the anterior superior iliac spine. The acute angle formed by the intersection of these two arms was recorded as the Q angle (Figure 2) (Havaslı, Demir, Çiçek, & Yoldaş, 2017). This standardized measurement technique ensures precision in capturing the angular relationship between the femur and tibia, which is critical for evaluating lower extremity biomechanics.

Horizontal jump distance measurement

In this study, horizontal jump performance was assessed using the standing broad jump test (Figure 3). Our study will center on the standing broad jump test, a key performance assessment in

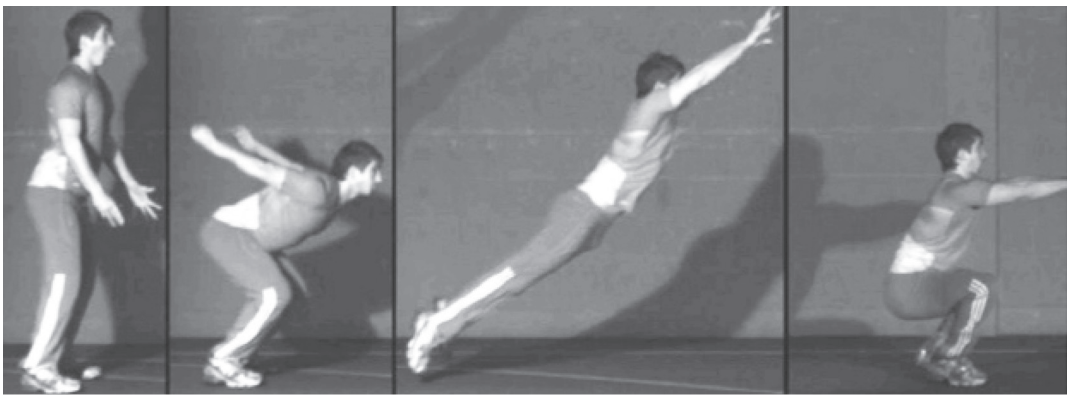

Figure 3. Standing broad jump test (Wild, Bezodis, Blagrove, & Bezodis, 2011).

which individuals propel themselves forward from a static position utilizing bilateral foot engagement to achieve maximal horizontal displacement (Ulusu, et al., 2018). For the horizontal jump test, participants positioned themselves behind a designated starting line on a level surface. Upon receiving the command to "Jump," they launched forward with both feet simultaneously, striving to achieve maximal distance. The horizontal distance from the starting line to the posterior edge of the participant's heel at landing was measured in centimeters. Each participant performed the jump test twice, with the longest distance achieved recorded for subsequent analysis (Ayan & Kavi, 2016). This testing protocol ensures reliability in the evaluation of participants' lower body explosive strength and jump performance capacity.

Statistical analyses

Data analysis was conducted using the Statistical Package for Social Sciences (SPSS) version 29.00 for Windows (IBM SPSS Statistics for Windows, Version 29.00, Armonk, NY: IBM Corp., USA). The sample size for the study was determined through *a priori* power analysis utilizing the G*Power 3.1.9.6 software (developed by Franz Faul at the University of Kiel, Germany), ensuring sufficient statistical power for the analyses undertaken.

The assumptions of normality for the dataset were evaluated using both the Kolmogorov-Smirnov and Shapiro-Wilk tests. Based on the results of these normality tests, Spearman correlation analyses were applied to identify and quantify the relationships between the variables.

The sample size for the study was established via an *a priori* power analysis. Considering an anticipated effect size of $\rho = 0.30$ and aiming for a statistical power of $1-\beta = 0.85$, the analysis determined that a minimum sample size of 96 participants is required to ensure adequate power for detecting the specified effect.

Results

The associations between the Q angle of the right leg and other parameters among all participants are presented in Table 1. A statistically significant negative correlation was observed between the right leg Q angle and the following variables: lower extremity length (Rho = -0.247*, p = .015), thigh length (Rho = -0.317**, p = .002), leg length (Rho = -0.280**, p = .006), hip circumference (Rho = -0.272**, p = .007), waist circumference (Rho = -0.262**, p = .010), foot length (Rho = -0.347**, p = .001), and horizontal jump distance (Rho = -0.245*, p = .016). These findings suggest an inverse relationship between the right leg Q angle and these anthropometric and performance variables, with the negative correlation coefficients indicating that as the right leg Q angle increases, the corresponding variable values tend to decrease.

Table 1. Relationships between the right leg Q angle and other variables in all participants (n=96)

Variables	Rho	p
Lower extremity length (cm)	-.247*	.015
Thigh length (cm)	-.317**	.002
Leg length (cm)	-.280**	.006
Hip circumference (cm)	-.272**	.007
Waist circumference (cm)	-.262**	.010
Foot length (cm)	-.347**	.001
Horizontal jump distance (cm)	-.245*	.016

Note. ** – significant at p<.01; * – significant at p<.05; cm: centimeter, Rho: correlation coefficient.

Table 2. Relationships between the left leg Q angle and other variables in all participants (n=96)

Variables	Rho	p
Lower extremity length (cm)	-.154 N.S	.133
Thigh length (cm)	-.195 N.S	.056
Leg length (cm)	-.169 N.S	.099
Hip circumference (cm)	-.263**	.010
Waist circumference (cm)	-.318**	.002
Foot length (cm)	-.343**	.001
Horizontal jump distance (cm)	-.249*	.014

Note. N.S. – non-significant (p>.05); ** – significant at p<.01; * – significant at p<.05; cm: centimeter, Rho: correlation coefficient.

Table 2 delineates the correlations between the Q angle of the left leg and other parameters across all participants. A statistically significant negative correlation was identified between the left leg Q angle and hip circumference (Rho = -0.263**, p = .010), waist circumference (Rho = -0.318**, p = .002), foot length (Rho = -0.343**, p = .001), and horizontal jump distance (Rho = -0.249*, p = .014). In contrast, no significant associations were observed between the left leg Q angle and lower extremity length, thigh length, or leg length (p > .05). These results indicate that increases in the left leg Q angle are associated with decreases in hip circumference, waist circumference, foot length, and horizontal jump distance, whereas no substantial relationship exists with the other examined variables.

Table 3 illustrates the relationship between horizontal jump distance and various parameters across all participants. A significant positive correlation was observed between horizontal jump distance and lower extremity length (Rho = 0.311**, p = .002), thigh length (Rho = 0.278**, p = .006), leg length (Rho = 0.385**, p = .000), and foot length (Rho = 0.478**, p = .000). These results suggest that increases in horizontal jump distance are associated

Table 3. Relationships between horizontal jump distance and other variables in all participants (n=96)

Variables	Rho	p
Lower extremity length (cm)	.311**	.002
Thigh length (cm)	.278**	.006
Leg length (cm)	.385**	.000
Hip circumference (cm)	-.002 N.S	.984
Waist circumference (cm)	.168 N.S	.102
Foot length (cm)	.478**	.000

Note. N.S. – non-significant (p>.05); ** – significant at p<.01; * – significant at p<.05; cm: centimeter, Rho: correlation coefficient.

with a greater lower extremity length, thigh length, leg length, and foot length. However, no statistically significant correlation was detected between horizontal jump distance and hip or waist circumference ($p > .05$). Overall, these findings indicate that while certain anthropometric measures are positively related to horizontal jump performance, hip and waist circumference do not exhibit a significant impact on this performance metric.

Discussion and conclusions

Upon a comprehensive review of the literature, it was observed that similar investigations have predominantly centered on professional or amateur athletic populations. However, there remains a paucity of data on the relationship between anthropometric characteristics and Q angle, particularly in relation to horizontal jump distance in healthy young adult males and females, highlighting a gap in the current research.

Pekel et al. (2004) reported positive correlations between various anthropometric measures—such as diameter, circumference, and length—and performance parameters, including speed, power, and strength, in children aged 10-13 years. Likewise, in a study of elite handball players (Yıldırım, & Özdemir, 2010a), forearm circumference, calf length, body height, body fat percentage, waist circumference, biacromial and biiliac diameters, wrist diameter, chest depth, and flexibility were identified as significant contributors to horizontal jump performance. Research conducted with football players also revealed a strong association between horizontal jump performance and anaerobic power. In the study by Günay, Erol, and Savaş (1994), a positive correlation was established between anaerobic power and thigh length. Furthermore, a study of male basketball players (Ulusu, et al., 2018) concluded that individuals with greater leg and arm lengths demonstrated superior horizontal jump distances.

The significant positive correlation observed between the lower extremity measurements—including thigh, leg, and foot lengths—and horizontal jump distance in our study is consistent with the findings of previous research. However, in contrast to these earlier studies, we did not identify a significant correlation between hip and waist circumferences and horizontal jump performance. This discrepancy may be attributed to the distinct demographic characteristics of our sample, which comprised general population of young adults aged 18-30 years, in contrast to the athletic populations typically examined in the existing literature.

Weiss, Hammond, Schilling, and Ferreira (2012) demonstrated that Q angle measurements obtained via goniometer are generally reliable. In our study, we similarly utilized a goniometer to assess the Q angle. Nevertheless, Skouras et al. (2022) has raised concerns regarding potential measurement inaccuracies when using a goniometer, particularly due to minor shifts in the patellar midpoint, with deviations ranging between 1-5 mm. Özüdoğru et al. (2024) evaluated range of motion of lower extremity joints in healthy participants using an electrogoniometer and reported excellent reliability for this measurement method. Furthermore, Byl, Cole, and Livingston (2000) highlighted that body positioning plays a crucial role in Q angle measurements, with the standing position exerting a greater influence on the ankle and hip joints compared to the supine position. This positional effect results in an increased Q angle when measured in the standing posture. Based on these findings, they advocated for the supine position to minimize potential positional biases, a recommendation we implemented in our study to enhance measurement accuracy. Panoutsakopoulos, Kotzamanidou, Giannakos, and Kollias (2022) explored the correlation between normative ankle joint range of motion and vertical jump performance in adult handball players. They reported a strong correlation between ankle joint range of motion—measured with the knee at 40 degrees of flexion—and vertical jump performance. Similarly, Kotsifaki, Korakakis, Graham-Smith, Sideris, and Whiteley (2021), in a study conducted with physically active individuals, found that horizontal jump distance was predominantly determined by the hip (44%) and ankle (43%) joints, accounting for 87% of the variance. During the landing phase, joint contribution was primarily from the knee (65%), followed by the hip (24%) and ankle (11%).

In their study, Davis et al. (2006) examined a sample of 78 recreational athletes, comprising 55 males and 23 females, with a mean age of 21.9 years. Their findings identified a weak yet positive correlation between femur length and vertical jump height in both sexes, with correlation coefficients of $r=0.18$ for males and $r=0.11$ for females. These results suggest a modest association between femur length and jumping performance, differing slightly by sex, though remaining statistically marginal in both groups.

Furthermore, Davis et al. (2006) also reported a weak but positive correlation between tibia length and vertical jump height in both male and female participants, with correlation coefficients of r=0.18 for males and r=0.15 for females. These findings indicate a slight association between tibia length and vertical jump performance across sexes, although the strength of this relationship remains limited in both groups.

In their study, Horton and Hall (1989) investigated 50 males and 50 females with no history of knee-related conditions and found a moderate negative correlation between femur length and the Q angle, with a correlation coefficient of r=-0.304. These results suggest that as femur length increases, the Q angle tends to decrease, highlighting a notable inverse relationship between these two anatomical parameters.

In another study, Caruso et al. (2012) examined 177 participants, including 143 athletes or individuals engaged in regular exercise and 34 sedentary individuals. The study revealed a weak positive correlation between thigh length and vertical jump height, with a correlation coefficient of r=0.29. These findings suggest a modest association between thigh length and jumping performance, regardless of the level of physical activity.

Moreover, Caruso et al. (2012) reported a weak yet positive correlation between leg length and vertical jump height, with a correlation coefficient of r=0.21. This suggests a modest association between leg length and jumping performance, indicating that a greater leg length may have a slight impact on vertical jump ability.

Aouadi et al. (2012), in their study with 33 male volleyball players training 12-16 hours per week, identified a strong positive correlation between lower limb length and vertical jump performance, with a correlation coefficient of r=0.83. These findings indicate a significant association, suggesting that a greater lower limb length is highly predictive of enhanced vertical jump ability in athletes engaged in intensive training regimens.

Contarlı and Özmen (2021), in their investigation involving gymnasts, assessed the correlation between the Q angle and vertical jump height, concluding that no statistically significant correlation existed between these two parameters. Furthermore, their findings indicated that the Q angle bore no meaningful correlation with dynamic balance performance**.** Our study's findings revealed an inverse relationship between Q angles (of both the right and left legs) and several anthropometric parameters, including hip and waist circumference, foot length, and horizontal jump distance. Notably, for the right leg, a negative correlation was observed between Q angle and measurements of lower extremity length, thigh length, and leg length. Interestingly, this correlation did not reach statistical significance for the left leg in relation to these specific parameters. The observed discrepancy between the right and left leg Q angle correlations with anthropometric characteristics suggests potential side-specific biomechanical variations.

Notably, as the Q angle increased in both legs, horizontal jump distance decreased, underscoring a direct negative impact of Q angle on jump performance. This suggests that the Q angle may be a critical determinant in horizontal jump efficacy.

Thus far, there are no studies that explicitly examine the relationship between the Q angle and long jump performance performed with two feet. Therefore, this study brings a new perspective to the literature and can serve as a fundamental reference source for future research. We recommend that future studies focus on athletic populations, investigate potential sex differences, and evaluate the relationship between the Q angle and the dominant leg. This will provide a more detailed understanding of the biomechanical effects of the Q angle on performance.

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Correspondence to:
Res. Assist. Emre Uğuz, M.Sc.
Kırşehir Ahi Evran University, Faculty of Medicine,
Department of Anatomy
Bağbaşı Campus 40100 Kırşehir
E mail:emre.uguz@ahievran.edu.tr
Phone: +90 551 396 02 89

ALEXITHYMIA AND INJURY ANXIETY IMPEDE INJURY RECOVERY: EVIDENCE FROM HIGH-PERFORMANCE ATHLETES

Marija V. Čolić[1,2], Ana Orlić[3], and Uroš Milanović[4]

[1]*Institute of Criminological and Sociological Research, Belgrade, Serbia*
[2]*Faculty of Media and Communications, Department of Psychology, Belgrade, Serbia*
[3]*University of Belgrade, Faculty of Sport and Physical Education, Belgrade, Serbia*
[4]*Fizio Group, Belgrade, Serbia*

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Abstract:

This study examined the relationship between alexithymia, sport injury anxiety, and injury recovery outcomes in athletes. A sample of 57 high-performance athletes (30 females) completed the Toronto Alexithymia
Scale, Sport Injury Anxiety Scale, and Return to Sport after Serious Injury Questionnaire. Multiple regression analysis showed that difficulties in identifying feelings (a component of alexithymia), and sport injury anxiety significantly predicted negative recovery outcomes (return concerns), together explaining 27.7% of variance. However, neither alexithymia nor injury anxiety predicted positive recovery outcomes (renewed perspective), and both were unrelated to injury risk. The prevalence of alexithymia in this sample was approximately 20%, which is notably higher than general population estimates (~10%). This study provides preliminary evidence that emotion-related traits like alexithymia and contextual anxiety measures may play important roles in sport injury recovery processes, highlighting potential targets for psychological intervention during rehabilitation.

Keywords: *sport injury, return to sport, emotion, personality, high-performance athletes, retrospective assessment*

Introduction

While the importance of stable individual differences has been recognised in sport injury psychology (Andersen & Williams, 1988; Brewer, Andersen, & Van Raalte, 2002; Wiese-Bjornstal, Smith, Shaffer, & Morrey, 1998), the study of personality traits influencing athlete's responses to injury and its outcomes is still in its infancy (Brewer, 2010; McKay, Rollo, Dillon, & Prapavessis, 2022). Our study aims to address this gap by exploring if alexithymia and sport injury anxiety affect athlete's self-assessed injury recovery. We begin by presenting the role of personality in contemporary sports injury models and reviewing the relevant empirical evidence. Then we outline the rationale for studying alexithymia and sport injury anxiety in injury recovery setting.

Psychology of sports injuries

Sport injury is defined as a medically recognised damage to bodily structure or function as a consequence of sport participation that requires absence from training and/or competition (Kerr, Comstock, Dompier, & Marshall, 2018). Beyond physical damage, injuries are now recognised as psychological events influenced by individual differences, from their occurrence to recovery (Arvinen-Barrow & Walker, 2013; McKay, 2022).

Sport injuries occur within a complex training and competition environment and are holistically shaped by multiple characteristics including training quality, programme design, and performance goals (Gabbett, 2016). Moreover, different sports present with different injuries and unique recovery challenges (Rice, et al., 2019). Further, rehabilitation quality varies considerably across settings and performance levels (Ardern, et al., 2016). Competitive level can influence both the pattern and severity of injuries as well as their psychological impact, with elite athletes potentially facing different demands than recreational participants (Jacobsson, et al., 2013). While acknowledging these important contextual factors, this paper focuses specifically on individual personality traits that influence injury experiences across different training contexts and performance levels.

Three theoretical models guide most sport injury psychology research. The Stress-Injury Model (SIM; Andersen & Williams, 1988; Williams & Andersen, 1998) highlights the role of stress in increasing injury risk and identifies personality traits that amplify stress responses. The Integrated Model (Wiese-Bjornstal, et al., 1998) extends the SIM to post-injury phases, showing how personal and situational factors interactively shape cognitive appraisals, emotional responses, and recovery outcomes. The Biopsychosocial Model (Brewer, et al., 2002) further emphasises that biological, psychological and socio-contextual factors influence rehabilitation success via intermediate biological outcomes. While SIM focuses on injury occurrence, the latter two models address injury recovery, with all three recognising that personality traits influence the entire injury experience from risk through rehabilitation outcomes.

Empirical studies on personality and injury

Studies have addressed the predictive potential of psychological factors for sports injury risk, especially the traits suggested by the SIM. In a review of 45 studies examining 20 psychological variables, approximately two-thirds identified significant associations with injury (Appaneal & Habif, 2013). Since our focus is on injury recovery, in this summary we will concentrate on stable personality traits (vs. states such as mood) conceptually linked to stress response, coping, and management. Our analysis centres on emotion-related traits most relevant to the injury recovery experience. We focus specifically on traits that could directly shape cognitive appraisals and emotional responses to injury (such as anxiety), rather than traits that might influence recovery only indirectly through behaviour (such as sensation seeking, which affects injury risk through increased risk-taking).

Anxiety and locus of control (LoC) received the most research attention. In addition, there is some indirect evidence that neuroticism is important in the sports injury context, but studies examining that relationship directly are lacking (McKay, et al., 2022). Studies of LoC show mixed results, with both internal and external LoC predicting injury risk in some studies, but others failed to register a significant relationship (Appaneal & Habif, 2013; McKay, et al., 2022). In contrast, anxiety (especially the competitive variant) has consistently been shown to increase the risk of injury (Appaneal & Habif, 2013; Cagle, Overcash, Rowe, & Needle, 2017; Ford, Ildefonso, Jones, & Arvinen-Barrow, 2017; McKay, et al., 2022), and its potential to influence injury recovery and return to play by shaping athlete's cognitive appraisals at various stages has been recognised (Ford, et al., 2017). However, some studies fail to find a significant relationship to injury risk (e.g., Devantier, 2011; Eckerman, Svensson, Edman, & Alricsson, 2019) and even when the relationship has been found, anxiety alone typically has small predictive power (Ford, et al., 2017). This aligns with the theoretical perspective suggesting complex and multifaceted relationship between psychological traits and sport injuries (Williams & Andersen, 1998). Some researchers suggest that using the context-specific anxiety measures (i.e., sport injury anxiety vs. general anxiety) could improve predictive power (Rex & Metzler, 2016).

In contrast to injury risk, personality has rarely been investigated in relation to injury recovery. Brewer's review (2010) of psychological factors influencing sports injury rehabilitation outcomes identified only one study examining personality in relationship to recovery outcomes—„a composite of hypochondriasis and hysteria"—plus several studies showing a positive relationship between internal health-injury-related locus of control and recovery. Recent research remains limited. One study found that openness to experience (but no other Big Five trait) and internal locus of control predicted the return-to-play composite in previously injured athletes from NCAA Division I Intercollegiate athletic teams (Osborne & Doty, 2022). Another study by Manko et al. (2024) found that all Big Five traits were related to injury perception, with different patterns for high vs. low-risk sports athletes. Finally, in a study of Slovene athletes surgically treated for knee injuries (Masten, Stražar, Žilavec, Tušak, & Kandare, 2014), emotional lability and „masculinity" (consisting of neuroticism and calmness) predicted a variety of psychological responses to injury, while extraversion did not.

A self-determination theory review of psychological factors associated with post-injury return to sport (Ardern, Taylor, Feller, & Webster, 2013) found tentative evidence that positive emotional responses were related to better recovery outcomes (higher rate of return, faster return, higher level of play after return). This evidence supports the hypothesis that emotion-related traits hold the most promise for predicting injury recovery. Together, current studies on injury risk and recovery suggest that emotion-related traits generally and sport injury anxiety specifically hold the most promise to predict recovery outcomes.

Why alexithymia?

Alexithymia („no words for feelings") encompasses difficulties in identifying, reflecting on, regulating, and verbally communicating emotional states (Taylor, 2000). These cognitive-experiential deficits further impair interpersonal emotion regulation by preventing the person from relying on other people to alleviate difficult emotional experiences.

Alexithymia is notably frequent in people with various psychiatric conditions (see e.g. Taylor, Bagby, & Parker, 1999), and somatic diseases with a suspected psychological component (see e.g. Holmes, Marella, Rodriguez, Glass, & Goerlich, 2022). Interestingly, recent studies have found high rates of alexithymia among athletes, a population typically conceived as „healthy adults" (Proenca-Lopes, et al., 2022a), especially high-performance athletes in confrontational (Proenca-Lopes, et al., 2022b) and high static-dynamic sports (Graham, Boat, Cooper, & Kinrade, 2025).

