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Fitness Assessment, Athlete's Monitoring Cycle and Training Interventions in Team Sports

Edited by

Filipe Manuel Clemente and Hugo Sarmento

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Fitness Assessment, Athlete's Monitoring Cycle and Training Interventions in Team Sports

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Preface to ”Fitness Assessment, Athlete’s Monitoring Cycle and Training Interventions in Team Sports”

This book provides solid evidence about the new advances in research on the topics of Fitness Assessment, Athlete’s Monitoring Cycle, and Training Interventions. The readers will find interesting findings regarding the use of fitness assessment for supporting training interventions and interesting reports about the use of monitoring strategies in order to adjust training prescriptions.

Filipe Manuel Clemente, Hugo Sarmento
Editors

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Article

Exercise Intensity and Technical Involvement in U9 Team Handball: Effect of Game Format

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Abstract: The purpose of this study was to quantify the exercise intensity and technical involvement of U9 boys' and girls' team handball during different game formats, and the differences between genders. Locomotor activity (total distance, distance in speed zones, accelerations, and decelerations), heart rate (HR), and technical involvement (shots, goals, and duels) metrics were collected during various 15 min game formats from a total of 57 Danish U9 players (37 boys and 20 girls). Game formats were a small size pitch (20 × 13 m) with 3 vs. 3 players and offensive goalkeepers (S3 + 1) and 4 vs. 4 players (S4), a medium size pitch (25.8 × 20 m) with 4 vs. 4 (M4) and 5 vs. 5 (M5) players, and a large size pitch (40 × 20 m) with 5 vs. 5 (L5) players. Boys and girls covered a higher total distance (TD) of high-speed running (HSR) and sprinting during L5 games compared to all other game formats ($p < 0.05$; ES = (-0.9 to -2.1), (-1.4 to -2.8), and (-0.9 to -1.3) respectively). Players covered the highest amount of sprinting distance in L5 games compared to all other game formats ($p < 0.01$; ES = 0.8 to 1.4). In all the game formats, players spent from 3.04 to 5.96 min in 180–200 bpm and 0.03 min to 0.85 min in >200 bpm of the total 15 min. In addition, both genders had more shots in S3 + 1 than M5 ($p < 0.01$; ES = 1.0 (0.4; 1.7)) and L5 ($p < 0.01$; ES = 1.1 (0.6; 2.2)). Team handball matches have high heart rates, total distances covered, and high-intensity running distances for U9 boys and girls irrespective of the game format. Locomotor demands appeared to be even higher when playing on larger pitches, whereas the smaller pitch size and fewer players led to elevated technical involvement.

Keywords: physiology; youth; heart rate; time motion; notational analysis

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1. Introduction

Team handball is an intermittent high-intensity body contact team sport, characterized by sprinting, jumping, throwing, blocking, and pushing [1]. Various studies have described the locomotor demands of team handball in different age and sex groups; on average, international male players cover 4370 ± 702 m [2], elite female players cover 4002 ± 551 m [3], and elite male adolescent players (15 years old) cover 1777 ± 264 m [4]. Overall, the physical and physiological demands, and therefore, the potential as a health-promoting activity of team handball have been predominantly investigated in adults and adolescent players [5]. Only one study investigated U13 boys and girls across different formats [6]. Youth team handball games in Denmark are played on different pitch dimensions and with a different number of players compared to adult games, similar to other team sports such as football [7]. For instance, in youth team handball games, the pitch and goal dimensions are smaller and the number of players is reduced. Extensive research in other team sports showed that manipulating the player numbers and the pitch size can alter the exercise intensity (i.e., locomotor activity, physiological responses) during a game in different sports [8]. Indeed, higher exercise intensity (e.g., heart rate (HR)) is reached when decreasing the number of players and increasing the pitch area [9]. On the other hand, reducing the number of players and pitch dimensions appears to induce higher technical involvement [7,10].

Moreover, the sex-specific timing of maturation [11,12] and the gender differences in morphological and neuromuscular characteristics are still early at this stage of age, and gender-related differences in explosive actions are therefore unlikely. Investigating differences in exercise intensity between gender may provide practitioners with a greater understanding of sex-specific training prescription. Overall, several external factors can influence the physiological and technical demands of training drills and thus, the desired conditioning stimulus [13]. Thus, information regarding the exercise intensity in children of both genders across different game formats could be of interest for practitioners involved with youth handball.

Based on previous findings in a study of the game format of U13 handball [6], we hypothesized that a larger court will increase the total distance and that fewer players on the court will increase the involvement of the players in terms of more shots and duels per player.

The purpose of this study was, therefore, to quantify the exercise intensity, the technical involvement, and a gender comparison of U9 boys' and girls' team handball during different game formats. The study provides useful knowledge that might change the game format used in tournaments for U9 players for relevant development and health promotion.