Alexithymia has been linked to high-risk sport participation, suggesting that high-alexithymic individuals derive emotion regulation benefits from activities that provide unambiguous frameworks for recognising and expressing emotions (Roberts & Woodman, 2015). Woodman and colleagues (Woodman, Le Scanff, & Luminet, 2020) extended this argument to sports performance in general, suggesting that sport participation offers highly alexithymic individuals an opportunity to experience and control anxiety with a clarity impossible to achieve in everyday life, contributing to their overall well-being. There is some evidence to this claim: for example, Woodman and Welch (2021) showed that anxiety was reduced in extreme endurance runners post-running, but only if they were high on alexithymia, suggesting that endurance running provided an emotion regulation function.

In our view, the paradox that alexithymic individuals may rely on sport for emotional clarity suggests that alexithymia could predict recovery difficulties when injury removes this coping mechanism.

Study goal

The goal of this study was to explore the relationship of alexithymia as a personality trait indicative of challenges in emotion regulation and sport injury anxiety to injury recovery outcomes. Based on existing theory and research about alexithymia in sport (Roberts & Woodman, 2015; Woodman, et al., 2020; Woodman & Welch, 2021), we propose that if athletes rely on sport participation to understand and regulate their emotional landscape, an injury not only arouses various emotions requiring regulation (Weinberg & Gold, 2023) but takes away the primary means of emotion regulation. We hypothesise that this could lead to two possible outcomes while favouring the former: high-alexithymic athletes might experience hindered progress in injury recovery and return to sport, or alternatively, they might be highly motivated to recover quickly to regain their primary method of emotion regulation. To our knowledge, this is the first study investigating alexithymia in the context of sport injuries. For sport injury anxiety, we aim to investigate if the importance of anxiety for injury risk extends to the post-injury phase, by using Rex and Metzler's (2016) contextually specific sport injury anxiety scale.

Method

Sample

We recruited a convenience sample of 61 athletes (31 females): 40 futsal (male) and football (female) players and 21 combat sport athletes (judo and mixed martial arts). This selection represents athletes of both genders in high-contact team and individual sports with high injury rates (Kujala, et al., 1995). Mean training load in our sample was 13.3 hours/week (SD = 5.37), and mean sport experience was ~11 years (M = 136.5 months, SD = 63.6). Among football and futsal players, most were members of their respective national teams (82.5%) at the time of participation, and 92.5% had been national team members at some point in their careers. Among combat athletes, 50% were national-level and 40% international-level athletes.

Athletes were asked to report all medically recognised injuries that required absence from training and/or competition for at least seven days. Inclusion criteria were: (1) being active competitive athletes, (2) being of minimum age of 15 years per Ethical guidelines of the Serbian Psychological Society, and (3) the history of at least one medically recognised injury requiring ≥ 7 days absence from training/competition. Four participants were excluded: three reported no injuries meeting inclusion criteria and one participant was underage. The final sample consisted of 57 athletes (30 females), aged 15 to 32 years (M = 23).

Instruments

Toronto alexithymia scale (TAS20; Bagby, Parker, & Taylor, 1994) was used for assessing alexithymia. TAS is a 20-item scale grouped in three indicators: identifying emotions (five items), describing emotions (seven items), and externally oriented thinking style (eight items). We used the adapted Serbian version of the TAS (Trajanović, et al., 2014). Participants responded on a 1-5 Likert scale. We opted to calculate the mean scores for each indicator instead of summary scores to facilitate comparison. We also calculated summary total scores in order to compare alexithymia prevalence in the population of athletes with alexithymia prevalence in the general population.

Sport injury anxiety scale (SIAS; Rex & Metzler, 2016) was used to measure general injury anxiety. SIAS consists of 21 items grouped in seven subscales (losing athletic ability, being perceived as weak, pain, letting down important others, reinjury, losing social support, impaired self-image). Each item was graded on a five-point Likert scale. The SIAS was back-translated to Serbian for this study. We calculated mean total score, and mean score for each subscale.

Recovery outcomes were measured with the Return to Sport after Serious Injury Questionnaire (RSSIQ; Podlog & Eklund, 2005) consisting of 15 items graded on a 7-point Likert scale and grouped in two indicators: return concerns (eight items) and renewed perspective (seven items), indicating negative and positive outcomes, respectively. The RSSIQ was also back-translated to Serbian for this study. Participants were instructed to respond to RSSIQ with respect to their most serious injury. Mean scores were calculated for each outcome separately.

Procedure

After providing informed consent, participants first provided socio-demographic information and reported on their sport experience and weekly training load, and then reported on their injuries (frequency, type, severity), after which they completed the RSSIQ, SIAS, and TAS-20 (in that order). Athletes were tested individually, and they completed the questionnaires either online (n = 22) or in printed form (n = 39), which took approximately 15-20 minutes to finish.

The study was approved by the Institutional Review Board of the University of Belgrade – Faculty of Sport and Physical Education (#02-757/25-2). All data, supplementary tables and study materials are available on OSF (https://osf.io/bsnjq/).

Data analysis

Descriptive statistics and Cronbach's alpha were calculated for all measures. Normality was assessed with the Shapiro-Wilks test, with the square-root transformation applied to variables with extreme skew. Pearson correlation coefficients were computed between alexithymia, sport injury anxiety, and recovery. Multiple regression analyses were performed to predict recovery from alexithymia and anxiety. Power analysis (G*Power; Faul, Erdfelder, Buchner, & Lang, 2009) indicated that our sample was adequately powered for large and somewhat underpowered for medium-sized effects (required N = 68 for power of .80 and α = .05). Two-way ANCOVA examined gender and sport type differences with sport experience as a covariate. Homogeneity of variances was assessed using the Levene's test. For the between-group comparison, our study was only suitable to detect large effects (required N = 64 for power of .80 and α = .05). Effect sizes were calculated using partial eta squared (ANCOVA) and standardized beta coefficients (regression). Analyses were performed using JASP (v. 0.18.1.0) with the significance level set at α = .05.

Results

Table 1 presents descriptive statistics and scale reliabilities for alexithymia, sport injury anxiety and recovery outcomes, and Table 2 presents TAS-20 alexithymia cutoff scoring categories in this sample of athletes. Reliability of the externally oriented thinking style scale of the TAS-20 was very low and much lower than reported in the original study (Bagby, et al., 1994) and the Serbian translation validation study (Trajanović, et al., 2013). We explored the reliability in detail and found two items negatively correlated to the total score (both related to preferences in consuming cinematographic content, Supplementary table on OSF), and several items with a low item-total correlation. Therefore, we

Table 1. Alexithymia, sport injury anxiety and recovery outcomes: Descriptives and scale reliabilities

		Min	Max	M	SD	SW	α
TAS	Identifying feelings	1.00	4.00	2.44	0.83	0.960	.79
	Describing feelings	1.00	4.80	2.71	0.91	0.966	.67
	Externally oriented thinking	1.00	3.63	2.40	0.53	0.986	.24
SIAS	Losing ability	1.00	5.00	2.46	1.20	0.919**	.92
	Being perceived as weak	1.00	4.33	2.00	1.06	0.849**	.83
	Pain	1.00	4.67	2.77	1.05	0.942**	.69
	Letting down important others	1.00	4.67	2.05	1.02	0.877**	.83
	Reinjury	1.00	5.00	2.56	1.17	0.939**	.86
	Losing social support	1.00	5.00	1.88	0.95	0.850**	.87
	Impaired self-image	1.00	5.00	2.48	1.21	0.915**	.84
	Total	1.00	4.38	2.31	0.80	0.972	.93
RSSIQ	Return concerns	1.00	6.30	3.46	1.52	0.952*	.92
	Renewed perspective	1.40	7.00	5.05	1.79	0.878**	.94

Note. Min – minimum; Max – maximum; M – mean; SD – standard deviation; SW – Shapiro-Wilks test; TAS – Toronto alexithymia scale; SIAS – Sport injury anxiety scale; RSSIQ – Return to sport after serious injury questionnaire; * p<.05; ** p<.01.

will present all the results from TAS but we invite caution in interpreting the externally oriented thinking scores and total alexithymia scores.

Despite the stated caveat, it is notable that almost 20% of the athletes scored 61 and above on TAS, the suggested cutoff value for alexithymia (Bagby, et al., 1994; Bagby & Taylor, 1997), and a similar number of athletes scored in the range of the „possible alexithymia" category (Table 2). Despite the high frequency of alexithymia as suggested by the cutoff total scores, the TAS scale means were somewhat below the theoretical average. SIAS average scores were also below the midpoint. A notable exception is the renewed perspective with high average scores and a negative skew. However, as the skew was not extreme in any of the scales, we chose to present the analysis of non-transformed data. We repeated the analysis with transformed variables, and found no notable changes in the results.

Pearson correlations between the variables are presented in Table 3**.** Difficulties in identifying feelings (TAS-ID) and describing feelings (TAS-DE) were positively correlated, but both were unrelated to externally oriented thinking (TAS-EOT), possibly due to the low internal consistency of the externally oriented thinking scale. In contrast, the scales of the SIAS were positively related and highly internally consistent, implying that athletes who reported higher injury anxiety tended to do so across appraisals. Injury anxiety (total score and five out of seven scales) was related to TAS-ID, but not to TAS-DE or TAS-EOT, meaning that athletes who reported higher injury anxiety also reported more difficulties in identifying feelings; however, the remaining aspects of alexithymia were independent from injury anxiety.

Recovery outcomes as indicated by the return concerns were positively related to both TAS-ID and SIAS (total and five out of seven scales), meaning that difficulties in identifying feelings and higher anxiety were associated with negative outcomes. In contrast, the renewed perspective indicator, measuring positive outcomes, was related to neither anxiety nor alexithymia.

Due to high internal consistency of the SIAS and small sample size in our study, we decided to use the SIAS total score to predict injury recovery. Alexithymia and anxiety predicted 27.7% of the variance in return concerns, $F(2, 54) = 10.78$, $p < .001$, $R = .534$, $R^2_{adj} = .259$. Specifically, identifying feelings, $\beta = .329$, , $t = 2.53$, $p = .014$, $\rho = .326$, and SIAS total scores, $\beta = .294$, , $t = 2.26$, $p = .028$, $\rho = .294$, had very similar contribution to predicting

Table 2. TAS-20 cutoff scores

Category	N	%	M	%	F	%
No alexithymia (0-51)	33	57.9	16	59.3	17	56.7
Possible alexithymia (52-60)	13	22.8	7	25.9	6	20.0
Alexithymia present (61-100)	11	19.3	4	14.8	7	23.3

Note. N – total sample; M – male athletes; F – female athletes.

Table 3. Alexithymia, injury anxiety and recovery outcomes: Correlations

	ID	DE	EOT	LA	BPW	PAIN	LDIO	RI	LSS	ISI	TOTAL	RC	RP
TAS-ID	1												
TAS-DE	.611**	1											
TAS-EOT	0.164	0.198	1										
SIAS-LA	.313*	0.104	0.027	1									
SIAS-BPW	.354**	0.247	.264*	.274*	1								
SIAS-PAIN	.373**	0.204	-0.006	.430**	.460**	1							
SIAS-LDIO	0.246	0.194	0.098	.568**	.482**	.449**	1						
SIAS-RI	.451**	0.118	-0.033	.435**	.393**	.677**	.439**	1					
SIAS-LSS	0.127	0.025	0.162	0.231	.349**	.456**	.391**	.304*	1				
SIAS-ISI	.463**	.269*	0.025	.607**	.419**	.482**	.594**	.447**	.541**	1			
SIAS-TOT	.466**	0.231	0.099	.714**	.656**	.774**	.768**	.734**	.625**	.812**	1		
RSSIQ-RC	.466**	0.253	-0.123	.329*	0.170	.357**	.348**	.565**	0.103	.360**	.448**	1	
RSSIQ-RP	0.051	0.114	-0.242	0.056	-0.187	0.161	0.036	-0.002	0.016	0.210	0.061	0.146	1

Note. * p<.05; ** p<.01; TAS – Toronto alexithymia scale; ID – identifying feelings; DE – describing feelings; EOT – externally oriented thinking; SIAS – sport injury anxiety scale; LA – losing ability; BPW – being perceived as weak; LDIO – letting down important others; RI – reinjury; LSS – losing social support; ISI – impaired self Image; RSSIQ – Return to sport after serious injury questionnaire; RC – return concerns; RP – renewed perspective.

Table 4. Alexithymia, sport injury anxiety and recovery outcomes: Descriptives and scale reliabilities per sport type and gender

		Gender				Sport type			
		Male		Female		Team		Individual	
		M	SD	M	SD	M	SD	M	SD
TAS	Identifying feelings	2.23	0.80	2.63	0.83	2.53	0.77	2.26	0.96
	Describing feelings	2.67	0.82	2.74	0.99	2.84	0.94	2.42	0.79
	Externally oriented thinking	2.58	0.48	2.23	0.52	2.39	0.49	2.41	0.61
SIAS	Losing ability	2.37	1.18	2.54	1.22	2.40	1.14	2.59	1.34
	Being perceived as weak	2.07	1.19	1.93	0.94	1.97	1.13	2.07	0.92
	Pain	2.72	1.01	2.82	1.10	2.73	1.11	2.87	0.94
	Letting down important others	2.14	1.06	1.97	0.99	1.93	0.96	2.30	1.11
	Reinjury	2.37	1.03	2.72	1.28	2.50	1.18	2.69	1.16
	Losing social support	1.98	1.12	1.80	0.78	1.86	0.94	1.93	1.01
	Impaired self-image	2.33	1.22	2.61	1.20	2.52	1.21	2.39	1.22
	Total	2.28	0.86	2.34	0.75	2.27	0.78	2.40	0.85
RSSIQ	Return concerns	3.14	1.44	3.76	1.56	3.49	1.54	3.42	1.52
	Renewed perspective	4.71	1.80	5.35	1.76	5.45	1.63	4.18	1.87

Note. M – mean; SD – standard deviation; TAS – Toronto alexithymia scale; SIAS – Sport injury anxiety scale; RSSIQ – Return to sport after serious injury questionnaire; * p<.05; ** p<.01.

Table 5. Injury risk: Descriptives

	Min	Max	M	SD	zSk	zKu	SW
Number of injuries	1	15	4.02	3.22	5.576	5.382	.808**
Length of absence (months)	0	18	4.68	3.87	4.264	2.731	.868**

Note. Min – minimum; Max – maximum; M – mean; SD – standard deviation; zSk – standardised skewness; zKu – standardised kurtosis; SW – Shapiro-Wilks test; * p<.05; ** p<.01.

return concerns. The more difficulties in identifying feelings and the higher injury anxiety, the more concerned athletes were about their return to sport following most serious injury they had experienced during their career.

Descriptive statistics on alexithymia, injury anxiety and injury recovery by gender and sport type are presented in Table 4, and the results of sport type x gender ANCOVA with sport experience as covariate are presented in Table 5. On alexithymia, female athletes scored higher on TAS-identifying feelings ($F(1, 52) = 4.15$, $p < .05$, $\eta^2_p = .07$) and males on TAS-externally oriented thinking style ($F(1, 52) = 5.11$, $p < .05$, $\eta^2_p = .09$); however, there were no significant effects of sport type nor interaction effects. On sport injury anxiety, there was a significant interaction between sport type and gender ($F(1, 52) = 4.05$, $p < .05$, $\eta^2_p = .07$), originating from female athletes in individual sports reporting higher injury anxiety compared to team sport athletes ($t(28) = -2.19$, $p < .05$, $d = .70$). Return concerns did not differ by gender and sport type; in contrast, athletes in team sports scored higher on renewed perspective compared to athletes in individual sports ($F(1, 52) = 6.61$, $p < .05$, $\eta^2_p = .11$). Sport experience as a covariate did not reach statistical significance in any of the analyses.

We also analysed the relationship of injury risk and alexithymia, injury anxiety and injury recovery. Descriptive statistics on injury risk are presented in Table 5. Injury risk was measured with the number of injuries athletes reported and their severity as indicated by the length of absence from training and competition. Both training and injury-related measures varied considerably in our sample. As the number of injuries and length of absence were extremely positively skewed, we applied the square-root transformation before correlating them to psychological antecedents and outcomes. Athletes who experienced more injuries during their careers reported a more positive outlook following their return to sport ($r = .382^{**}$). No other correlation with the number of injuries and length of absence was statistically significant.

Discussion and conclusions

In this study, we investigated the relationship between alexithymia, sport injury anxiety and injury recovery. To our knowledge, this is the first study to explore the role of alexithymia in injury recovery. While we favoured the hypothesis that high alexithymia might impede recovery through emotional processing deficits, we acknowledged an alternative possibility within current theoretical frameworks on sport injury. Our results should be interpreted as an exploratory first step to studying alexithymia in the injury recovery context. Regarding sport injury anxiety, we hypothesised that anxiety, especially an injury-focused anxiety measure would reliably predict recovery outcomes. While previous studies have linked trait anxiety to injury risk (Appaneal & Habif, 2013; Cagle, et al., 2017; Ford, et al., 2017; McKay, et al., 2022), our study was also the first to directly examine its relationship to injury recovery.

Both hypotheses were partially confirmed: one component of alexithymia, difficulties in identifying feelings, and sport injury anxiety predicted negative consequences of injury (return concerns following most serious injury), but not positive consequences (renewed perspective to sport and injuries). While this study is the first evidence for the negative role of alexithymia in injury recovery, our results are in line with previous research suggesting that traits indicative of emotional difficulties are important for injury recovery process (Ardern, et al., 2013; Masten, et al., 2014). We did not lay out predictions regarding specific components; however, differential effects of alexithymia components align with previous studies on alexithymia and stress-related outcomes (Pollatos, et al., 2011), suggesting that alexithymia might not be a unitary construct. Findings that higher injury anxiety predicted worse recovery outcomes confirms the importance of anxiety in sport injury research (Ford, et al., 2017) and extends its domain of influence to recovery process as well; however, injury anxiety did not predict injury risk, thereby leaving the question of general vs. specific anxiety measures unresolved. Moreover, alexithymia and anxiety predicting only negative but not positive aspects is not in line with previous research registering effects of personality on both (e.g., Ardern, et al., 2013; Osborne & Doty, 2022).

Sport injuries provoke an array of negative feelings that could hinder rehabilitation and return to sport (Tamminen, Dunn, & Gairdner, 2020; Walker & Heaney, 2013). While the Integrated Model of sport injury (Wiese-Bjornstal, et al., 1998) suggests that personality shapes cognitive appraisals, which in turn influence emotional and behavioural responses, its circular core allows for reverse influences as well. We believe that traits like injury anxiety and alexithymia could affect our emotional responses both through appraisals and directly, by determining the type of emotional responses that typically arise and the athlete's capacity to regulate them. For example, injury anxiety could intensify negative responses via catastrophic beliefs and heightened emotional reactivity, thus disrupting coping. Alexithymia could impair recovery through emotion recognition deficits, poor regulation strategy selection, and ineffective implementation (Luminet & Zamariola, 2018; Preece, et al., 2023). In our study, only one component of alexithymia—difficulties in identifying feelings—predicted return concerns, despite theoretical relevance of the entire construct. Moreover, difficulties in identifying feelings and injury anxiety contributed equally to predicting return concerns, consistent with studies suggesting these constructs overlap (Berthoz, Consoli, Perez-Diaz, & Jouvent, 1999; Marchesi, Brusamonti, & Maggini, 2000; Motan & Gençöz, 2007). Without assessing rehabilitation process, any interpretation of the mechanism of influence of these traits on recovery would be tentative. Nevertheless, athletes with high injury anxiety and difficulties in identifying feelings reported greater return concerns, which emphasises the importance of emotion-related traits for negative recovery outcomes.

In contrast, neither alexithymia nor anxiety predicted positive recovery outcomes. Participants scored higher on renewed perspective than return concerns, consistent with the RSSIQ validation study (Podlog & Eklund, 2005). In addition, athletes with more injuries and team athletes scored higher on renewed perspective. It may be the case that traits other than alexithymia and anxiety are more relevant for positive injury outlook. However, in our view, it may be that the renewed perspective scale of the RSSIQ reflects survivor bias, positive memory bias, or capture socially desirable self-narratives („cultural scripts") frequent among athletes (Howells & Everard, 2020) rather than genuine experiences. Further studies are needed to resolve this issue.

Exploratory analysis of gender and sport type differences revealed that female athletes scored higher on difficulties in identifying feelings, which contrasts previous studies on general population (Mendia, et al., 2024). Moreover, we registered both main and interactive influences of sport type (individual vs. group) on injury anxiety and renewed perspective, which highlights the importance of systematically including those differences into study design. However, these group differences did not extend to return concerns, indicating that the relationships between emotion-related traits and negative recovery outcomes remained consistent across gender and sport contexts.

Alexithymia prevalence in our study was ~20%, higher in females, doubling the general population estimates of ~10%, although the estimates vary (see e.g. Franz, et al., 2008, for a study on a representative sample of the German population;

see also Kokkonen, et al., 2001; Mason, Tyson, Jones, & Potts, 2005; Matilla, Salminen, Nummi, & Joukamaa, 2006; Salminen, Saarijärvi, Äärelä, Toikka, & Kauhanen, 1999). This is in line with recent studies on athlete samples (Graham, et al., 2025; Proenca-Lopes, et al., 2022a,b). However, these estimates should be taken with caution. TAS authors denounced the cutoff scores as they imply alexithymia is categorical rather than dimensional (Bagby, Parker, & Taylor, 2020). Moreover, cross-cultural and cross-language comparisons of alexithymia has also been criticised, especially the externally oriented thinking (Ryder, Sunohara, Dere, & Chentsova-Dutton, 2018), which may reflect preferences rather than difficulties. Lower reliability of this scale is suggested to stem from conceptual issues beyond translation, as certain groups could hold specific norms regarding emotional expression. In our view, this may also be the case with athletes as a highly non-representative population with specific norms and values. In line with this interpretation, EOT scale showed poor reliability in our study (α=.24), contrasting with the acceptable reliability in the Serbian TAS validation study (Trajanović, et al., 2013).

Our study has several important limitations. Firstly, the sample size was relatively small, and the athletes were heterogeneous with respect to the number of injuries and their severity, as well as athletic experience and training load. Moreover, despite we included both the individual and team sports, our selection did not represent well the variety of sport disciplines with respect to important dimensions shaping injury experience (for example, contact vs. no-contact sport, high-risk vs. low-risk, etc). Additionally, we did not control for many potential moderators between personality and recovery outcomes, such as injury severity (beyond the days missed), quality of rehabilitation services, support network, or pre-injury psychological states. Thus, our results should be considered preliminary and replicated with a bigger sample that would enable comparison across different types of sport and different types of injuries and allow for modelling complex relationships between bio-psycho-social variables suggested by theoretical models on injury recovery (Wiese-Bjornstal, et al., 1998). Finally, our design was retrospective and based on self-report, which could be subject to social desirability bias, and we cannot claim for certain that stable traits shape the recovery outcome directly, but only its self-assessment in hindsight. Future studies should adopt a prospective and/or experimental designs and use a wider variety of recovery indicators to provide more reliable conclusions.

This study provides the first empirical evidence that difficulties in identifying feelings (a component of alexithymia) and sport injury anxiety predict negative recovery outcomes in high-performance athletes, together explaining 27.7% of variance in return concerns. Despite stated limitations, our results highlight the importance of emotion-related traits in sport injury recovery. The high prevalence of alexithymia (~20%) combined with its predictive relationship with return concerns suggests that incorporating a brief screening for alexithymia and injury anxiety into pre-season assessments or early rehabilitation could help identify athletes requiring additional psychological support focusing on emotional awareness and anxiety management.

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Correspondence to:
Marija V. Čolić
Institute of Criminological and Sociological Research
Faculty of Media and Communications, Belgrade, Serbia
E mail: marija.colic@fmk.edu.rs

RELIABILITY AND VALIDITY OF THE MEDICINE BALL THROW TEST IN CHILDREN AND ADOLESCENTS: A SYSTEMATIC REVIEW AND META-ANALYSIS

Daniel González-Devesa[1], Silvia Varela[2,3], Jose Carlos Diz-Gómez[3,4], Diego López-Amoedo[4], and Carlos Ayán-Pérez[2,3]

[1]*Research Group on Physical Activity, Education, and Health (GIAFES), Catholic University of Ávila, Ávila, Spain*
[2]*Well-Move Research Group, Galicia Sur Health Research Institute (IIS Galicia Sur), SERGAS-UVIGO, Vigo, Spain*
[3]*Department of Special Didactics, University of Vigo, Pontevedra, Spain*
[4]*Faculty of Education and Sport Sciences, University of Vigo, Pontevedra, Spain*

Systematic review
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Abstract:

The purpose of this study was to investigate the evidence regarding the reliability and validity of the medicine ball throw test when applied to children and adolescents. Systematic search was conducted in four electronic databases (Scopus, Web of Science, SPORTDiscus, and MEDLINE/PubMed) from their inception until November 2024. The meta-analysis of relative inter-session reliability synthesized data from nine studies using the intraclass correlation coefficient (n=293) and identified good test-retest reliability for the medicine ball throw test (ICC: 0.80; 95%CI [0.72-0.86]). When analysed separately, the standing chest medicine ball throw test (four studies; n=129) demonstrated fair test-retest reliability (ICC: 0.72; 95%CI [0.58-0.83]), while the seated chest medicine ball throw test (three studies; n=193) exhibited good test-retest reliability (ICC: 0.84; 95%CI [0.48-0.96]). Only three studies examined the relationship between the medicine ball throw test and other fitness measures. Various protocols are used to administer the medicine ball throw test in children and adolescents, with the seated chest medicine ball throw test proving to be particularly reliable due to its strong relative reliability. Although the medicine ball throw test demonstrates acceptable reliability, the limited investigation into its validity, particularly criterion validity, hinders definitive protocol recommendations.

Keywords: *evaluation, explosive power, field test, fitness, reproducibility*

Introduction

Monitoring and surveillance of physical fitness among children and adolescents is a priority in today's society due to its strong relationship with physical and mental health, as well as its association with lower morbidity and mortality later in life (Joensuu, et al. 2024). In this context, field-based tests are an essential tool, as they provide a low-cost and easy-to-administer method for assessing the fitness levels of children and adolescents across various settings (Castro-Pinero, et al. 2010). Among the wide variety of field-based tests and fitness batteries designed for this population, cardiorespiratory fitness and upper body strength are the most commonly assessed fitness dimensions (Marques, et al. 2021). Since these tests are not laboratory-based and are typically not considered gold-standard measures, they must demonstrate adequate psychometric properties when administered to children and adolescents before being considered reliable for identifying fitness levels.

Several systematic reviews have been conducted to identify the validity and reliability of various cardiorespiratory fitness tests administered to children and adolescents, given its importance as a health marker in this population (González-Devesa, Diz-Gómez, Sanchez-Lastra, Rodríguez & Ayán-Pérez, 2024; Lang, et al., 2018; Martínez-Lemos, Rodríguez, Diz, & Ayán-Pérez, 2024). However, there is a notable gap in systematic reviews specifically focused on the psychometric properties of field tests assessing upper body strength, despite established links between muscular fitness and lower adiposity, reduced cardiovascular and metabolic disease risk, improved academic outcomes, and higher quality of life in youth (Brazo-Sayavera, et al., 2024)

In this context, the medicine ball throw test (MBT), a cost-effective, quick measurement of upper-extremity power, emerges as a physical fitness field-based test worthy of further investigation. The MBT was first introduced as a fitness measurement tool in the early 1930s (Dunder, 1933) and has since been used for various purposes in research on children and youth across different contexts, such as physical education (Petrušič, Trajković, & Bogataj 2022), epidemiological and intervention studies (Han, Fu, Cobley, & Sanders, 2018; Kryst, Żegleń, Artymiak, Kowal, & Woronkowicz, 2023), or sports training and performance (Garcia-Carrillo, et al. 2023; Koya, Kitamura, & Takahashi, 2022). Its continued application for over nine decades highlights its longstanding presence and relevance in the field of physical fitness assessment.

Despite its widespread use, there is a lack of research that consolidates and critically evaluates the psychometric properties and practical applicability of the MBT as a tool for estimating muscular power in children and adolescents. Psychometric properties refer to the measurement qualities that determine whether an assessment tool is reliable, valid, responsive, and precise in capturing the construct it intends to measure (Ginty, 2020; Monticone, Galeoto, Berardi, & Tofani, 2021). This is crucial, as field tests designed for fitness assessment must undergo a thorough evaluation of its reliability and validity to ensure the credibility and robustness of the results (Domone, Mann, Sandercock, Wade, & Beedie, 2016). Under these circumstances, this systematic review and meta-analysis aimed to provide the best available scientific evidence of the reliability and validity of the MBT for estimating upper body muscular fitness in children and adolescents.

Material and methods

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page, et al. 2021).

Search strategy

A systematic search was conducted in four electronic databases (Scopus, Web of Science, SPORTDiscus, and MEDLINE/PubMed) covering the period from their inception until November 2024. The following search terms, Boolean operators, and combinations were used: ("Throw* Test" OR "Ball Throw*" OR "Medicine Ball") AND ("Reliab*" OR "Consistency Agreement" OR "Valid*" OR "Reproducib*" OR "Measure*" OR "Accuracy" OR "Test-retest").

Eligibility criteria

Eligible studies included those that provided information on the validity and/or reliability of the MBT in children and/or adolescents. Investigations were excluded if they met any of the following criteria: a) the sample included adults, unless separate data were specifically available for children and adolescents, b) a ball-throw test was administered but a medicine ball was not used (e.g., a tennis ball or basketball was used instead), c) specific data on the validity/reliability of the MBT were not provided. To qualify for the initial screening, studies needed to be published or in-press in peer-reviewed journals (i.e., abstracts from conference proceedings, books, theses, and dissertations were not considered) and have an abstract available for review. Studies were not excluded based on the language of publication.

Study selection

The Rayyan software (QCRI, Qatar) was used to remove duplicate references before screening (Ouzzani, Hammady, Fedorowicz, & Elmagarmid, 2016). The authors (D.G.-D. and D.L.-A.) independently assessed the titles and abstracts of the identified studies to evaluate their eligibility. Following this initial review, the selected studies were examined by the mentioned authors to confirm inclusion. Any discrepancies were resolved through discussion and consensus. Full-text versions of potentially relevant studies were then obtained. When studies were unavailable, their authors were contacted directly.

Data extraction

A single researcher (D.G.-D.) extracted data from the original reports, including details on the country, year of the study, sample characteristics, MBT procedure and administration, reliability, time interval (when available), and validity. The other author (S.V.) then cross-verified the extracted data (see Table 1).

Quality appraisal

The quality evaluation of studies reporting data on the MBT reliability was conducted using a checklist assessing the precision in describing the sample (i), the time interval (ii), the results (iii), and the suitability of the statistical methods employed (iv). Each criterion was scored on a scale from 0 to 2. Based on the total scores, studies were classified into three categories: very low quality (score < 2), low quality (score 2–5), and high quality (score ≥ 6), following the methodology described by Cuenca-Garcia et al. (2022).

The methodological quality of studies addressing criterion-related validity was appraised through three specific criteria: sample size (i), description of the study population (ii), and statistical analysis (iii). Each of these was also rated from 0 to 2. Studies with a total score exceeding 5 were considered high quality, those scoring between 3 and 4 were labeled as low quality, and scores below 3 indicated very low quality. This classification approach aligns with the framework suggested by Castro-Piñeiro et al. (2010).

These quality tools had previously been used in other studies. The evaluation process was initially performed by one researcher (S.V.) and subsequently verified by the other (D.L.-A.). In cases of disagreement, the third researcher (D.G.-D.) provided the final decision.

Meta-analysis

We performed the meta-analysis calculations in Microsoft Excel with Meta-Essentials Workbooks (Workbook 5, correlational data 1.5) (Suurmond, van Rhee, & Hak, 2017). We selected the random effects model for all analysis to account for the sources of heterogeneity among different studies, and the forest plot was used to summarize the findings. Results of intraclass correlation coefficient (ICC) were interpreted using these ranges: 0.90-1 excellent, 0.80-0.89 good, 0.70-0.79 fair and < 0.69 poor reliability (Shrout & Fleiss 1979).

The I^2 was applied to assess statistical heterogeneity and inconsistency. An I^2 value of 0% indicates no observed heterogeneity, and higher values indicate greater heterogeneity. In addition to 95% confidence intervals (CI), we calculated the prediction intervals (PI). Funnel plot with Egger's test and trim-and-fill analysis were used to evaluate statistically the presence of any publication bias. We also conducted sensitivity analyses to test the robustness of the results.

Results

Studies selection

We obtained 2417 records from the database search (Web of Science=822, Scopus=722, SportDiscus=466, and PubMed=407). After excluding duplicates, we screened the titles and abstracts of 1241 records, and subsequently, 63 articles were retrieved for the full-text assessment. Finally, 16 studies (ten identified through the main databases and six discovered via citation searching) met the inclusion criteria and were included in the systematic review (Figure 1).

Reliability

After reviewing the selected studies, reliability data were categorized into relative (inter-session, intra-session, and inter-rater) and absolute (inter-session and intra-session) reliability.

Relative inter-session reliability. A total of nine studies informed about the inter-session reliability of the MBT (Table 1). Samples ranged from 12 (Khemiri, Teboulbi, Gritli, Hachana, & Attia, 2022) up to 105 participants (Davis, et al., 2008). All investigations involved males, except for Davis et al. (2008), Jarnig, Jaunig, Kerbl, Lima, and Van Poppel (2022), Khemiri et al. (2022), and Fjørtoft, Pedersen, Sigmundsson, and Vereijken (2011),

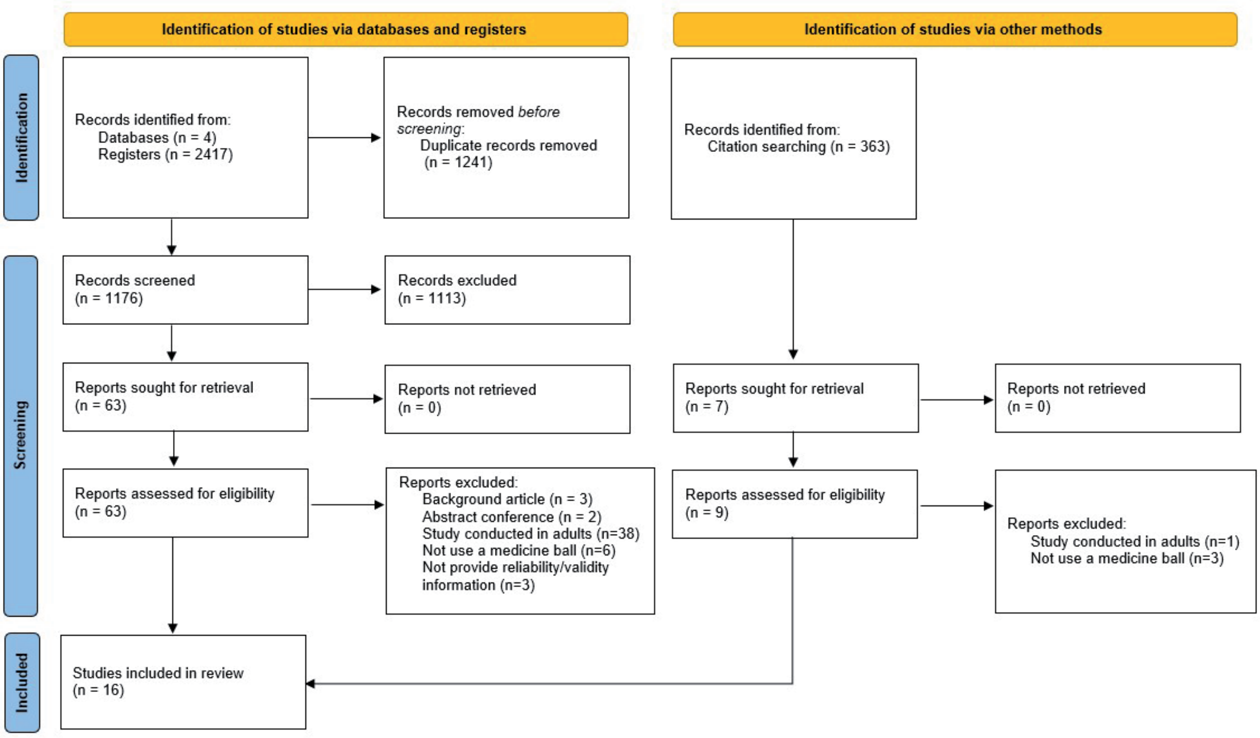

Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) study flow diagram.

Table 1. Studies on the reliability and/or validity of the medicine ball test

Author (year), Country	Sample Characteristics	Test procedure and results	Reliability	Validity
Hermassi et al. (2021), Qatar	**Participants (n; sex):** 28 young handball players; 28M **Age, *years* (mean; SD):** 10.9 ± 0.72 **BMI, kg/m^2 (mean; SD):** 24.4 ± 8.01	**Test:** Seated Chest MBT **Ball weight:** 3kg **Administration:** The sitting participant had to grasp the medicine ball with both hands, and on the given signal forcefully had to push the ball from the chest. The score was calculated from the front of the sitting line to the place where the ball landed. **Distance reached, *meters* (mean; SD):** test= 4.88 ± 0.90, re-test= 4.74 ± 0.86	**Inter-session reliability** • **ICC, 95% CI:** 0.98 (0.91-1.00) • **CV (%), 95% CI:** 2.8 (2.1-4.2) **Time interval:** 14 days **Familiarization session**: All individuals were first familiarized during ad hoc preliminary sessions.	-
Davis et al. (2008), USA	**Participants (n; sex):** 105 children; 60M + 45F **Age, *years* (mean; SD):** 5.54 ± 0.5 **BMI, kg/m^2(mean; SD):** 17.44 ± 3.17	**Test:** Seated Chest MBT **Ball weight:** 2lb **Administration:** Each student was seated on the floor with their back against the wall, holding the ball with both hands resting on their lap. Upon the tester's command ("go"), they were instructed to lift the ball to their chest and throw it forward with maximum force. Each participant completed two practice throws, followed by three recorded throws, with a 1- to 2-minute rest interval between each attempt. **Distance reached, *cm* (mean; SD):** test= 123.41 ± 41.97, re-test= 126.01 ± 39.11	Inter-session reliability • **ICC:** 0.88 **Time interval: 7** days **Familiarization session**: NR **Intra-session reliability:** • **ICC, test:** 0.93 • **ICC, re-test:** 0.94	Concurrent validity - Correlation with: ***Modified pull-up test:*** r=-0.04
Carron et al. (2024), Austria	**Participants (n; sex):** 47 young rugby players; 47M **Age, *years* (mean; SD):** 16.2 ± 1.3 **BMI, kg/m^2:** NR	**Test:** Seated Chest MBT **Ball weight:** 2kg **Administration:** Players were seated on a flat bench with their backs in contact with an adjacent wall, knees flexed to 90°, and feet in full contact with the floor. Players were not permitted to break contact with the bench or floor during each throw. **Distance reached, *meters* (mean; SD):** test= 7.06 ± 0.64, re-test= 7.07 ± 0.71	Inter-session reliability • **ICC, 95% CI:** 0.733 (0.566-0.842) • **CV (%):** 3.72 • **SEM:** 0.347 • **MDC:** 0.963 **Time interval:** 7 days **Familiarization session**: NR	-
Biggar et al. (2022), USA	**Participants (n; sex):** 113 adolescents; 56M + 57F ***12-13 years M:*** 25 ***12-13 years F:*** 31 ***13-15 years M:*** 29 ***13-15 years F:*** 25 **Age, *years* (range):** 12-15 **BMI, kg/m^2 (mean; SD):** ***12-13 years M:*** 21.5 ± 5.9 ***12-13 years F:*** 21.2 ± 5.9 ***13-15 years M:*** 22.6 ± 5.1 ***13-15 years F:*** 21.7 ± 3.2	**Test:** Seated Chest MBT **Ball weight:** 2kg **Administration:** Participants started by sitting at a 90° angle against a designated wall with their legs straight out and their head resting on the wall. Participants pushed the medicine ball in a chest-pass motion as forcefully as possible without their back or their head leaving the wall. **Distance reached, *meters* (mean; SD):** ***12-13 years M:*** 4.3 ± 0.7 ***12-13 years F:*** 3.4 ± 0.5 ***13-15 years M:*** 5.2 ± 0.8 ***13-15 years F:*** 3.7 ± 0.5	**Intra-session reliability:** • **r:** 0.85-0.97 **Familiarization session**: NR	-
Chiwaridzo et al. (2021), Zimbabwe	**Participants (n; sex):** 41 young rugby players; 41M **Age, *years* (mean; SD):** 17.5 ± 0.9 **BMI, kg/m^2 (mean; SD):** 25.9 ± 3.3	**Test:** Seated Chest MBT **Ball weight:** 2kg **Administration:** Players threw a medicine ball (dimensions=21.5cm) horizontally as far as possible while seated with the back, and legs straight. **Distance reached, *meters* (mean; SD):** test= 9.3 ± 1.3, re-test= 9.41 ± 1.3	**Inter-session reliability** • **ICC, 95% CI:** 0.89 (0.80-0.94) • **CV (%), 95% CI:** 4.48 (3.4-6.1) • **SEM, 95% CI:** 0.42 (0.2-0.67) • **MDC, 95% CI:** 1.16 (0.98-1.27) **Time interval: 7** days **Familiarization session**: Two familiarization sessions were conducted	-
Chiwaridzo et al. (2019), Zimbabwe	**Participants (n; sex):** 100 adolescents; 100M ***U16 elite rugby players:*** 41 ***U16 sub-elite rugby players:*** 30 ***U16 cricket players:*** 29 **Age, *years* (mean; SD):** 14.9 ± 0.31 **BMI, kg/m^2:** NR	**Test:** Seated Chest MBT **Ball weight:** 2kg **Administration:** Players threw a medicine ball (dimensions=21.5cm) horizontally as far as possible while seated with the back, and legs straight. **Distance reached, *meters* (mean; SD):** ***U16 elite rugby players:*** 6.97 ± 0.64 ***U16 sub-elite rugby players:*** 5.91 ± 0.86 ***U16 cricket players:*** 5.83 ± 0.86	**Subsample =** 41 U16 elite rugby players **Intra-session reliability** • **ICC:** 0.91 • **CV (%):** 1.45 • **Time interval:** 2 minutes **Familiarization session**: Two familiarization sessions were conducted	-