2. Materials and Methods

2.1. Design

U9 players from ten Danish teams (local handball clubs around the region of Funen) participated in a 1-day tournament. Up to 5 games per player were used. Game formats were classified according to the pitch size and number of players that represent possible official games:

- (S3 + 1): 3 vs. 3 + offensive goalkeepers on a small size pitch size of 20 × 13 m (37 m^2 per player);
- (S4): 4 vs. 4 on a small size (33 m^2 per player);
- (M4): 4 vs. 4 on a medium size pitch size of 25.8 × 20 m (65 m^2 per player);
- (M5): 5 vs. 5 on a medium size (52 m^2 per player);
- (L5): 5 vs. 5 on a large size pitch size of 40 × 20 m (80 m^2 per player).

In all of the above formats, goalkeepers participated, but they only were tracked in S3 + 1. To remove the effect of exercise volume and fatigue, the game duration was maintained at 15 min, and the games were played in a randomized order on the same day. All games were played on indoor team handball pitches. The sizes of the goals were 1.6 × 2.4 m on the small pitch, 1.78 × 3 m on the medium pitch, and 2 × 3 m on the large pitch. The games were played with all the official rules of the team handball game. The study was carried out according to the Helsinki protocol.

2.2. Participants

Six teams of U9 boys (n = 37) and four teams of U9 girls (n = 20) participated in the study. All participants were 8–9-year-old recreational handball players.

2.3. Activity Profile

The activity patterns were recorded using a wearable device incorporating a 200 Hz accelerometer and gyroscope (Polar Team Pro system, Polar, Kempele, Finland), which was placed on the lower sternum using an elastic band. The following variables were adopted: total distance (TD) covered, peak speed (V_{peak}) attained, and number of sprints (>18 km/h). Exercise intensity was also distributed in the following running zones: standing/walking (St/W; 0.00–2.99 km/h), jogging (3.00–7.99 km/h), moderate-speed running (MSR, 8.00–12.99 km/h), high-speed running (HSR, 13.00–17.99 km/h), and sprinting (>18 km/h), according to previous studies describing the locomotor demands of team sports' children [14,15].

In addition, the number of accelerations and decelerations were measured with the following zones: Acc < 1.49 $m \cdot s^{-2}$, Acc 1.50 to 2.30 $m \cdot s^{-2}$, Acc > 2.30 $m \cdot s^{-2}$, Dec < -1.49 $m \cdot s^{-2}$, Dec -1.50 to -2.30 $m \cdot s^{-2}$, and Dec < -2.30 $m \cdot s^{-2}$ [14,15]. The total number of accelerations and decelerations was also quantified. The activity profiles and HR data were stored in the device and downloaded using the manufacturer's software (POLAR, software version 1.3.1, POLAR, Polar Electro Oy, Kempele, Finland) [16].

2.4. Heart Rate and Subjective Perceptions

HRs were recorded in 1 s intervals during each game. The HR data were downloaded and expressed as the mean and max HR for the full match. In addition, the HR data were expressed as the time spent in HR zones as follows: <120, 120 to 160, 160 to 180, 180 to 200, and >200 bpm, as previously described [7]. Furthermore, after each game, a Visual Analogue Scale was used to assess the rating of perceived exertion (RPE) and enjoyment/fun (RPF), as previously done in similar studies since it is a well-accepted method to describe subjective phenomena [17,18]. Immediately after the 15 min matches, every player had a paper and pencil to record their scores. All players underwent a brief familiarization session in which three researchers explained the procedure, underlining the importance of scoring their perception of exertion (not fatigue or tiredness). For physical exertion, the players placed a mark on a 17.4 cm line ranging from 'maximally demanding' to 'not demanding at all', while for perceived fun, a similar line was used, ranging from 'maximal fun' to 'not fun at all'. The result was obtained by measuring with a ruler the length (in centimeters) from 0 to the mark made by the player.

2.5. Technical Analysis

Notational analysis was performed by video analysis by five experienced handball coaches (an observer-to-player ratio of 1:1) engaged by the Danish Handball Federation (DHF). The operational definitions of these variables were the following: goal (an attempt with successful scoring), shot (an attempt to score a goal made with any (legal) part of the body, either on or off-target), successful shot (an attempt that successfully scores a goal, given by the ratio between goals and shots and expressed as a percentage), 1 vs. 1 duels (offensive breakthrough to an opponent with the ball) [19,20].