Hackett et al. (2017), Australia	**Participants (n; sex):** 190 adolescents; 130M + 60F **Age, *years* (mean; SD):** ***M:*** 12.8 ± 0.5 ***F:*** 12.8 ± 1.0 **BMI, *kg/m²:*** NR	**Test:** Seated Chest MBT **Ball weight:** 3kg **Administration:** Participants sat on an upright bench. The seat position was adjusted so that their knees were at approximately 90 degrees of flexion, with their feet flat on the floor. Participants were instructed to push a medicine ball from the center of their chest as far as possible, keeping their head, shoulders, and lower back in contact with the bench. A 10-meter tape measure was placed alongside the bench, and a researcher visually assessed the initial ground contact point of the ball for each attempt. **Distance reached, *cm* (mean; SD):** test= 339.9 ± 75.8, re-test= 348.5 ± 78.5	**Intra-session reliability** • **ICC, 95% CI:** 0.98 (0.96-0.98) • **CV (%), 95% CI:** 3.4 (2.9-4) • **ME:** 7.4 • **TE (%):** 2.2 **Time interval: <**1 day **Familiarization session**: Participants were allowed one to two practice attempts to familiarize themselves with the procedure before beginning the actual attempts.	-
Jarnig et al. (2022), Austria	**Participants (n; sex):** 821 children; 58M + 28F **Age, *years* (mean; SD):** 8.3 ± 0.7 **BMI, *kg/m²* (mean; SD):** 16.9 ± 2.9	**Test:** Standing Chest MBT **Ball weight:** 1kg **Administration:** Each child stood on a starting line holding a medicine ball with both hands, the ball touching their chest, then threw the ball with both hands as far forward as possible. **Distance reached, *cm* (mean; SD):** test= 411 ± 84, re-test= 436 ± 76	**Subsample=** 17 children **Inter-session reliability** • **ICC, 95% CI:** 0.70 (0.35-0.88) **Time interval: 7** days **Familiarization session**: NR Inter-rater reliability • **ICC, 95% CI:** 0.99 (0.99-0.99)	-
Bös et al. (2001) Germany	**Participants (n; sex):** 138; Kindergarten: 40 Elementary school: 50 Secondary school: 48 **Age, *years* (range):** 6-10 **BMI, *kg/m²*:** NR	**Test:** Standing Chest MBT (with upper body swing) **Ball weight:** 1kg **Administration:** Participants were instructed to hold a medicine ball with bent arms in front of their chest and to push the ball as far as possible from a standing position. They stood upright with their back against the wall, with the tips of their shoes touching the starting line. Swinging the upper body up to the wall was permitted. **Distance reached, *cm* (mean; SD):** Reported by age and sex	**Subsample=** 38 children **Inter-session reliability** • **r:** 0.73-0.85 **Time interval:** 10 days **Familiarization session**: NR	-
Dobbin et al. (2018), UK	**Participants (n; sex):** 50 young rugby players; 50M **Age, *years* (mean; SD):** 17.1 ± 1.1 **BMI, *kg/m²*:** NR	**Test:** Standing Chest MBT (with squat) **Ball weight:** 4kg **Administration:** Participants began standing upright with the ball above their head. They then lowered the ball toward their chest while squatting down to a self-selected depth before extending up onto their toes and pushing the ball as far as possible. Feet remained shoulder width apart, stationary, and behind a line that determined the start of the measurement. **Distance reached, *meters* (mean; SD):** ***Trial 1***= 6.4 ± 0.8 ***Trial 2***= 6.9 ± 0.7 ***Trial 3***= 6.6 ± 1	**3 separate occasions* **Inter-session reliability** • **ICC, 95% CI:** 0.74 (0.57-0.84) • **CV (%), 95% CI:** 9 (7.9-10.5) • **TE, 95% CI:** 0.5 (0.4-0.6) • **SWC:** 0.2 **Time interval:** 5-14 days **Familiarization session**: NR **Comparisons, *Trial 1 vs 2:*** • **ICC, 95% CI:** 0.71 (0.28-0.86) • **CV (%), 95% CI:** 6.9 (5.8-8.3) • **TE, 95% CI:** 0.5 (0.4-0.5) **Comparisons, *Trial 1 vs 3:*** • **ICC, 95% CI:** 0.5 (0.11-0.71) • **CV (%), 95% CI:** 14 (11.9-17.1) • **TE, 95% CI:** 0.7 (0.6-0.85) **Comparisons, *Trial 2 vs 3:*** • **ICC, 95% CI:** 0.73 (0.5-0.85) • **CV (%), 95% CI:** 10.7 (9.1-13.1) • **TE, 95% CI:** 0.5 (0.43-0.6)	-

Fjørtoft et al. (2011), Norway	**Participants (n; sex):** 195 children; 94M +101F ***5 years:*** 21 ***6 years:*** 21 ***7 years:*** 21 ***8 years:*** 21 ***9 years:*** 21 ***10 years:*** 21 ***11 years:*** 21 ***12 years:*** 21 **Age, *years* (mean; SD):** 8.3 ± 2.21 **BMI, *kg/m²* (mean; SD):** ***5 years:*** 15.4 ± 1.6 ***6 years:*** 16.8 ± 2.01 ***7 years:*** 16.6 ± 1.46 ***8 years:*** 17.8 ± 1.84 ***9 years:*** 17.6 ± 1.58 ***10 years:*** 16.7 ± 1.89 ***11 years:*** 18.5 ± 3.22 ***12 years:*** 19.1 ± 2.38	**Test:** Standing Chest MBT **Ball weight:** 1kg **Administration:** The starting position is with the feet parallel to each other and shoulder width apart, with the ball held against the chest. **Distance reached, *meters* (mean; SD):** test= 3.34 ± 0.47, re-test= 3.44 ± 0.53	**Subsample =** 24 children **Inter-session reliability** • **ICC, 95% CI:** 0.54 (0.18-0.77) • **SEM, 95% CI:** 0.34 (0.28-0.45) **Time interval:** 7 days **Familiarization session**: NR	**Concurrent Validity - Correlation with:** ***Standing broad jump:*** r= 0.72 ***Jumping on 2 feet:*** r=0.43 ***Jumping on 1 foot:*** r=0.41 ***Throwing a tennis ball:*** r=0.80 ***Climbing wall bars:*** r=0.83 ***Shuttle run:*** r=0.72 ***Running 20 m:*** r=0.77 ***Reduced Cooper test:*** r=0.54
Luna-Villouta et al. (2022), Chile	**Participants (n; sex):** 86 young tennis players; 58M + 28F **Age, *years* (mean; SD):** 15.4 ± 0.8 **BMI, *kg/m²*:** NR	**Test:** Standing Overhead MBT **Ball weight:** 3kg **Administration:** The players stood at a line facing the throwing direction, feet slightly apart. They brought the ball behind their head with both hands and threw it forward as far as possible without moving their feet or crossing the line for the overhead MBT. **Distance reached, *meters* (mean; SD):** ***Total sample:*** test= 7 ± 1.5, re-test= 6.9 ± 1.5 ***M:*** test= 7.7 ± 1.3, re-test= 7.6 ± 1.3 ***F***: test= 5.7 ± 1, re-test= 5.7 ± 1	**Intra-session reliability** • SEM: ***Total sample:*** 0.07; ***M:*** 0.09; ***F***: 0.03 • **MDC** ***Total sample:*** 0.16; ***M:*** 0.20 **Time interval:** < 1 day **Familiarization session**: NR	-
van den Tillaar & Marques (2011), Portugal	**Participants (n; sex):** 63 adolescents; 24M + 39F **Age, *years* (mean; SD):** 16.5 ± 1.8 **BMI, *kg/m²*:** NR	**Test:** Standing Overhead MBT **Ball weight:** 1kg and 3kg **Administration:** Participants stood with feet parallel, holding the ball with both hands in front. They performed 2-handed overhead throws, aiming for maximum distance and speed, while keeping both feet grounded and avoiding torso or hip rotation. Non-compliant attempts were disqualified and repeated. The maximal throwing velocity was determined using a Doppler radar gun **Throwing velocity, $m \cdot s^{-1}$:** NR	**Intra-session reliability** • **ICC *(1-kg medicine ball):*** 0.93 • **ICC *(3-kg medicine ball):*** 0.86 **Time interval:** <1 day **Familiarization session**: Participants underwent a practice session to familiarize themselves with 2-handed overhead throws using different weighted balls.	-
Khemiri et al. (2022), Tunisia	**Participants (n; sex):** 12 young volleyball players; 12M **Age, *years* (mean; SD):** 16.5 ± 0.52 **BMI, *kg/m²*:** 21.63 ± 1.8	**Test:** Backwards Overhead MBT **Ball weight:** 3kg **Administration:** Participants started standing, feet shoulder-width apart, facing backward. The starting line was set at heel level. Holding the medicine ball with straight arms, they performed a countermovement by bending hips and knees, lowering the ball below hip level, and then extending to throw it backward. **Distance reached, *meters* (mean; SD):** test= 11.08 ± 0.72, re-test= 11.27 ± 0.93	**Inter-session reliability** • **ICC, 95% CI:** 0.83 (0.393-0.950) • **CV (%):** 5.7 **Time interval:** 1 day **Familiarization session**: NR	-
Duncan & Hankey (2010), UK	**Participants (n; sex):** 47 adolescents; 22M + 25F **Age, *years* (mean; SD):** 12.7 ± 1.5 **BMI, *kg/m²*:** NR	**Test:** Backwards Overhead MBT **Ball weight:** 3kg **Administration:** The exercise involved participants standing with feet shoulder-width apart, holding a medicine ball at shoulder height. They performed a countermovement by bending hips, knees, and trunk to lower the ball below hip height. Then, they extended their hips, knees, and trunk, raising the ball back to shoulder height and throwing it overhead, allowing their feet to leave the ground to minimize deceleration. **Distance reached, *meters* (mean; SD):** 5.6 ± 1.3	**Intra-session reliability** • **ICC, 95% CI:** 0.89 (0.71-0.96) • **CV (%):** 6.6 **Familiarization session**: Participants were familiarized with the tests	**Concurrent Validity- Correlation with:** ***Peak power of the CMJ:*** r=0.806 ***Peak power of the WSJ:*** r= 0.632 ***Relative power output of the CMJ:*** r= 0.79 ***Relative power output of the WSJ:*** r=0.203

Duncan et al. (2005), UK	**Participants (n; sex):** 28 adolescents rugby players; 28M **Age, *years* (mean; SD):** 15.1 ± 0.5 **BMI, *kg/m²*:** NR	**Test:** Backwards Overhead MBT **Ball weight:** 3kg **Administration:** The exercise involved participants standing with feet shoulder-width apart, holding a medicine ball at shoulder height. They performed a countermovement by bending hips, knees, and trunk to lower the ball below hip height. Then, they extended their hips, knees, and trunk, raising the ball back to shoulder height and throwing it overhead, allowing their feet to leave the ground to minimize deceleration. **Distance reached, *meters* (mean; SD):** ***Trial 1***= 9.7 ± 1.4 ***Trial 2***= 10.1 ± 1.7 ***Trial 3***= 9.6 ± 1.5 ***Trial 4***= 10 ± 1.5 ***Trial 5***= 10.5 ± 1.4 ***Trial 6***= 10.6 ± 1.4	**Intra-session reliability** • **ICC, *Trial 5 vs 6*:** 0.983 • **LOA (%), *Trial 5 vs 6*:** 3.3 • **TE, *Trial 1 vs 2*:** 0.84 • **TE, *Trial 2 vs 3*:** 0.66 • **TE, *Trial 3 vs 4*:** 0.48 • **TE, *Trial 4 vs 5*:** 0.31 • **TE, *Trial 5 vs 6*:** 0.10 **Familiarization session**: NR	-

Note. BMI: body mass index; CI: confidence interval; CMJ: counter movement jump; CV: coefficient of variation; F: female; ICC: intraclass correlation coefficient; LOA: limits of agreement; M: male; MBT: medicine ball throw; MDC: minimal detectable change; ME: measurement error; NR: not reported; SD: standard deviation; SDC: smallest detectable change; SEM: standard error of measurements; SWC: smallest worthwhile change; TE: Typical Error; WSJ: weighted (7kg bar) squat jump.

which involved mixed samples. However, Bös et al. (2001) did not provide information regarding participants' sex. Participants' age ranged from 5 to 18 years, with three investigations including preschoolers (Bös, et al., 2001; Davis, et al., 2008; Fjørtoft, et al., 2011).

A wide variety of protocols were identified. Four studies provided data on the seated chest MBT. Of these, three utilized a seated position on the floor (Chiwaridzo, Ferguson, & Smits-Engelsman, 2019; Davis, et al., 2008; Hermassi, van den Tillaar, Bragazzi, & Schwesig, 2021), while the remaining study involved participants seated on a bench (Carron, Scanlan, & Doering, 2024). The weights of the medicine balls varied, ranging from 0.90 kg (2 lb) (Davis, et al., 2008) to 3 kg (Hermassi, et al. 2021). Similarly, four studies provided information on the standing chest MBT. In two of these studies, participants were not allowed to use any upper body swing (Fjørtoft, et al., 2011; Jarnig, et al., 2022), one investigation permitted upper body swing (Bös, et al., 2001), and the remaining research allowed participants to perform a squat to generate additional force (Dobbin, Hunwicks, Highton, & Twist, 2018). The weights of the medicine balls used in these studies ranged from 1 kg (Bös, et al., 2001; Fjørtoft, et al., 2011; Jarnig, et al., 2022) to 4 kg (Dobbin, et al., 2018). Finally, one investigation provided information on the backwards overhead MBT (Khemiri, et al., 2022) using a 3 kg medicine ball.

Time interval was reported in all studies, with a duration between five (Dobbin, et al. 2018) to 14 days (Dobbin, et al., 2018; Hermassi, et al., 2021). Information regarding familiarization sessions was only provided in two out of the nine studies (Chiwaridzo, et al., 2021; Hermassi, et al., 2021). Seven studies evaluated the consistency of test results using intraclass correlation coefficients, which ranged from 0.54 to 0.98. The remaining study reported Pearson's correlation coefficient values, which ranged from 0.73 to 0.85 (Bös, et al., 2001).

The pooled data from nine samples (n= 293) indicated a good test-retest reliability for the MBT (ICC*:* 0.80; 95% CI [0.72-0.86]) (Figure 2), without evidence of publication bias (Egger 1.22 [0.45; 2], p=0.74; trim and fill= 0). When the data were meta-analyzed separately, the standing chest MBT (four studies; n=129) demonstrated a fair test-retest reliability (ICC: 0.72; 95% CI [0.58–0.83]) while the seated chest MBT (three studies; n=193), showed good test-retest reliability (ICC: 0.84; 95% CI [0.48–0.96]). Additionally, the standing version exhibited higher heterogeneity (I^2=63%) than the seated version (I^2=0%) (Figure 3).

Relative intra-session reliability. Seven studies assessed the intra-session reliability of the MBT (Table 1), with sample sizes ranging from 28 participants (Duncan, Al-Nakeeb, & Nevill, 2005) to 190 participants (Hackett, Davies, Ibel, Cobley, & Sanders, 2017). Most studies involved mixed samples, except for Chiwaridzo et al. (2019) and Duncan et al. (2005), which included only male participants. While adolescents formed the primary focus of these studies, Davis et al. (2008) uniquely included children aged 5-6 years.

In terms of test procedures, three investigations evaluated the seated chest MBT with participants seated on the floor (Biggar, Larson, & Debeliso, 2022; Chiwaridzo, et al., 2019; Davis, et al., 2008), while one study assessed the seated chest MBT with participants seated on a bench (Hackett, et al., 2017). The weight used in these studies ranged from 0.9 kg (2 lbs) to 3 kg. Additionally, one study reported data on the standing overhead MBT (van den Tillar & Marques 2011) with medicine balls weighing 1 kg and 3 kg. Finally, two other studies (Duncan, et al., 2005; Duncan & Hankey, 2010) evaluated the intra-session reliability of the back-

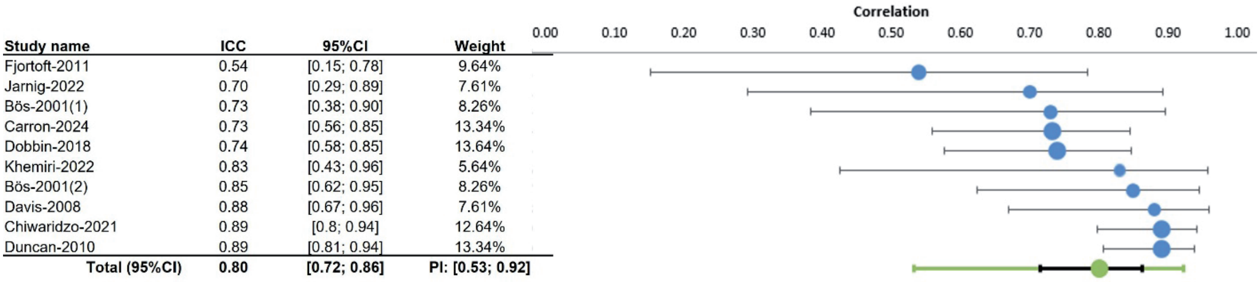

Figure 2. Forest plot for the test-retest reliability. A total of 281 participants in nine different samples. Random effects model. I^2=57%. ICC: intraclass correlation coefficient, CI: confidence interval, PI: prediction interval.

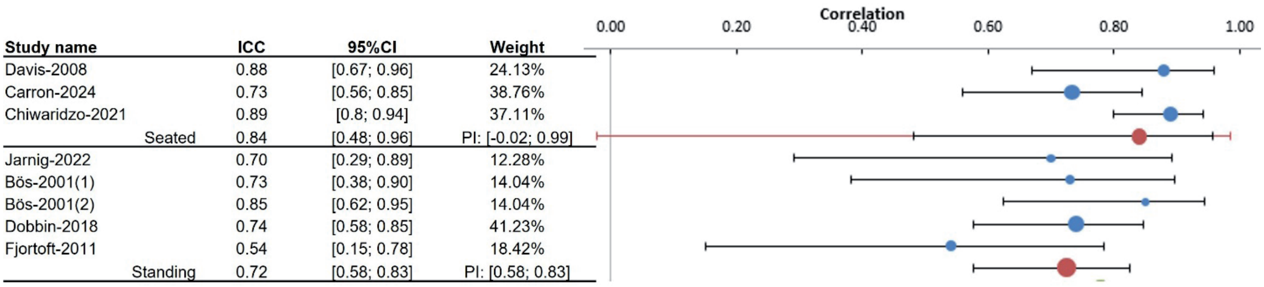

Figure 3. Forest plot for the test-retest reliability in subgroups of different samples according to throwing method. A total of 234 participants in eight studies. Random effects model. I^2=63% for seated and I^2=0% for standing. ICC: intraclass correlation coefficient, CI: confidence interval, PI: prediction interval.

wards overhead MBT using a 3 kg medicine ball.

Five studies employed ICCs to measure consistency, reporting values between 0.86 and 0.98. One study, Biggar et al. (2022), used Pearson's correlation coefficients, which ranged from 0.85 to 0.97.

Relative inter-rater reliability. One research analysed the relative inter-rater reliability of the MBT (Jarnig, et al., 2022) in a mixed sub-sample of 17 children. The study utilized the standing chest MBT with a 1 kg medicine ball. Inter-rater reliability was exceptionally high (ICC: 0.99; 95% CI [0.99–0.99]).

Absolute inter-session reliability. Six out of the 16 studies included in this review reported data on the absolute inter-session reliability of the MBT. Hermassi et al. (2021) evaluated the seated chest MBT performed on the floor with a 3 kg medicine ball and observed a coefficient of variation (CV) of 2.8% (95% CI: 2.1–4.2). Similarly, Chiwaridzo et al. (2021) analysed the same protocol with a 2 kg medicine ball and reported a CV of 4.48% (95% CI: 3.4–6.1), standard error of measurement (SEM) of 0.42 (95% CI: 0.2–0.67), and minimum detectable change (MDC) of 1.16 (95% CI: 0.98–1.27). Carron et al. (2024) examined the seated chest MBT performed on a bench and found a CV of 3.72%, SEM of 0.347, and MDC of 0.963.

For the standing chest MBT, Fjørtoft et al. (2011) observed a SEM of 0.34 (95% CI: 0.28–0.45) when the test was performed with 1 kg medicine ball. Dobbin et al. (2018) investigated the standing chest MBT with squat assistance using a 4 kg medicine ball and reported a CV of 9% (95% CI: 7.9–10.5), a technical error (TE) of 0.5 (95% CI: 0.4–0.6), and a smallest worthwhile change (SWC) of 0.2.

The only study that provided data on the backwards overhead MBT was conducted by Khemiri et al. (2022), who reported a CV of 5.7%.

Absolute intra-session reliability. Five investigations reported data on the absolute intra-session reliability of the MBT. Chiwaridzo et al. (2019) investigated the seated chest MBT performed on the floor using a 2 kg medicine ball and found a CV of 1.45%. Hackett et al. (2017) analysed the same test performed on a bench with a 3 kg medicine ball. Their findings included a CV of 3.4% (95% CI: 2.9–4), a measurement error (ME) of 7.4, and a TE of 2.2%.

Two additional studies focused on the backwards overhead MBT protocol, both using a 3 kg medicine ball. Duncan and Hankey (2010) observed a CV of 6.6%, while Duncan et al. (2005) examined reliability across repeated trials (Trial 5 vs. Trial 6) and reported limits of agreement (LOA) of 3.3% and a TE of 0.10.

Only one study analysed the absolute intra-session reliability of the standing overhead MBT (Luna-Villouta, et al., 2022) using a 3 kg medicine ball. The SEM was 0.07 for the total sample, 0.09 for males, and 0.03 for females. The MDC was 0.16 for the total sample and 0.20 for males (data for females were not reported).

Validity

A total of three studies provided information on the validity of the MBT (Table 1). Sample size ranged from 47 (Duncan & Hankey, 2010) to 195 (Fjørtoft, et al., 2011) participants and the three studies involved mixed samples (male and female). According to the studies' initial sample, the participants' age ranged from 5 (Davis, et al., 2008; Fjørtoft, et al., 2011) to 14 years old (Duncan & Hankey, 2010). Results by age group were not specifically reported. The association between the MBT and various fitness measures was reported with validity coefficients ranked from highest to lowest. Fjørtoft et al. (2011) observed the strongest correlations for the standing chest MBT with climbing wall bars (r=0.83), throwing a tennis ball (r=0.80), standing broad jump and shuttle run (both r=0.72), running 20 m (r=0.77), and the reduced Cooper test (r=0.54). Duncan and Hankey (2010) found strong correlations for the backwards overhead MBT with the peak power of the CMJ (r=0.806) and relative power output of the CMJ (r=0.79), while weaker correlations were reported for the peak power (r=0.632) and relative power output (r=0.203) of the WSJ. Finally, Davis et al. (2008) identified a weak correlation with the modified pull-up test (r=0.04).

Quality appraisal

Regarding reliability, six out of the 16 analyzed studies were classified as high quality (Carron, et al., 2024; Chiwaridzo, et al., 2021; Davis, et al., 2008; Hackett, et al., 2017; Hermassi, et al., 2021; Khemiri, et al., 2022), whereas the remaining studies were rated as low quality (Table 2). The three investigations that provided data on the MBT validity were deemed to be of low (Duncan & Hankey, 2010) or very low quality (Davis, et al., 2008; Fjørtoft, et al., 2011) (Table 3).

Table 2. Quality assessment criteria for reliability studies (n=16)

Study		Description of the participants	Time interval	Description of results	Statistical analysis	Total score
Hermassi et al. (2021)	Inter-session	1	2	1	2	6
Davis et al. (2008)	Inter-session	1	2	1	2	6
	Intra-session	1	2	0	2	5
Carron et al. (2024)	Inter-session	1	2	2	2	7
Biggar et al. (2022)	Intra-session	1	2	0	0	3
Chiwaridzo et al. (2021)	Inter-session	1	2	2	2	7
Chiwaridzo et al. (2019)	Intra-session	1	2	0	2	5
Hackett et al. (2017)	Intra-session	2	1	1	2	6
Luna-Villouta et al. (2022)	Intra-session	1	1	1	2	5
van den Tillaar & Marques (2011)	Intra-session	1	1	1	2	5
Khemiri et al. (2022)	Inter-session	1	2	1	2	6
Jarnig et al. (2022)	Inter-session	0	2	1	2	5
	Inter-rated	0	2	1	2	5
Bös et al. (2001)	Inter-session	0	2	1	0	3
Dobbin et al. (2018)	Inter-session	1	1	1	2	5
Fjørtoft et al. (2011)	Inter-session	0	2	1	2	5
Duncan & Hankey (2010)	Intra-session	1	2	0	2	5
Duncan et al. (2005)	Intra-session	0	2	1	2	5

Note. ≥6: high quality; 2-5: low quality; <2: very low quality.

Table 3. Quality assessment criteria for criterion-related validity studies (n=3)

Study	Number of study subjects	Description of the study population	Statistical analysis	Total score
Davis et al. (2008)	2	0	0	2
Fjørtoft et al. (2011)	1	0	0	1
Duncan & Hankey (2010)	1	1	1	3

Note. >5: high quality; 3-4: low quality; <3: very low quality.

Discussion and conclusions

Researchers and practitioners must accurately measure youth muscular strength with results supported by evidence of reliability and validity. This review presents findings on both psychometric dimensions of the MBT when administered to children and adolescents, while also evaluating its accuracy and practical utility.

According to Shrout and Fleiss (1979), relative reliability is classified as excellent for ICC values between 0.90 and 1.00, good for 0.80–0.89, fair for 0.70–0.79, and poor for values below 0.69. We identified a substantial number of studies investigating the inter-session test-retest reliability of the MBT, with pooled data demonstrating good agreement. These results are consistent with findings from previous systematic reviews on upper-body physical performance tests (ICC>0.70) (Barbosa, Calixtre, Fialho, Locks, & Kamonseki, 2024), and ball throwing velocity and distance tests (ICC ≥ 0.76) (Paraskevopoulos, Pamboris, Plakoutsis, & Papandreou, 2023). Other well-known upper-body field-based muscular strength tests such as the handgrip test or the basketball throw test yielded higher coefficients (ICC>0.90) when administered to children (Belhaidas, Dahoune, Eather, & Oukebdane, 2021; Fernandez Santos, Ruiz, Gonzalez-Montesinos, & Castro-Piñero, 2016). In contrast, lower inter-session test-retest reliability coefficients have been reported for commonly used upper-body strength assessments included in the Fitnessgram® battery, such as the flexed arm hang test (k: 0.60) and the push-up test (k: 0.48) (Morrow, Martin, & Jackson, 2010).

Regarding other muscular power field-based tests available for young populations, the existing scientific evidence primarily focuses on the lower body extremities. In this regard, inter-session test-retest reliability was generally higher than that observed for the MBT, with the standing long jump test showing an ICC of 0.95 when administered to children and adolescents (Fernandez-Santos, Ruiz, Cohen, Gonzalez-Montesinos, & Castro-Piñero, 2015), and the Sargent jump test reporting ICC values ranging from 0.84 to 0.95 when performed by preschoolers (Ayán-Pérez, Cancela-Carral, Lago-Ballesteros, & Martínez-Lemos, 2017).

An interesting finding of this research is that the position in which the MBT is performed appears to influence its inter-session test-retest reliability, with meta-analyzed data revealing higher coefficient values for the seated chest tests using a 2 kg ball (n=3) compared to the standing chest tests (1 kg: n=3; 4 kg: n=1). The inter-session test-retest reliability of the seated chest MBT has been reported to be good for young adults (ICC: 0.77) (Ferreira et al., 2021), high for older adults (ICC>0.90) (Harris, et al., 2011) and very high for university students (ICC: 0.97) (Harasin, Dizdar, & Marković, 2006). Regarding the standing MBT, the literature is limited, with studies reporting good values for the overhead MBT among university students (r: 0.84) (Rosni, Abas, & Mohamad, 2014) and high reliability coefficients for the backward overhead MBT in volleyball players (r>0.9) (Stockbrugger & Haennel, 2001). In any event, our findings are in line with previous research, suggesting a higher reliability for the seated vs. the standing MBT (van den Tillaar & Marques, 2013). Based on these findings and considering that the seated chest SMBT demonstrated good predictive ability for muscular strength and power in adolescents (Hackett, et al., 2017), this test appears to be the most suitable option currently available for use.

The MBT is a quick and easy test to administer. However, a familiarization process is essential for achieving stable scores (Duncan, et al., 2005). Notably, very few of the reviewed investigations reported including a familiarization phase, despite its importance as a crucial factor in ensuring the reliability of fitness field-based tests (González-Devesa, et al., 2024). This omission is particularly relevant for practitioners, as failing to incorporate a familiarization session may compromise the accuracy of test results by introducing avoidable variability due to a lack of prior exposure to the task. In applied settings, especially with children and adolescents unfamiliar with maximal throwing tasks, this step becomes essential to reduce learning effects and improve measurement consistency. On the other hand, several studies informed on the intra-session reliability of the MBT, which was considered to be high. This is a noteworthy finding, as this type of reliability reflects the random variability, inaccuracy of the measurement itself, or variations in the performance of the subject and the tested phenomenon (Bauer, Gröger, Rupprecht, & Gaßmann, 2008). The intra-session reliability values observed in this review align with results from prior research conducted with college students performing various medicine ball throw distance tests (ICC: 0.88-0.97) (van den Tillaar & Marques, 2009, 2013).

In contrast, only one of the reviewed studies reported data on inter-rater reliability, which was deemed very high. The scarcity of research on inter-rater reliability for upper-body physical performance and throwing distance tests has been previously noted (Barbosa, et al., 2024; Paraskevopoulos, et al., 2023), highlighting a potential area for future investigation.

Absolute reliability is a critical psychometric property in sports science, as it aids in predicting the magnitude of a “real” change following an intervention (Atkinson & Nevill, 1998). Several of the reviewed investigations explored this aspect, with their findings corroborating those of previous studies. For instance, Ferreira et al.

(2021) reported a SEM of 13 cm and a MDC of 36 cm when analyzing inter-session reliability of the seated MBT among young adults. Similarly, Borms and Cools (2018) found a SEM of 11 cm and an MDC of 30 cm when investigating the intra-session reliability of the overhead MBT performed by athletes. Regarding the CV, the results from the reviewed studies were comparable to those reported for undergraduate students performing the seated MBT (intra-session CV%: 3.2–4.7%) (Beckham, et al., 2019) and the standing overhead MBT (inter-session CV%: 7.82%) (Rosni, et al., 2014). Additionally, Johnson, Maurya, Sisneros, Ford, & Palmer, (2024) observed a CV of approximately 9% when analyzing the inter-session reliability of the supine MBT performed by young women. All together, these findings support selecting the MBT for assessing the effectiveness of strategies aimed at improving upper-body muscular strength among children and adolescents.

Physical fitness field-based tests must exhibit strong validity to ensure they accurately measure the intended variable. Ideally, these tests should demonstrate robust criterion-related validity, which reflects the degree to which the test correlates with the criterion measure, often referred to as the gold standard (Currell & Jeukendrup, 2008). In this sense, the available scientific evidence on the validity of the MBT remains limited. Indeed, only a few studies addressing the validity of this test were identified, and these lacked methodological rigor. Furthermore, these investigations primarily focused on convergent validity, comparing MBT scores with those from other fitness tests. The reported validity coefficients varied widely, underscoring the necessity for further rigorous research into this psychometric property.

In this sense, other investigations have tried to explore the criterion-related validity of the MBT through the use of different strategies. For instance, Leite et al. (2016) compared upper limb muscle power measured using the MBT with performance in the bench press exercise, utilizing a Myotest® accelerometer attached to the bench press bar to estimate muscle power in a sample of rugby players. In this line, Harris et al. (2011) proposed using an explosive push-up test on a floor-mounted force platform as a criterion measure for assessing the validity of the MBT among older adults. In this line, Roe et al. (2018) introduced the innovative approach of embedding an accelerometer in a medicine ball to establish a criterion measure for monitoring upper-body neuromuscular performance.

From a practical standpoint, the seated chest MBT is recommended for use in school and general physical education contexts, especially with younger children or in large group settings, due to its simplicity and high inter-session reliability. For adolescents involved in competitive or performance-focused programs, standing or overhead variations may offer a more sport-specific alternative, although standardization and familiarization remain essential. Therefore, professionals should select the protocol that best aligns with their assessment objectives, available resources, and participant characteristics.

This review represents the first systematic evaluation and meta-analysis of the psychometric properties of the MBT when administered to children and adolescents. Despite its originality, several limitations must be acknowledged. Firstly, there was a lack of consensus on the MBT protocols investigated, and in some cases, the statistical approaches were insufficiently detailed. Secondly, the large heterogeneity in procedures, including body position, ball weight, number of attempts, and the presence or absence of familiarization protocols, should be noted, as it may significantly influence inter-session reliability and complicates comparisons across studies. Thirdly, the small number of validity studies identified precluded the possibility of conducting a meta-analysis on this outcome. Fourthly, most studies did not report inter-rater reproducibility data, limiting the assessment of consistency between evaluators. Lastly, although a comprehensive search was undertaken, the omission of specific grey literature databases may have limited the scope of studies included.

In conclusion, various protocols exist for administering the MBT to children and adolescents, with the seated chest MBT emerging as a particularly reliable option due to its good relative reliability. While different investigations report acceptable absolute reliability values for the MBT, the limited research on its validity, especially criterion validity, hinders a conclusive determination of the most appropriate protocol for assessing upper-body muscular strength in this population. Therefore, findings related to the validity should be interpreted with caution, and further research in this area is strongly recommended.

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Correspondence to:
Prof. Daniel González-Devesa, Ph.D.
Catholic University of Ávila, Faculty of Humanities and Education
C/ Canteros, 05005, Ávila, Spain
Email: danidevesa4@gmail.com

MODERN EVOLUTIONARY CHANGES IN FIELD GOAL SHOOTING PATTERNS WITHIN PROMINENT EUROPEAN BASKETBALL LEAGUES

Raúl Nieto-Acevedo[1], Anthony S. Leicht[2], Pierpaolo Sansone[3,4], Sergio L. Jiménez-Sáiz[5], and Enrique Alonso-Pérez-Chao[1,6]

[1]Faculty of Sports Sciences, Universidad Alfonso X el Sabio, Villanueva de la Cañada, Spain
[2]Sport and Exercise Science, James Cook University, Townsville, Australia
[3]Department of Theoretical and Applied Sciences, eCampus University, Novedrate, Italy
[4]Department of Movement, Human and Health Sciences, University of Rome "Foro Italico", Rome, Italy
[5]Sport Sciences Research Centre, Universidad Rey Juan Carlos, Madrid, Spain
[6]Faculty of Sports Science, Universidad Europea de Madrid, Villaviciosa de Odón, Spain

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Abstract:

The aims of this study were to identify the evolution of field goal shooting trends within leading European basketball leagues, and the subsequent impact of a change in 3-point line distance on these trends, providing valuable information for coaches and strategists. Data were collected from the 2002-2003 to the 2022-2023 season (21 seasons) from the prominent basketball leagues of Spain, Italy, France, and Greece. The analyzed variables were: 2-point field goals made (2PM), 2-point field goal attempts (2PA), 2-point field goal percentage (2P%), 3-point field goals made (3PM), 3-point field goal attempts (3PA), and 3-point field goal percentage (3P%). One-way repeated-measures ANOVA or Friedman's test were used to determine evolutionary changes in variables over time. Additionally, comparisons between variables before and after the change in 3-point line distance were also conducted via independent t-tests. Over the past 21 seasons, 3PA and 3PM significantly increased from an average of 20.80 to 25.17 per match. In contrast, 2PA, 2PM, 2P% and 3P% remained unchanged during the same period. Following the change in distance of the 3-point line, 3PA and 3PM increased over 5%, while no change in 3P%, 2PA, 2PM and 2P%. Over the past 21 seasons, there were substantial increases in 3PA and 3PM, especially since the change in 3-point line distance in 2010-2011, without changes in 2-point shooting trends and efficiency (i.e., 2P%, 3P%), within the leading basketball leagues of Europe. Collectively, these results demonstrated substantial evolutionary change in 3-point shooting behavior, requiring offensive and defensive upskilling of athletes and coaches for successful match-play, and potentially informing the development of new training paradigms in modern basketball.

Keywords: *trend analysis, match outcomes, males, scoring, team sport*

Introduction

In basketball, game-related statistics are considered crucial resources for obtaining valuable insights into team and player performance (Puente, Coso, & Salinero, 2015). These statistics have been collected and analyzed using various methods throughout the years, ranging from simple statistic sheets to the now widely adopted box-score format (Mandić, Jakovljević, Erčulj, & Štrumbelj, 2019). Notably, several game-related statistics have been shown to discriminate winning and losing basketball teams (Gomez, Lorenzo, Barakat, Ortega, & Palao, 2008; Leicht, Gomez, & Woods, 2017), making it an essential aspect for coaches and analysts (Zajac, et al., 2023) to consider when developing game strategies. The evaluation of game-related statistics should be adapted to relevant contextual factors that can affect game-play, such as leagues and their different rules, season phases, and game location (Gomez, et al., 2008; Lorenzo, J., Lorenzo, A., Conte, & Giménez, 2019).

Over the past two decades, there have been notable rule changes in international basketball. For example, in season 2010-2011, the international 3-point line was moved further away from the basket (i.e., from 6.25 to 6.75 meters away from the basket compared with 7.25 meters in the National Basketball Association (NBA). Rule changes can lead to significant changes in game-play that significantly impact athlete development and team strategies (Štrumbelj, Vračar, Robnik-Sikonja, Dežman, & Erčulj, 2013). For example, the introduction of the 3-point line in the NBA changed the style of play, with changing the number of 3-point shots attempted by a team per match in the NBA (Zajac, et al., 2023) from 2.8 in 1979 to 32.0 in 2018-2019, an ~1100% increase (Zajac, et al., 2023). This style of play has not only increased the points scored in games (Zajac, et al., 2023) but also extended the field of play for basketball players, which required their enhanced physical fitness qualities to cover the extended court area compared to those in the past (Sliz, 2017). Similarly, the reduction of the shot clock from 30 to 24 seconds (year 2000) has substantially increased the game pace, which is higher in more competitive leagues (i.e., NBA) (Mandić, et al., 2019). Such changes have also required adaptations in perspectives of coaches and game analysts in order to properly prepare players and teams for competition and optimize their production on the court (Puente, et al., 2015).

Determining the key factors for victory in basketball is a complex task as successful performance results from a range of multiple elements (Alonso Pérez-Chao, et al., 2023). For example, defensive rebounds, turnovers and field goal (i.e., 2- and 3-point) shooting were reported to be crucial for success at the elite level (Leicht, et al., 2017; Zhang, S., et al., 2020). Specifically, field goal shooting effectiveness (i.e., shots made/shots attempted) has been reported to be a prominent contributor to elite match success (Li, et al., 2025). Teams with a greater field goal shooting efficiency than their opponents tended to win ~81% of matches during the regular season with winning efficiency increased to 90% in the playoffs (Mandić, et al., 2019). Since many of these studies were conducted within unique competitions (e.g., Olympics' tournaments), the applicability to other competitions (e.g. European leagues) that may have different styles of play might be limited (Leicht, et al., 2017). Furthermore, due to the progressive changes in the 3-point line distance and the continuous evolution of offensive strategies in basketball, it is essential to quantify the historical trends in shooting performance. Several studies have shown how regulatory modifications can lead to strategic adaptations and long-term changes in shot selection and game dynamics (Caporale & Collier, 2015; Sliz, 2017; Štrumbelj, et al., 2013). To our knowledge, this is one of the first studies to longitudinally examine field goal shooting behavior across multiple top-tier European leagues with a clear division based on a rule change—the extension of the 3-point line. By comparing trends before and after this modification, the present study offers novel insights into how regulatory adjustments can shape tactical and performance-related behaviors in elite basketball over time. Therefore, the main aim of the current study was to identify the evolution of field goal shooting trends within the principal European basketball leagues. As the distance of the 3-point line had changed during the past 20 seasons (Sliz, 2017), differences between seasons before the change (2002-2010), and seasons after the change (2011-2023) were examined as a secondary aim. Based on earlier work that demonstrated similar offensive activities between the NBA and Euroleague competitions (Selmanović, Škegro, & Milanović, 2015), we hypothesized that field goal shooting trends in Europe will vary due to the change in the three-point line. Understanding shooting pattern changes in European basketball may help coaches and athletes with strategic development and recruitment of players, as well as game strategies to optimize team success.

Materials and methods

Study design

A longitudinal observational design was used to examine the evolution of shooting performance across two decades in elite European basketball. The study focused on identifying trends over time and comparing performance before and after a major rule change—the extension of the 3-point line.

Sample

The sample comprised a total of 2,546 official matches from senior men's professional basketball across four leading European leagues: Spain, Italy, France, and Greece. These matches were selected from 21 consecutive seasons, spanning from season 2002-2003 to 2022-2023.

These four leagues were selected due to the consistent availability of detailed, reliable, and standardized match statistics throughout the entire study period. While other prominent European leagues (e.g., Turkey, Israel) have also achieved notable international success, they were not included in this analysis due to limited historical data availability. This should be considered a limitation of the present study.

Data collection procedure

Match statistics were obtained from open-access archives hosted on www.basketball-reference.com (accessed on September 10, 2023), which have been previously reported as reliable sources for long-term basketball performance analysis (Belk, Marshall, McCarty, & Kraeutler, 2017; Zajac, et al., 2023). The specific field goal-related variables extracted included the following:

- 2-point field goals made (2PM)
- 2-point field goal attempts (2PA)
- 2-point field goal percentage (2P%)
- 3-point field goals made (3PM)
- 3-point field goal attempts (3PA)
- 3-point field goal percentage (3P%).

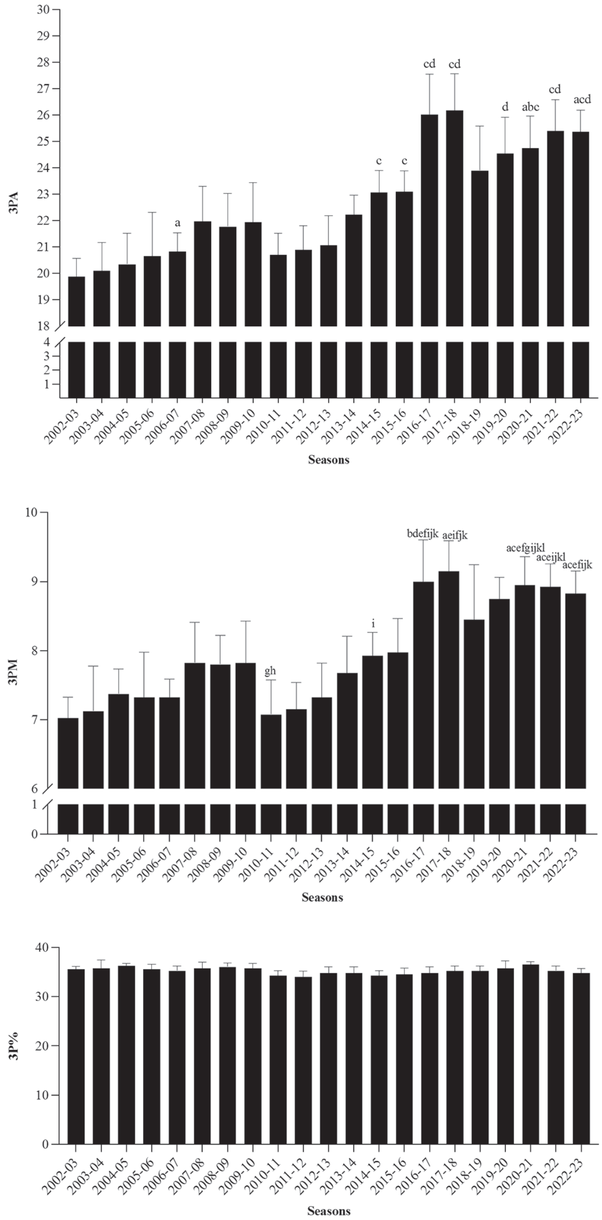
These indicators have been associated with success in elite basketball competitions and were thus selected as key outcome variables (Casals & Martinez, 2013; Puente, et al., 2015; Zhang, S., et al., 2020).

Statistical analysis

All data were screened prior to analysis. Missing values were handled using listwise deletion to ensure consistency across variables. Outliers were identified as values exceeding three standard deviations from the mean and were subsequently examined on a case-by-case basis. Outliers attributable to recording or tracking errors were removed. All results were expressed as mean (M) ± standard deviation (SD). To examine within-subject changes across time and conditions, we employed repeated measures ANOVA and paired-sample *t*-tests. Prior to the analysis, assumptions of normality and homogeneity of variances (homoscedasticity) were assessed using the Shapiro-Wilk and Mauchly's tests, respectively. Additionally, as there had been changes in the distance of the 3-point line during this period, differences between seasons before the change (2002-2010), and seasons after the change (2011-2023), were compared using Student's *t*-tests. When appropriate, pairwise comparisons with a Bonferroni correction or a Durbin-Conover test were used as *post hoc* tests. All analyses were performed using Jamovi (version 2.3, Sydney, Australia) or GraphPad Prism 9 (Boston, USA).

Results

Results of ANOVAs or Friedman's tests are shown in Table 1. During the last 21 Eurobasketball seasons, 3PA significantly increased from 20.80 to 25.17 per match (~21%) with comparable increasing trends for 3PM that resulted in a maintenance of 3P% across the study period (Figure 1). In contrast, 2PM and 2P% remained unaffected from 2002 to 2023, despite minor fluctuations in 2PA across the study period (Figure 2).

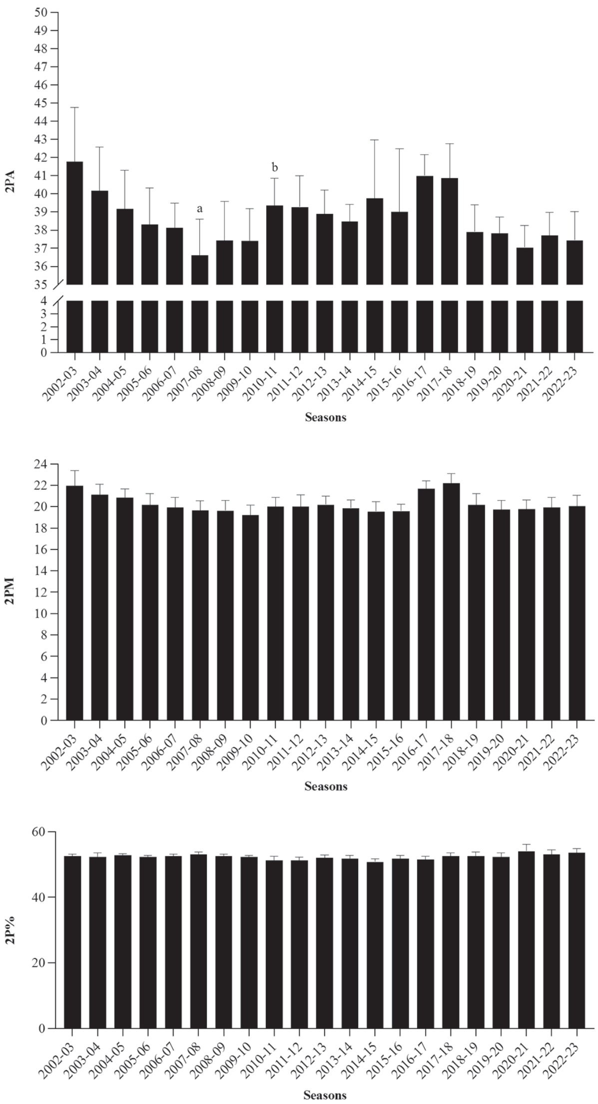


Note. [a]p<.05 vs. 2002-2003; [b]p<.05 vs. 2003-2004; [c]p<.05 vs. 2004-205; [d]p<.05 vs. 2005-2006. [e]p<.05 vs. 2006-2007; [f]p<.05 vs. 2007-2008; [g]p<.05 vs. 2008-2009; [h]p<.05 vs. 2009-2010; [i]p<.05 vs. 2010-2011; [j]p<.05 vs. 2011-2012; [k]p<.05 vs. 2012-2013; [l]p<.05 vs. 2014-2015.

Figure 1. Total 3-point attempts (3PA), 3-point shots made (3PM), and 3-point shooting percentages (3P%) per match over the past 21 Eurobasketball seasons.

Table 1. Results of ANOVAs or Friedman tests between decades for 3PA, 3PM and 2PA, 2PM

Variable	M	SD	ANOVA or Friedman test	p-value
3PA	22.61	229	Test =70.85	<.001
3P%	0.35	0.011	Test =30.62	.061
2PA	38.33	4.75	Test = 56.18	<.001
2P%	0.52	0.01	F= 2.30	.007



Note. ^{a}p<.05 vs. 2002-2003; ^{b}p<.05 vs. 2006-2007.˝c

Figure 2. Total 2-point attempts (2PA), 2-point shots made (2PM) and 2-point shooting percentages (2P%) per match for the past 21 Eurobasketball seasons.

Changing the distance of the 3-point line (i.e., 2003-2010 vs. 2011-2023 matches) resulted in significantly greater 3PA and 3PM with no change in 3P%, 2PA, 2PM, and 2P% (Figure 3).

Discussion and conclusions

The present study aimed to examine the evolutionary change of shooting trends within the leading basketball leagues of Europe. Across 21 seasons, there was a significant increase in 3PA and 3PM, while no statistically significant changes were evident for 3P%, 2PA, 2PM, and 2P%. Further, significant increases in 3PA and 3PM occurred following the 3-point line rule change with no significant differences in other shooting variables. Extending the 3-point line distance significantly increased 3-point shooting behavior but not efficiency within the European Basketball Leagues that has extended the competitive region of the court for athletes. These relevant changes in strategies require athletes and coaches to modify technical-tactical plans, which better adapt to the novel shooting trends.

The extension of the 3-point line for international basketball competition around the year 2010 resulted in a court arrangement similar to that of the NBA. Subsequently, it was no surprise that such a change in European Basketball Leagues would result in a similar NBA result of increased 3PA (Zajac, et al., 2023). Interestingly, the 3PA increase was not as pronounced for the European leagues compared to the NBA (21% vs. 1100%), which may reflect differences in athletes' ability and match strategies between the competitions. Further, the shooting change may reflect a greater use of advanced analytics (Zajac, et al., 2023) where European teams are engaging novel analytical techniques to enhance offensive efficiency (Caporale & Collier, 2015; Sliz, 2017). Consequently, European coaching staff may have adapted their traditional team strategies, recognizing the 3-point shot as a match-changing element for the modern basketball competition. This strategic shift has ushered in an increased focus on perimeter play, emphasizing the value of spacing and outside shooting (Caporale & Collier, 2015). Curiously, such focus did not result in changes in 2-point shooting trends or 3-point efficiency, which hints toward the importance of the number of ball possessions per match (Selmanović, et al., 2015), which has been shown to increase for most elite basketball leagues in the past years. Teams may develop a greater focus on maximizing the scoring potential of each possession (i.e., reward of 3-points), regardless of the risk (i.e., a greater risk of missing a shot from a further distance, which can facilitate fast-breaks and easier scoring opportunities for the opponent team). This greater risk-reward behavior underscores the evolving nature of strategic decision-making in modern basketball. Coaches and athletes alike may adapt to a dynamic style of play that place greater focus on offensive efficiency and creating more scoring opportunities by increasing the pace and the number of ball possessions beyond traditional methods (Zhang, F., Yi, Dong, Yan, & Xu, 2025). By embracing the 3-point shot as a high-reward option, teams may be challenging conventional norms and redefining offensive strategies. This trend may lead to a more dynamic and unpredictable style of play, forcing opponents to adjust defensively, which altogether contributes to the ongoing evolution of basketball tactics (Mandić, et al., 2019).

As highlighted previously, 2- and 3-point shooting accuracy remained relatively consistent over the past 21 seasons within the leading European basketball leagues. This constant accuracy, despite a greater 3PA, possibly occurred as a result

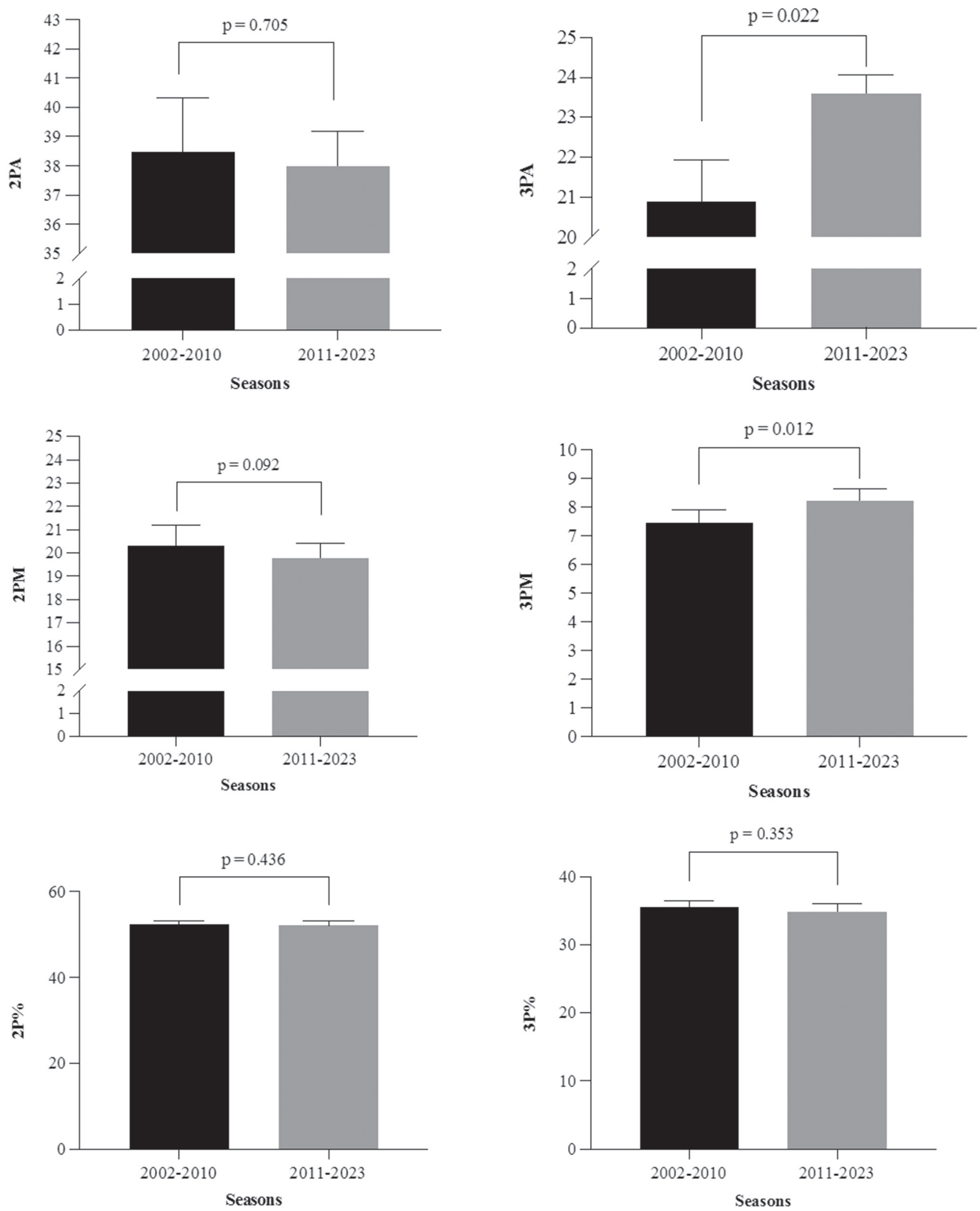


Figure 3. Effect of change in 3-point line distance (i.e., 2002-2010 vs. 2011-2023) on 3-point attempts (3PA), 3-point shots made (3PM), 3-point shooting percentage (3P%), 2-point attempts (2PA), 2-point shots made (2PM), and 2-point shooting percentage (2P%) per Eurobasketball match.

of adaptations in athletes' ability as well as team strategic approaches. For example, athletes would have trained to enhance their 3-point shooting ability while extending their defensive skills to a greater court area to cover to counteract the increasing number of 3-point shots taken by the opposition. Likewise, improvements in both offensive and defensive skills in athletes could underpin for the maintenance of shooting accuracy despite the increased 3PA. Since training strategies are developed for teams to be well-prepared for official matches, it is plausible that the attention and time dedicated to developing the players' 3-point shooting abilities have increased in modern basketball teams. Further, teams may have implemented cohesive team strategies that focus on creating and defending open shot opportunities, while exploiting defensive weaknesses (Wang & Zheng, 2022). An important note to add to the current study was the lack of a significant increase in 3PA and 3PM following the impact of COVID-19 (2019-2021). The pandemic brought about unprecedented challenges, leading to disruptions in regular training schedules, altered game dynamics, and psychological stress for players (Alonso, Lorenzo, Ribas, & Gómez, 2022). In fact, players faced a prolonged break from training in high-quality facilities and from playing official games, with plausible negative influences for physical qualities and technical-tactical abilities (Santos & Janeira, 2009). Further, the uncertainty and anxiety caused by the pandemic could have affected coaches and players' focus and confidence during games. The altered game atmosphere, with matches often played in empty arenas or with limited spectators, might have also impacted players' comfort levels and shooting performances. The extraordinary circumstances brought about by the COVID-19 pandemic likely influenced the unusual trends observed in 3-point shooting during that period. However, as the world gradually recovers from the pandemic, we are beginning to see a return to more typical patterns in 3-point shooting in the years following COVID-19.

While the observed shift in shooting patterns highlights the importance of 3-point shooting in the modern game, coaches must also consider the potential advantage of recruiting athletes who excel at shooting from the 2-point range. Subsequently, coaching staff must determine the appropriate team composition for 2- and 3-point shooting abilities of athletes when developing tactical strategies, which increases chances of success.

Limitations of the study and directions for further research

This study has several limitations that should be taken into account when interpreting the findings. Firstly, only shooting metrics were examined, without linking them to match outcomes (e.g., wins or losses). This limits our ability to assess the actual impact of the observed changes in shooting behavior on competitive success. Secondly, the analysis was restricted to the regular seasons of men's professional basketball in four European leagues (Spain, Italy, France, and Greece). As such, the results may not be generalized to playoff contexts—where tactical intensity and player rotations often differ—or to women's competitions, semi-professional and amateur leagues, or other geographic regions with different playing styles.

Another important limitation is that the variables were not adjusted for the number of possessions. Consequently, some observed increases (e.g., in three-point attempts) might reflect a general acceleration in pace rather than an intentional strategic shift. This may overestimate the degree of behavioral change in shooting patterns. While we chose to analyze absolute values to describe raw trends over time, future studies should normalize performance metrics per possession to better isolate tactical and technical developments.

Overall, these limitations suggest caution in overgeneralizing the results. Nonetheless, they also highlight important avenues for future research, which should include broader samples and normalized data to confirm the robustness of the trends identified and to better understand the evolution of shooting behavior in international basketball. Additionally, the study focused on four specific European leagues, excluding other competitive leagues such as Turkey or Israel due to data availability constraints. This may limit the generalizability of the results across the full spectrum of the European basketball.

In conclusion, our study documented the evolution of 2- and 3-point shooting performance within the leading Eurobasketball leagues from 2002 to 2023. During this time, a greater reliance on 3-point shots has been demonstrated, especially after extending the 3-point line distance. Despite this significant rule change, overall shooting accuracy was maintained, which highlights the evolution of tactical strategies and increased pacing in elite male basketball. These findings have important practical implications: coaches can leverage this knowledge to design training programs that prioritize developing players' long-range shooting skills and conditioning for faster-paced games. Players may benefit from adapting their decision-making to embrace higher-risk, higher-reward shot selections. Basketball analysts and strategists can use these insights to better understand game trends and inform real-time tactical adjustments. Coaches and players may be adapting to a novel style based on higher-risk shooting strategies that emphasize scoring efficiency and a more dynamic style of play, thus reshaping traditional basketball tactics.

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Correspondence to:
Sergio L. Jiménez-Sáiz, Ph.D.
Sport Sciences Research Centre
Universidad Rey Juan Carlos
Madrid, Spain
E-mail: sergio.jimenez.saiz@urjc.es

THE INFLUENCE OF EXPLOSIVE LOWER LIMB PERFORMANCE, MUSCLE MASS, AND TRAINING EXPERIENCE ON OLYMPIC WEIGHTLIFTING PERFORMANCE

Florian Venus, Lena Danner, Michael Buchecker, and Herbert Wagner

Paris Lodron University of Salzburg

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Abstract:

Explosive lower limb performance, muscle mass, and training experience are considered critical factors in determining Olympic weightlifting performance, yet most studies have focused on single performance levels (such as elite-level athletes) or on only one or two of these performance factors. This study aimed to provide a more holistic analysis of these determinants by evaluating their influence across three performance levels: fitness-based weightlifting, competitive weightlifting, and national team athletes. Twenty-nine weightlifters (16 males, 13 females) participated, with performance assessed via the Sinclair score. Explosive lower limb performance was measured using countermovement jump (CMJ) height on a force plate, muscle mass was evaluated via bioelectrical impedance analysis, and training experience was calculated as a function of years, weeks, and weekly sessions. Multiple regression analysis identified CMJ height as the strongest predictor of the Sinclair score, followed by training experience, while muscle mass showed no significant influence. The model accounted for 66.7% of the variance in Sinclair scores, highlighting power and training experience as key performance drivers. These findings suggest that training programs should prioritize explosive lower limb performance development and training frequency to optimize weightlifting outcomes, while muscle mass appears to play a lesser role.

Keywords: *Olympic weightlifting, performance, muscle mass, training experience, snatch, clean & jerk*

Introduction

The sport of Olympic weightlifting involves two technical demanding disciplines: the snatch and the clean and jerk. They are characterized by rapid force production and coordination, demanding a strong interplay between physical attributes and neuromuscular efficiency. Three primary factors—explosive lower limb performance, muscle mass, and training experience—have been identified as key determinants of performance in weightlifting (Storey & Smith, 2012; Zaras, et al., 2021).

Olympic weightlifters demonstrate some of the highest peak power outputs ever recorded, particularly during the snatch and clean and jerk. For instance, male athletes achieve power output values as high as 6981 W, respectively, during the second pull phase of these lifts (Garhammer, 1993). Additionally, weightlifters demonstrate superior isometric peak force (approximately 15-20% greater) and contractile rate of force development (approximately 13-16% greater) compared to athletes in other strength and power sports (Storey & Smith, 2012).

These findings emphasize the unique neuromuscular characteristics of weightlifters, which contribute to their ability to generate explosive force with their lower limbs in these highly technical lifts.

Lean body mass, particularly in the lower body, seems to be a crucial determinant of success in Olympic weightlifting (Zaras, et al., 2021). Additionally, weightlifters possess significantly higher proportions of type IIA muscle fibers and relative myosin heavy chain IIA isoform content compared to recreationally active individuals (Fry, et al., 2003). General scientific consensus states that these fast-twitch muscle fibers are associated with rapid force generation and explosive movements, essential for the snatch and clean and jerk. Furthermore, weightlifting performance correlates strongly with the percentage of type IIA fibers ($r = 0.94$) and the percentage of muscle area occupied by these fibers ($r = 0.83$) (Fry, et al., 2003). This evidence highlights how specific skeletal muscle adaptations, driven by resistance training, play a central role in influencing performance.

Long-term training (several months to years) in Olympic weightlifting significantly enhances both strength and explosivity through neuromuscular adaptations. Improvements in peak force (PF) and contractile rate of force development (RFD) have been observed in male and female weightlifters after moderate- to long-term training (Haff, et al., 2008; Häkkinen, Pakarinen, Alen, Kauhanen, & Komi, 1988).These adaptations are largely attributed to the frequent high-intensity training performed by weightlifters, which not only increases muscular strength but also improves neural activation of motor units and preferential recruitment of fast-twitch fibers (Aagard, Simonsen, Andersen, Magnusson, & Dyhre-Poulson, 2002; Ewing, Wolfe, Rogers, Amundson, & Stull, 1990).

However, no studies have comprehensively explored the relationship between explosive lower limb performance, muscle mass, and training experience in Olympic weightlifting as a unified model. Most research examines these factors in isolation, often focusing on only one or two at a time, which limits a comprehensive understanding of their relative importance. This fragmented approach risks misinterpreting key success factors. For example, a study focusing solely on lower limb explosivity might conclude that it is a definitive predictor of success, overlooking the possibility that other factors, such as muscle mass or training experience, might play equally or more significant roles.

Furthermore, instead of focusing solely on elite-level athletes, we included athletes from different performance levels to obtain a more holistic view of the factors influencing success in weightlifting. For instance, if less successful athletes also demonstrate strong lower limb explosivity such as elite-level athletes, but still underperform, it could indicate that lower limb explosivity alone is not a decisive success factor.

By integrating all these aspects into a single comprehensive analysis, this study aims to identify which of these determinants—explosive lower limb performance, muscle mass, or training experience—has the most significant influence on Olympic weightlifting performance. It is hypothesized that explosive lower limb performance, followed by muscle mass and training experience will emerge as the strongest determinants of success.

Methods

Subjects

A total of twenty-nine weightlifters (16 males, 13 females; age: 29.4 ± 8.2 years; body mass: 76.3 ± 12.6 kg) participated in this study. Participants were stratified into three performance levels to represent different stages of expertise:

– Fitness-level (n=12; age: 34.2. ± 5.6 years; body mass: 70.3 ± 8.2 kg): Recreational lifters engaged in fitness-based weightlifting.
– Competitive-level (n=7; age: 29.3 ± 9.4 years; body mass: 78.0 ± 12.0 kg): Competitive athletes who participate in regional or national-level competitions.
– Elite-level (n=10; age: 23.7 ± 6.8 years; body mass: 82.3 ± 14.9 kg): Elite athletes from the Austrian national team.

All participants were healthy and free of injury or medical conditions that could impair performance.

Study design

This cross-sectional study aimed to evaluate the influence of explosive lower limb performance (ELLP), skeletal muscle mass and training experience on Olympic weightlifting performance. All measurements were conducted on three test days, with each level being tested in one day. Participants were divided into nine groups of 3-4 subjects. Each group completed the following protocol:

– Initial assessments: Bioelectrical impedance analysis (BIA) to measure skeletal muscle mass, conducted in a fasted state in the morning.
– 15 min break and warm-up: A 10-minute standardized warm-up, including dynamic stretches and movement preparation.
– ELLP testing: 3 maximal countermovement jumps (CMJ) with arm-swing and 1-minute break in between were conducted using a piezoelectrical force plate.
– Training Experience Questionnaire: Participants reported their training history, including years of training and average number of weekly sessions.
– Olympic weightlifting performance was conducted using the Sinclair score.

To ensure ecological validity, the performance test was conducted during active training phases. National team athletes were assessed during centralized training camp as part of their competition preparation phase. Similarly, competitive-level athletes were tested while in regular in-season training, aligned with their competition calendar. Recreational fitness lifters, who do not follow periodized competition schedules, were tested during their typical year-round training routine which does not include formal tapering or rest periods.

Study methods

Muscle mass was measured using the seca mBCA 525 bioelectrical impedance analysis (BIA) device (seca Gmbh & Co. KG, Hamburg, Germany). Participants were measured in the morning in a fasted state following standardized BIA procedures. This included lying supine for at least 10 minutes prior to testing, shaving hair at electrode placement sites, and performing electrode placement and data acquisition in the supine position. BIA device has been validated against dual-energy X-ray absorptiometry (DXA) for accuracy (Lopez-Gonzalez, Wells, & Clark, 2022). To cancel out body weight differences between subjects, we used relative skeletal muscle mass (RSMM) for our analysis:

$$RSMM = \frac{Skeletal\ Muscle\ Mass\ (kg)}{Body\ Weight\ (kg)}$$

After the measurement of muscle mass, participants had a 15 min break after which they started the 10 min warm-up for testing the ELLP. The warm-up consisted of easy running (3 min), world's greatest stretch (10 repetitions per side), bodyweight squats (10 repetitions), shoulder circling (10 repetitions forward and backwards), push-ups with shoulder taps in between (10 repetitions), dynamic hamstring and quadriceps stretch (10 repetitions) and 5 consecutive counter movement jumps. ELLP was assessed using countermovement jump (CMJ) height. Participants performed three maximal CMJs with arm swing and one-minute rest intervals between jumps. For measuring the CMJ height, we used the piezoelectric force plate Kistler Quattro Jump® Typ 9290DD (Kistler Instrumente AG, Winterthur, Switzerland), which is validated for reliability in assessing jump performance metrics (Mauch, Rist, & Kaelin, 2024). The highest recorded jump height was used for our analysis.

When participants completed the CMJ test, they were asked about their training experience. Training experience was quantified by multiplying self-reported years of Olympic weightlifting practice (snatch and clean and jerk) and by the average number of weekly training sessions and the number of weeks in a year.

$$Training\ Experience = Total\ Training\ Sessions = Training\ Years\ x\ Average\ number\ of\ sessions\ per\ week\ x\ 52$$

Finally, Olympic weightlifting performance was assessed using the Sinclair score. This score system is a widely accepted metric in Olympic weightlifting competition that adjusts an athlete's total lifted weight (snatch + clean and jerk) according to their body weight and sex, allowing for fair comparison of performance across different weight classes and between sexes. For competitive and elite-level athletes, the Sinclair scores from the current time span of January to March 2024 were accessed via the Austrian Weightlifting Federation's online database. Fitness-level participants and other participants who did not have official records of their current Sinclair score and therefore maximal weight lifted in the snatch and clean and jerk had to proceed with the following 1RM warm-up protocol on a self-selected day soon (Sheppard & Triplett, 2016, p.495):

1. Instruct the athlete to warm up with a light resistance that allows for 5 to 10 easy repetitions.
2. Take a 1-minute rest.
3. Estimate a warm-up load with which the athlete can perform 3 to 5 repetitions by adding approximately 10%.
4. Take a 2-minute rest.
5. Estimate a conservative, near-maximal load that allows the athlete to complete 2 to 3 repetitions by adding approximately another 10%.
6. Take a 2-to-4-minute rest.
7. Increase the load by approximately 10%.
8. Instruct the athlete to attempt a 1RM.
9. If the attempt is successful, take a 2-to-4-minute rest and return to step 7. If the attempt is unsuccessful, take a 2-to-4-minute rest, reduce the load by approximately 5%, and return to step 8. Continue increasing or decreasing the weight until the athlete can complete one repetition with the correct technique.

Ideally, the athlete's 1RM should be identified within three to five testing sets.

After completing this test for the snatch first, a 10-minute rest period should be observed before proceeding with the clean and jerk max test. This sequence closely reflects realistic conditions in Olympic weightlifting competition.

The Sinclair score is calculated by summing the maximal snatch and clean and jerk weights and applying the Sinclair coefficient based on sex and body weight (KSC ARGOS & AK HERMANN, n.d.).

Men's Sinclair score calculation:

$$(10^{\left(0{,}722762521 \times LOG\left(\frac{Bodyweight}{193{,}609}\right)^2\right);4)} \times (Snatch\ Weight\ [kg] + Clean\ \&\ Jerk\ Weight\ [kg])$$

Women's Sinclair score calculation:

$$(1{,}5\ \times (10^{\left(0{,}787004341 \times LOG\left(\frac{Bodyweight}{153{,}757}\right)^2\right);4)} \times (Snatch\ Weight\ [kg] + Clean\ \&\ Jerk\ Weight\ [kg])$$

Statistics

All statistical analyses were performed using Jamovi (Version 2.5.7.0, The Jamovi Project, Sydney, Autralia), JASP (Version 0.18.3, JASP Team, Amsterdam, Netherlands) and MATLAB

(Version R2024b, MathWorks, Natick, MA, USA). A multiple linear regression model was employed to determine the influence of ELLP (CMJ height), muscle mass (RSMM), and training experience (total training sessions) on Olympic weightlifting performance. Sex (coded as female = 0, male = 1) was included as a control variable.

To ensure the validity of the statistical analysis, key assumptions were tested and confirmed. Linearity was verified through an examination of residuals versus fitted values plots, ensuring a consistent relationship between predictors and the outcome variable. Homoscedasticity was assessed by evaluating the spread of residuals, confirming their consistency across levels of the predictor variables. The absence of multicollinearity was determined using the variance inflation factor (VIF), with all values remaining below the threshold of 5, indicating no significant collinearity among predictors. Finally, the normality of residuals was evaluated using a Q-Q plot and further supported by the results of the Shapiro-Wilk's test (p=.296), confirming that the residuals followed a normal distribution. These steps ensured the robustness and reliability of the statistical model.

In addition to the unstandardized coefficients (b), standardized coefficients (β), t- and p-values, we used the following equation to calculate the semi-partial correlation (sr) values. This allowed us to assess the unique contribution of each predictor variable to the criterion variable (Sinclair score), independent of the other predictors.

$$sr_i = t_i \times \sqrt{\frac{1 - R^2}{n - k - 1}}$$

Results

Descriptive statistics

Values for relative skeletal muscle mass (RSMM), countermovement jump (CMJ) height, training experience (total number of training sessions), and Sinclair score across all subjects and performance levels are presented in Table 1.

Regression analysis

The analysis showed that CMJ height and the number of training sessions were significant predictors of the Sinclair score (p<.05). Overall, the 4-predictor model was able to explain approximately 66.7% of the variance in the Sinclair score (adjusted R^2 = 0.611, R^2 = 0.667, F(4,24) = 12.0, p<.001). CMJ height proved to be the strongest predictor with a positive relationship to the Sinclair score (t(24) = 4.25, p<.001), followed by the number of training sessions (t(24 = 3.39, p=.002). However, RSMM had no significant influence on the Sinclair score (t(24) = -0.81, p=*.428).*

Table 1. Mean (± SD) values of relative skeletal muscle mass (RSMM), countermovement jump (CMJ) height, training experience (total number of training sessions), and Sinclair score of all subjects and performance levels

Variables	All subjects	Fitness-level	Competitive-level	Elite-level
RSMM [%]	40.3 ± 3.9	40.2 ± 3.7	41.7 ± 3.9	39.5 ± 4.1
CMJ height [m]	0.38 ± 0.10	0.31 ± 0.7	0.41 ± 0.09	0.44 ± 0.10
Training experience	2035 ± 2380	767 ± 490	1033 ± 620	4259 ± 2942
Sinclair score	275.10 ± 75.53	208.53 ± 23.99	264.00 ± 30.09	362.76 22.76

Table 2. Results of multiple linear regression of relative skeletal muscle mass (RSMM), countermovement jump (CMJ) height, training experience (total number of training sessions), and sex (coded: female = 0; male = 1) on Sinclair score in Olympic weightlifters (dependent variable)

Variables	*b*	*β*	*sr*	*sr²*	*t*	p
RSMM [%]	-3.28 [-11.6757, 5.1200]	-0.17 [-0.6058, 0.2569]	-0.09 [-0.3391, 0.1493]	0.01 [0, 0.0223]	-0.81	.43
CMJ height [m]	6.5339 [3.3579, 9.7100]	0.9653 [0.5022, 1.4284]	0.5002 [0.2495, 0.7508]	0.2502 [0.0622, 0.5637]	4.2460	<.001
Training experience	0.0177 [0.0069, 0.0285]	0.4911 [0.2074, 0.7749]	0.3993 [0.1463, 0.6524]	0.1595 [0.0214, 0.4256]	3.3901	.002
Sex	-77.0891 [-142.1084, -12.0698]	-0.5379 [-0.9890, -0.0869]	-0.2882 [-0.5389, -0.0376]	0.0831 [0.2904, 0.0014]	-2.4470	.022
						R^2 = 0.667 [0.3839, 0.7372] Adjusted R^2 = 0.611

Note. 95% confidence intervals are reported in parentheses.

This analysis results in the following multiple linear regression equation:

Sinclair score = 159.2439 – 3.2778 x Muscle Mass + 6.5339 x ELLP + 0.0177 x Training Experience – 77.0891 x Sex

Discussion and conclusion

The primary objective of this study was to examine the influence of muscle mass (measured as relative skeletal muscle mass, RSMM), explosive lower limb performance (ELLP; assessed via CMJ height), and training experience (quantified by the total number of training sessions) on the Sinclair score in Olympic weightlifting. To account for potential sex-related differences, the factor sex was included as an additional predictor in the regression model. The analysis revealed CMJ height and training experience as significant predictors of Sinclair score, while RSMM did not demonstrate a significant impact.

CMJ height emerged as the strongest predictor of the Sinclair score, explaining 25.0% of its variance. This finding aligns with previous research highlighting the critical role of ELLP in weightlifting performance (Storey & Smith, 2012; Travis, Goodin, Beckham, & Bazyler, 2018; Ulupınar & İnce, 2021). The second pull phase of the snatch and clean and jerk relies heavily on rapid force generation, which is captured effectively through CMJ performance (Garhammer, 1993). Athletes with superior ELLP are better equipped to achieve the high velocities required for successful lifts, reinforcing the importance of explosive-centric training strategies in weightlifting.

Training experience, quantified as the total number of training sessions, also significantly contributed to the Sinclair score, accounting for 16.0% of its variance. This finding supports the principle of specificity, where consistent and focused training enhances technical proficiency and neuromuscular adaptations (Panayotov & Yankova, 2022; Stone, Hornsby, Suarez, Duca, & Pierce, 2022). Weightlifting is not only a display of power but also a skill-dependent sport, where regular, high-quality training facilitates improvements in movement patterns, motor coordination, and efficiency.

Conversely, RSMM did not significantly predict the Sinclair score. This result is consistent with the understanding that, while muscle mass provides the structural foundation for force production, other factors— such as neuromuscular efficiency and technique—might play more dominant roles in elite performance (Zaras, et al., 2021).

A few limitations of this study must be acknowledged. First, muscle mass was assessed as total body relative skeletal muscle mass, which does not differentiate between upper- and lower-body musculature. Given the dominant role of the lower body in Olympic weightlifting, this broader measure may have diluted the specific contribution of lower-body muscle mass to performance outcomes (Vidal Pérez, Martínez-Sanz, Ferriz-Valero, Gómez-Vicente, & Ausó, 2021). Additionally, the homogeneity of muscle mass among the trained athletes in this study likely minimized variability, reducing its statistical significance as a predictor. Most participants were experienced athletes, and it is possible that some compensated for lower levels of lower-body muscle mass with relatively greater upper-body development. This potential compensation could have influenced the results, although further research would be needed to confirm this explanation.

Second, training experience was quantified as the total number of training sessions, which simplifies the complex nature of training variables. More detailed measures could include the volume and intensity an athlete dedicates to specific lifts. For instance, a more specific approach might be tracking the total number of repetitions performed at 80-90% of the one-repetition maximum (1RM: the maximum weight an individual can lift for one repetition) in the snatch and clean and jerk across all training years. These variables could provide deeper insights and should be incorporated into future research to better understand their influence.

However, this study underscores the critical role of ELLP and training frequency in determining Olympic weightlifting performance, while challenging the traditional emphasis on muscle mass as a primary predictor of success. ELLP, as measured by countermovement jump (CMJ) height, emerged as the strongest predictor of the Sinclair score, accounting for the largest portion of explained variance. This finding reinforces the importance of explosive strength in generating the high forces and velocities required during the snatch and clean and jerk. Training experience also significantly contributed to performance, highlighting the value of consistent, structured practice in fostering neuromuscular adaptations and technical proficiency.

These findings emphasize the need for training programs to focus not only on muscle mass development but also on enhancing the functional application of that muscle through ELLP-focused and skill-specific exercises. Training recommendations based on these findings include prioritizing conditional development through plyometric exercises such as countermovement jumps and Olympic lifting variations (Hackett, Davies, Soomro, & Halaki, 2016; Ulupınar & İnce, 2021). For exercises like the power clean and hang power clean, utilizing heavier loads (≥70% of 1RM) has been shown to produce greater peak power outputs (Soriano, Jiménez-Reyes, Rhea, & Marín, 2015). To enhance training experience, a regular training frequency of 4–6 sessions per week, incorporating progressive overload and consistent technical refinement, is essential for optimizing neuromuscular adaptations and performance improvements in most athletes. (Panayotov & Yankova, 2022; Sheppard & Triplett, 2016, p. 490; Stone, et al., 2022,). Elite-level athletes may train more frequently, often twice per day.

Future research should refine assessments of muscle mass by focusing specifically on lower-body musculature and its architectural properties. Additionally, exploring detailed training variables such as volume and intensity will provide deeper insights into optimizing training protocols for weightlifters across all levels.

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Correspondence to:
Florian Venus, B.Sc.
Paris Lodron University of Salzburg
Schlossallee 49, 5400 Hallein, Austria
E mail: florian.venus@plus.ac.at

A CONTEXTUAL EXAMINATION OF PHYSICAL AND TECHNICAL PERFORMANCE VARIATIONS IN PROFESSIONAL SOCCER

Koray Biber[1], Ömür Serdal Altunsöz[2], and Mustafa Söğüt[1]

[1]Department of Physical Education and Sports, Faculty of Education, Middle East Technical University, Ankara, Turkey
[2]National Team Coach, Turkish Football Federation, İstanbul, Turkey

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Abstract:

The purpose of this study was to analyse the variations in physical and technical performance parameters of professional soccer players according to match outcome (winning, drawing, or losing) and team quality (top-, middle-, and bottom-ranked). The data were collected from 122 matches of the Turkish Super League during the 2019-2020 season using the semi-automatic multi-camera tracking system. The results revealed that the winning teams performed more high-intensity running activities, particularly when in ball possession, and produced higher number of shots on target. The distance covered in high-intensity running and sprinting when in ball possession, as well as the number of successful crosses, shots on target, corner kicks, and short passes were greater in top-ranked teams. The coaches, performance analysts, and practitioners should consider performance parameters that are influenced by contextual variables before designing training programmes and match evaluations.

Keywords: *football, contextual variables, match analysis, match running, match variables*

Introduction

Match analysis is widely accepted as an efficient feedback strategy in soccer (Drust, 2010). It does not only indicates the strengths and weaknesses of a team (Castellano, Casamichana, & Lago, 2012) but also plays an essential role in determining key performance indicators as has been well documented in several studies (Alves, et al., 2019; Andrzejewski, Konefał, Chmura, Kowalczuk, & Chmura, 2016; Carling, 2011; Castellano, et al., 2012; García-Rubio, Gómez, Lago-Peñas, & Ibáñez Godoy, 2015; Hoppe, Slomka, Baumgart, Weber, & Freiwald, 2015; Lago-Peñas & Lago-Ballesteros, 2011; Liu, T., García-De-Alcaraz, Zhang, L., & Zhang, Y., 2019; Rampinini, Impellizzeri, Castagna, Coutts, & Wisløff, 2009; Taylor, Mellalieu, James, & Shearer, 2008; Zhou, Zhang, Lorenzo Calvo, & Cui, 2018).

Earlier studies indicated that more successful teams performed a greater number of short passes, successful short passes, tackles, shots, and shots on target compared to less successful teams in the Italian Serie A (Rampinini, et al., 2009), Spanish La Liga (Lago-Peñas, Lago-Ballesteros, Dellal, & Gómez, 2010), UEFA Champions League (Lago-Peñas, Lago-Ballesteros, & Rey, 2011), FIFA World Cup 2014 (Liu, H., Gomez, Lago-Peñas, & Sampaio, 2015; Yi, et al., 2019), and Chinese Super League (Zhou, et al., 2018). However, the number of crosses, dribbles, shots blocked, and red cards were more related to losing teams (Liu, H., et al., 2015). The findings from the German Bundesliga (Hoppe, et al., 2015) and Italian Serie A (Rampinini, et al., 2009) suggested that high-speed running activities with ball possession were related to success, whereas total distance covered, and the number of high-speed running activities were not related to success. Accordingly, Aquino et al. (2019) found that total distance covered did not differ among successful and unsuccessful teams during FIFA World Cup 2018. In contrast, findings from the English Premier League (Di Salvo, Gregson, Atkinson, Tordoff, & Drust, 2009) indicated that high-intensity running distance in ball possession was not related to team success. Further, total distance covered at high-intensity running, sprinting distance, and high-intensity running distance without ball possession were significantly higher in lower ranked teams compared to higher ranked teams in English Premier League (Di Salvo, et al., 2009).

Several studies suggested that performance parameters were influenced by the quality of opposition (Taylor, et al., 2008; Teixeira, et al., 2021). For instance, Aquino et.al (2021) found that top-ranked teams covered greater distance while playing against top-ranked teams compared to lower-ranked teams in the Brazilian Second Division League. Additionally, similar results were reported in two separate studies across the Spanish La Liga (Castellano, Blanco-Villaseñor, & Álvarez, 2011; Lago, Casais, Dominguez, & Sampaio, 2010). Also, findings from one of the major European national league (Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007) demonstrated that the distance covered at high-intensity running was greater as the quality of opposition increased, as compared to lower-ranked opponents.

The great majority of the performance analysis related studies investigated the higher ranked leagues in Europe such as the English Premier League (Bradley, et al., 2011), Spanish La Liga (Oliva-Lozano, Rojas-Valverde, Gómez-Carmona, Fortes, & Pino-Ortega, 2021), Italian Serie A (Rampinini, et al., 2009), German Bundesliga (Vogelbein, Nopp, & Hökelmann, 2014), French Ligue 1 (Carling, 2011) or high-level international tournaments such as UEFA Champions League (Lago-Peñas, et al., 2011), and FIFA World Cup (Liu, H., et al., 2015). To the best of the authors' knowledge, there is limited evidence across lower-ranked leagues such as the Turkish Super League, which is ranked 20th based on the UEFA Country Coefficients. Variations in team performance can be observed according to the type of competition, from both the between- and within-team aspects (Gómez, Lago-Peñas, & Pollard, 2013). Given that the majority of previous research has focused on higher-ranked leagues, examining performance variations in a lower-ranked league offers valuable insights into whether similar contextual patterns exist in lower-tier competitions, thereby enhancing the generalizability and practical value of performance analysis across various levels of play. Therefore, this study aimed to investigate the variations in physical and performance parameters of elite soccer players in Turkish Super League in relation to match outcome and team quality.

Methods

Data collection

Turkish Super League is the top-tier level of soccer in Turkish Association Football. In the 2019-2020 season, a total of 306 matches were played by 18 teams that competed against each other twice, at home and away, during the 34 match-days. The available data were provided by Sentio Sports Analytics Company, who collected data from 122 of the 306 matches by utilizing a semi-automatic multi-camera tracking system. Sentiscope was experimented several times in official soccer matches during its evolution and it was chosen for its effectiveness compared to other multiple object tracking methods (Baysal & Duygulu, 2015). To collect the data, two 4K cameras were installed close to the midline of the pitch, as high as possible, and calibrated to the field prior to the kick-off. The written consent was received from the Sentio Sports Analytics Company to use their data.

Sample and procedures

Ethics committee (Human Subjects Ethics Committee) approval was received from the Middle East Technical University (approval number: 425-ODTU-2021). Variations in physical and technical performance parameters of elite soccer players were investigated in relation to two different contextual variables, i.e., match outcome and team quality. With respect to the match outcomes, data from 85 winning and losing teams, and 74 draws were collected. Regarding the second contextual variable, team quality, the teams were categorized as the top (data from teams ranked 1-6, n=80), middle (data from teams ranked 7-12, n=89), and bottom (data from teams ranked 13-18, n=75) according to their final ranking at the end of the season.

Variables

A total of 12 physical and 15 technical performance parameters were selected as dependent variables, similar to previous studies (Alves, et al., 2019; Gai, Leicht, Lago, & Gómez, 2019; Harrop & Nevill, 2014; Konefał, et al., 2020; Kubayi & Toriola, 2020; Lago-Peñas, et al., 2010; Liu, H., Gómez, Gonçalves, & Sampaio, 2016; Rampinini, et al., 2007; Yang, Leicht, Lago, & Gómez, 2018; Yi, et al., 2019; Zhou, et al., 2018). The independent variables were classified as two groups: (1) match outcome (winning, losing, and drawing) and (2) team quality (top, middle, and bottom). The operational definitions of performance variables are presented in Table 1 (Zhou, et al., 2018).

Statistical analysis

Descriptive statistics for match outcome and team quality were computed and shown in Table 2 and Table 3, respectively. All values were reported as means and standard deviations. Normality is an inherent assumption in parametric tests such as the one-way analysis of variance (ANOVA) (Gravetter & Wallnau, 2017). Since each sample size included sufficient observations (n>30) in this study, the violation of normality assumption should not have caused a major problem as previously reported by Ghasemi and Zahediasl (2012). One-way ANOVA was used to examine the variations in physical and technical performance parameters of soccer players

Table 1. Operational definitions of variables

Total distance (TD): The sum of covered distance in meters by all the team players.
High-intensity distance (HID): The sum of covered distance in meters at speed between 20km/h and 24km/h by all the team players.
Sprint distance (SD): The sum of covered distance in meters at the speed over 24km/h by all the team players.
Number of high-intensity runs (NHIR): Number of running in a match at a speed between 20km/h and 24km/h by all the team players.
Number of sprints (NS): Number of sprinting by all the team players.
Average speed (AS): Average speed of running, walking, and jogging performed by all the team players.
Total distance in possession (TDP): The sum of covered distance in meters when in ball possession by all the team players.
Total distance out of possession (TDOP): The sum of covered distance in meters when out of ball possession by all the team players.
High-intensity distance in possession (HIDP): The sum of covered distance in meters when in ball possession at speed between 20km/h and 24km/h by all the team players.
High-intensity distance out of possession (HIDOP): The sum of covered distance in meters when out of ball possession at speed between 20km/h and 24km/h by all the team players.
Sprint in possession (SP): The sum of covered distance in meters at the speed over 24km/h when in ball possession by all the team players.
Sprint out of possession (SOP): The sum of covered distance in meters at the speed over 24km/h when out of ball possession by all the team players.
Successful passes (SUCP): Number of the balls played between teammates without interruption.
Unsuccessful passes (UNSUCP): Number of failed attempts to play the ball between teammates.
Long passes (LP): Number of the balls played over more than 30 meters between teammates without interruption.
Short passes (SHP): Number of the balls played over less than 30 meters between teammates without interruption.
Average pass length (AVPL): The mean length of successful passes.
Shots on target (SOT): An attempt to score a goal that required the intervention to stop it going in or resulted in a goal/shot which would go in without being diverted.
Shots off target (SOFT): An attempt to score a goal, made with any (legal) part of the body, off target.
Successful crosses (SUCC): Any ball sent into the opposition team's area from a wide position that meets with a teammate.
Unsuccessful crosses (UNSUCC): Any ball sent from the wide position targeting the teammate which is failed.
Corner (COR): Ball goes out of play for a corner kick.
Fouls committed (FC): Any infringement that is penalised as foul play by a referee.
Yellow cards (YC): Where a player was shown a yellow card by the referee for reasons of foul, persistent infringement, hand ball, dangerous play, time wasting, etc.
Red cards (RC): It is shown by the referee to remove a player from the game either directly or in consequence of a second yellow card.
Offside (OFF): Being caught in an offside position resulting in an indirect free-kick to the opposing team.
Possession (POS): Duration of a team's control over the ball as a proportion of the total time when the ball is in play.

according to the match outcome and team quality. The Bonferroni *post-hoc* test was applied to identify pairwise differences. To measure the effect size, eta-squared ($\eta 2$) was computed ($\eta 2 = 0.01$: small effect size, $\eta 2 = 0.06$: medium effect size, $\eta 2 = 0.14$ or higher: large effect size) (Cohen, 1988). The significance level was set at $p<.05$. The IBM SPSS Statistic for Windows, Version 25.0 (SPSS Inc., Chicago IL) was used to perform each statistical analysis.

Results

Match outcome

Descriptive statistics of physical and technical performance parameters according to match outcome and the results of ANOVA are shown in Table 2. The number of high-intensity runs (NHIR) $F(2, 241) = 4.558$, $p=.011$ was greater in the winning and losing teams than in the drawing teams. Furthermore, the average speed (AS) was

Table 2. Physical and technical performance parameters according to the match outcome

Variable	Winning (n= 85)		Losing (n= 85)		Drawing (n= 74)		*F*	*p*	η2	*Post hoc*
	M	SD	M	SD	M	SD				
Physical performance parameters										
TD (m)	108985.60	6922.11	107292.00	6756.19	108283.40	4213.27	1.619	0.200	0.013	
HID (m)	4532.86	594.19	4492.20	584.76	4309.73	565.47	3.230	0.041*	0.026	
SD (m)	2551.48	499.13	2475.95	455.12	2458.43	506.82	0.845	0.431	0.007	
NHIR	255.44	44.87	253.47	43.24	235.35	49.03	4.558	0.011*	0.036	D<W, D<L
NS	100.52	28.12	98.38	27.28	90.42	29.42	2.758	0.065	0.022	
AS (km/h)	6.43	0.30	6.31	0.28	6.30	0.27	5.004	0.007*	0.040	L<W, D<W
TDP (m)	37417.8	7087.04	35869.93	6920.13	35932.77	7404.49	1.259	0.286	0.010	
TDOP (m)	37887.61	7385.26	38748.22	7188.16	37372.24	7906.80	0.693	0.501	0.006	
HIDP (m)	1839.08	411.87	1691.68	426.55	1622.99	408.86	5.684	0.004*	0.045	D<W
HIDOP (m)	2058.14	529.54	2213.12	519.46	1946.91	513.34	5.26	0.006*	0.042	D<L
SP (m)	1273.49	360.49	1006.72	239.64	1065.70	302.09	17.805	<0.001*	0.129	L<D<W
SOP (m)	1046.44	292.03	1248.94	343.61	1102.16	303.34	9.366	<0.001*	0.072	W<L, D<L
Technical performance variables										
SUCP	352.07	105.43	342.73	87.84	326.3	107.86	1.322	0.269	0.011	
UNSUCP	80.67	13.03	83.39	13.33	89.69	18.97	7.256	0.001*	0.057	W<L<D
LP	61.06	15.11	62.81	16.5	64.15	16.11	0.757	0.470	0.006	
SHP	375.21	104.83	363.31	89.35	351.84	102.20	1.108	0.332	0.009	
AVPL	19.52	1.99	19.70	1.87	20.12	2.26	1.783	0.170	0.015	
SOT	11.07	4.20	6.98	3.44	8.16	3.73	25.905	<0.001*	0.177	L<W, D<W
SOFT	5.76	2.74	5.35	2.74	5.65	3.16	0.461	0.631	0.004	
SUCC	4.51	2.34	4.51	2.92	4.24	2.57	0.258	0.772	0.002	
UNSUCC	12.14	5.82	15.54	6.78	13.84	7.26	5.607	0.004*	0.044	W<L
COR	4.80	2.21	4.81	2.51	4.51	2.66	0.365	0.695	0.003	
FC	13.08	3.83	12.27	3.64	13.43	3.79	2.040	0.132	0.017	
YC	2.20	1.37	2.72	1.56	2.72	1.49	3.418	0.034*	0.028	
RC	0.06	0.24	0.26	0.6	0.15	0.39	4.431	0.013*	0.035	W<L
OFF	1.89	1.65	1.92	1.39	1.89	1.71	0.007	0.993	0	
POS (%)	51	8	49	8	50	9	0.494	0.610	0.004	

significantly higher in the winning teams compared to the drawing and losing teams F(2, 241) = 5.004, p=.007. The winning teams performed greater high-intensity distance coverage in possession (HIDP) than the drawing teams F(2, 241) = 5.684, p=.004. The high-intensity distance coverage out of possession (HIDOP) was greater in the losing teams compared to the drawing teams F(2, 241) = 5.26, p=.006. The sprint in possession (SP) F(2, 241) = 17.805, p=<.001 was greater in the winning teams than in the drawing and losing teams. However, the losing teams had greater sprint out of possession (SOP) F(2, 241) = 9.366, p=<.001 than the wining and drawing teams. The results of ANOVA indicated that unsuccessful passes (UNSUCP) were significantly greater in drawing teams, losing teams, and winning teams, respectively F(2, 241) = 7.256, p=.001. The number of shots on target (SOT) were greater in the winning teams than in both the losing and drawing teams F(2, 241) = 25.905, p =<.001. In addition, the losing teams had greater number of unsuccessful crosses (UNSUCC) than

Table 3. Physical and technical performance parameters according to the team quality

Variable	Top (n= 80)		Middle (n= 89)		Bottom (n= 75)		F	p	η2	*Post hoc*
	M	SD	M	SD	M	SD				
Physical performance parameters										
TD (m)	108135.40	5354.53	108282.70	6628.73	108114.3	6519.1	0.018	0.982	0	
HID (m)	4487.48	613.86	4553.48	582.67	4290.56	536.46	4.424	0.013*	0.035	B<M
SD (m)	2514.96	516.85	2564.35	479.77	2397.76	449.47	2.500	0.084	0.02	
NHIR	250.20	44.47	253.42	45.99	241.37	48.22	1.449	0.237	0.012	
NS	97.96	30.45	97.39	27.50	94.56	27.56	0.316	0.729	0.003	
AS (km/h)	6.31	0.26	6.36	0.26	6.37	0.34	0.877	0.417	0.007	
TDP (m)	37718.51	6866.12	36429.58	7745.85	35050.24	6464.09	2.745	0.066	0.022	
TDOP (m)	36849.15	7263.02	38078.43	7338.87	39235.73	7741.93	1.994	0.138	0.016	
HIDP (m)	1803.86	398.79	1773.43	440.68	1574.29	396.68	7.026	0.001*	0.055	B<T, B<M
HIDOP (m)	2054.20	526.11	2154.89	510.6	2013.43	552.89	1.58	0.208	0.013	
SP (m)	1180.33	333.06	1150.28	304.82	1011.72	318.81	6.161	0.002*	0.049	B<T, B<M
SOP (m)	1096.01	305.97	1190.06	361.57	1107.61	291.80	2.139	0.120	0.017	
Technical performance variables										
SUCP	364.26	103.8	331.64	105.28	327.29	87.46	3.283	0.039	0.027	
UNSUCP	85.74	17.56	82.11	15.76	85.53	12.66	1.462	0.234	0.012	
LP	62.99	15.42	60.75	16.55	64.40	15.55	1.107	0.332	0.009	
SHP	387.01	96.68	356.37	107.23	348.43	87.14	3.426	0.034*	0.028	B<T
AVPL	19.44	1.83	19.68	1.97	20.20	2.27	2.875	0.058	0.023	
SOT	9.99	4.24	8.61	4.06	7.64	3.95	6.487	0.002*	0.051	B<T
SOFT	6.10	2.77	5.56	3.10	5.07	2.62	2.549	0.08	0.021	
SUCC	5.24	2.80	4.47	2.50	3.51	2.25	9.065	<.0001*	0.070	B<T, B<M
UNSUCC	14.41	6.07	14.19	7.47	12.81	6.49	1.281	0.28	0.011	
COR	5.35	2.67	4.75	2.39	4	2.11	6.128	0.003*	0.048	B<T
FC	12.88	4.23	12.92	3.60	12.92	3.49	0.004	0.996	0	
YC	2.45	1.45	2.58	1.43	2.57	1.60	0.203	0.816	0.002	
RC	0.10	0.34	0.16	0.42	0.21	0.55	1.260	0.286	0.010	
OFF	1.91	1.59	1.90	1.56	1.89	1.6	0.003	0.997	0	
POS (%)	51	8	50	9	48	7	2.732	0.067	0.022	

the winning teams $F(2, 241) = 5.607$, $p=.004$. Moreover, the losing teams received significantly more red cards (RC) than the winning teams $F(2, 241) = 4.431$, $p=.013$.

Team quality

According to the ANOVA results, presented in Table 3, the following physical performance parameters were higher in the middle-ranked teams than in the bottom-ranked teams: HID $F(2, 241) = 4.424$, $p=.013$; HIDP $F(2, 241) = 7.026$, $p=.001$; SP $F(2, 241) = 6.161$, $p=.002$. Additionally, HIDP and SP were significantly higher in the top-ranked teams compared to the bottom-ranked teams. The results also indicated that the top-ranked teams had significantly greater mean values in several technical performance parameters including SHP $F(2, 241) = 3.426$, $p=.034$, SOT $F(2, 241) = 6.487$, $p=.002$, SUCC $F(2, 241) = 9.065$, $p=<.001$, and COR $F(2, 241) = 6.128$, $p=.003$ than the bottom-ranked teams.

In addition, the middle-ranked teams had significantly higher number of SUCC than the bottom-ranked teams.

Discussion and conclusion

The aim of the present study was twofold: a) to identify the variations of physical and b) technical performance variables according to the match outcome and team quality in elite soccer players competing in the Turkish Super League. The results of the study suggested that physical and technical performance parameters can vary in relation to the contextual variables, i.e., match outcome and team quality in elite soccer. The mean average speed was significantly higher in the winning teams. The distance covered in ball possession with high-level activities such as sprinting and high-intensity running was greater in the winning teams, while ball possession was not different according to the match outcome. Contrary, the losing teams covered greater distance in sprinting when out of ball possession. These findings were consistent with results from the Chinese Super League (Zhou et al., 2018). The results of the current study indicated that winning depends not only on higher speed but also on the ability to perform high-intensity running and sprinting while in possession of the ball in Turkish Super League. Thus, sprinting abilities should be developed within the context of ball possession scenarios, rather than improving sprinting and high-intensity running in isolation.

Moreover, the number of shots on target was greater for the winning teams. Accordingly, previous studies from the Spanish La Liga (Lago-Peñas, et al., 2010), German Bundesliga (Yue, Broich, & Mester, 2014) and three consecutive FIFA World Cups (Castellano, et al., 2012) also found that the quality of the shots was more related to winning than the quantity of the shots. Therefore, practitioners should consider improving the shot quality in their players. An association between winning and the number of successful passes was reported in national leagues and international competitions including the Spanish La Liga (Lago-Peñas, et al., 2010), UEFA Champions League (Lago-Peñas, et al., 2011), and FIFA World Cup (Alves, et al., 2019). Similar to previous findings, the winning teams had less unsuccessful passes and crosses. Achieving more successful passes could result in more successfully completed attacks, which eventually increases the chance of scoring a goal. The RC was significantly lower in the winning teams, unsurprisingly, which was also reported previously in the Spanish La Liga (Lago-Peñas, et al., 2010) and UEFA Champions League (Lago-Peñas, et al., 2011). The winning teams in the Africa Cup of Nations 2017 (Kubayi & Toriola, 2020) had lower ball possessions, while it was higher in the winning teams than in the losing teams in UEFA Champions League (Lago-Peñas, et al., 2010). However, the results of this study showed that ball possession did not differ in relation to match outcome.

The results indicated that match performance variables, including HID, HIDP, and SP were significantly lower in the bottom-ranked teams compared to the middle-ranked teams, while the last three variables were also lower in comparison with the top-ranked teams. These findings were in line with earlier studies that examined data from Italian Serie A (Rampinini, et al., 2009) and German Bundesliga (Hoppe, et al., 2015). A previous study conducted on data from the English Premier League (Di Salvo, et al., 2009) suggested that distance covered in high-intensity running in total and when out of ball possession was significantly greater in the middle- and bottom-ranked teams. On the contrary, the present study showed that high-intensity running activities without ball possession were not significantly different among teams with different end-of-season rankings.

Furthermore, the top-ranked teams performed a greater number of SOT than the bottom-ranked teams. Thus, the results showed that the number of SOT is more important than the total shot attempts. Earlier findings from Italian Serie A (Rampinini, et al., 2009), Spanish La Liga (Liu, H., et al., 2016), and German Bundesliga (Yue, et al., 2014) also emphasized the quality of shots for success in elite soccer. Moreover, the SHP was higher in the top-ranked teams, which was in accordance with the results from Italian Serie A (Rampinini, et al., 2009). It is most likely because attempting more short passes is increasing the number of completed attacks that results in a goal. In the context of a lower-ranked league, the greater use of short passes by the top-ranked teams may also reflect superior technical ability and a more structured style of play, allowing them to dictate the tempo of the game more effectively compared to the lower-ranked teams. Other attacking related variables, SUCC and COR, were also found higher in the top-ranked teams than in the bottom-ranked teams. Several previous studies reported that the number of crosses were greater in less successful teams (Liu, Gómez, et al., 2016; Liu, Hopkins, & Gómez, 2016), while the results of the present study demonstrated that the top-ranked teams had more SUCC as compared to the bottom-ranked teams. Therefore, the findings of this study suggest that the quality of crosses rather than the quantity of crosses should be considered by practitioners.

This study has several limitations. The utilized data, from a single season (2019-2020), including a total of 122 matches, had a limited sample size which decreases the power of generalisation. Thus, future studies should include larger sample sizes. Environmental factors such as heat, stress, and altitude can also influence the performance variables in elite soccer (Trewin, Meylan, Varley, & Cronin, 2017). However, this study was conducted without taking environmental factors into account, and following studies should consider the influence of the aforementioned parameters. Finally, the 2019-2020 season of the Turkish Super League was suspended for approximately three months due to the COVID-19 pandemic. The post-pandemic period of the season was played without an audience which might have decreased the home advantage. Hence, data collected from regular seasons with fan support should be preferred.

This study investigated the variations in physical and technical performance variables of elite soccer players, in relation to match outcome and team quality. To the best of the authors' knowledge, this study is the first to enable a better understanding of soccer match analysis in the Turkish Super League. Based on the results it can be concluded that winning teams are expected to cover greater distances in ball possession using high-level running activities. They are also likely to produce a higher number of shots on target. The greater distance covered when in ball possession at high-intensity running, sprinting, and greater number of shots on target are characteristic of the best teams at the top level of soccer.

Practical implications

The coaching staff and other practitioners may consider adopting high-level running activities when in ball possession either for match strategies or training programmes to develop necessary skills in their players. In addition, the quality of shots rather than the quantity of shots should not be neglected. The results also suggest that the end-of-season ranking might be related with the number of short passes, corner kicks, successful crosses, and shots on target. Therefore, improving the accuracy of crosses as well as performing more short pass game strategies may help teams to be placed higher at the end of the season.

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Correspondence to:
Koray Biber
Department of Physical Education and Sports
Faculty of Education, Middle East Technical University
Ankara, Türkiye, 06800
E-mail: koray.biberr@gmail.com

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FOCUS AND SCOPE

Kinesiology – International Journal of Fundamental and Applied Kinesiology (print ISSN 1331- 1441, online ISSN 1848-638X) publishes twice a year scientific papers and other written material from kinesiology (a scientific discipline which investigates the art and science of human movement; in the meaning and scope close to the idiom "sport sciences") and other adjacent human sciences focused on sport and exercise, primarily from anthropology (biological and cultural alike), medicine, sociology, psychology, natural sciences and mathematics applied to sport in its broadest sense, history, and others. Contributions of high scientific interest, including also results of theoretical analyses and their practical application in physical education, sport, physical recreation and kinesitherapy, are accepted for publication. The following sections define the scope of the journal: Sport and sports activities, Physical education, Recreation/leisure, Kinesiological anthropology, Training methods, Biology of sport and exercise, Sports medicine and physiology of sport, Biomechanics, History of sport and Book reviews with news.

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Journals

Sallis, J.F., & McKenzie, T.L. (1991). Physical education's role in public health. *Research Quarterly for Exercise and Sport*, *62*(2), 124–137. Trstenjak, D., & Žugić, Z. (1999). Sport as a form of social involvement – the case of tennis. *Kinesiology, 31*(2), 50–61.

Chapters in books

Sparkes, A.C. (1997). Reflections on the socially constructed self. In K. Fox (Ed.), *The physical self: From motivation to well-being* (pp. 83–110). Champaign, IL: Human Kinetics.

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Kasović, M., Medved, V., & Vučetić, V. (2002). Testing of take-off capacities in the lower extremities of top football players. In D. Milanović & F. Prot (Eds.), *Proceedings Book of 3rd International Scientific Conference "Kinesiology – New Perspectives"* (pp. 677–680). Zagreb: Faculty of Kinesiology, University of Zagreb.

Electronic resources (computer software, computer and information services, on-line sites)

U.S. Department of Education. (1997). *Title IX: 25 years of progress* /on-line/. Retrieved April 15, 1999 from: www.ed.gov/pubs/TitleIX/title.html

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Theses

Marelić, N. (1998). *Kineziološka analiza karakteristika ekipne igre odbojkaša juniora*. [Kinesiological analysis of the junior volleyball team play characteristics. In Croatian.] (Unpublished doctoral dissertation, University of Zagreb) Zagreb: Fakultet za fizičku kulturu Sveučilišta u Zagrebu.

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