2.6. Statistical Analyses

Differences between game formats and between sexes were analyzed using a linear mixed model with unstructured covariance, considering the fact that participants differed regarding the number of game formats they participated in [21]. The game format was set as a fixed effect and the individual subjects and teams were set as random effects. Physical, physiological, and perceptual variables were dependent variables. If a significant effect was found, a pairwise comparison was tested using the Bonferroni post-hoc test. Magnitude-based inferences were adopted to interpret differences between game formats and sexes [22]. Effect sizes (ES) were calculated using mean differences and pooled standard deviation, and classified according to Hopkins and Marshall [22] as following: trivial (ES < 0.2), small (ES = 0.2–0.6), moderate (ES = 0.6–1.2), large (ES = 1.2–2.0), very large (ES = 2.0–4.0), and huge (ES > 4.0). When 90% confidence intervals overlapped positive and negative values, the effect was deemed as unclear. Otherwise, the effect was deemed as the observed magnitude [23]. Significance was set at $p \leq 0.05$. Data analysis was performed using the Statistical Package for Social Science statistical software (version 23, IBM SPSS Statistics, Chicago, IL, USA) and an online-available Excel spreadsheet [24].

3. Results

3.1. Activity Profile

Boys covered more TD, HSR, and sprinting and performed more sprints in L5 compared to S3 + 1, S4, M4, and M5 ($p < 0.05$; ES = 0.9 to 1.9). Moreover, the TD was moderately higher in S3 + 1 compared to M5 ($p = 0.026$; ES = 0.9 [0.4; 1.3]). Higher peak speed were reached during L5 compared to S4 and M5 ($p = 0.01$; ES = 0.9 to 1.1) (Table 1) (Figure 1A).

Table 1. Differences in peak and average values and total distance between game formats.

Variables (U9)	Sex	S3 + 1	S4	M4	M5	L5
Activity profile						
TD (m)	Boys	1133 ± 171	988 ± 141	1106 ± 157	977 ± 172 ^{a}	1320 ± 232 ^{a,b,c,d}
	Girls	965 ± 195	878 ± 159	999 ± 156	846 ± 124 ^{c}	1125 ± 134 ^{a,b,d}
V_{peak} (km·h^{-1})	Boys	21.4 ± 3.2	20.1 ± 3.0	22.4 ± 3.1	20.7 ± 2.8	23.6 ± 3.0 ^{b,d}
	Girls	19.0 ± 2.3	19.5 ± 2.6	19.5 ± 2.8	19.9 ± 2.7	21.6 ± 2.4 ^{a}
Sprints (counts)	Boys	5.1 ± 5.4	2.9 ± 3.6	5.8 ± 5.2	4.6 ± 5.5	11.9 ± 7.5 ^{a,b,c,d}
	Girls	2.9 ± 3.5	1.5 ± 1.5	2.4 ± 2.6	2.7 ± 2.5	8.4 ± 7.6 ^{a,b,c,d}
Acc_{total} (counts)	Boys	212.0 ± 20.3	209.0 ± 21.2	200.7 ± 20.0	186.1 ± 21.6 ^{a,b}	172.2 ± 23.2 ^{a,b,c,d}
	Girls	198.0 ± 14.4	197.1 ± 25.3	200.3 ± 21.4	177.4 ± 21.7 ^{a,b,c}	160.7 ± 15.0 ^{a,b,c,d}
Dec_{total} (counts)	Boys	219.8 ± 17.3	209.8 ± 21.7	203.6 ± 17.8	191.5 ± 19.7 ^{a,b,c}	182.7 ± 24.0 ^{a,b,d}
	Girls	201.1 ± 18.1	197.1 ± 26.4	204.1 ± 17.8	184.7 ± 20.9 ^{a,b,c}	173.2 ± 13.6 ^{a,b,d}
Heart rate						
HR_{avg} (bpm)	Boys	175.8 ± 10.3	165.9 ± 11.2	167.9 ± 11.5	165.8 ± 13.1	169.7 ± 14.8
	Girls	174.7 ± 10.2	171.1 ± 9.7	168.8 ± 11.1	164.6 ± 13.5	172.8 ± 8.7
HR_{peak} (bpm)	Boys	195.1 ± 10.3	185.6 ± 10.1 ^{a}	192.3 ± 10.5	189.2 ± 11.6	191.2 ± 11.1
	Girls	196.3 ± 8.6	191.9 ± 11.4	189.4 ± 9.5	186.1 ± 12.8	192.3 ± 8.3
Subjective perceptions						
RPE (AU)	Boys	8.4 ± 3.8	10.2 ± 4.2	8.5 ± 4.1	9.2 ± 5.2	6.9 ± 4.9
	Girls	6.9 ± 3.3	10.1 ± 3.0	6.4 ± 3.3	6.8 ± 4.4	6.5 ± 4.8
RPF (AU)	Boys	4.3 ± 4.6	5.2 ± 4.7	5.2 ± 4.3	4.5 ± 5.1	5.0 ± 5.4
	Girls	3.8 ± 2.7	5.0 ± 3.7	5.1 ± 2.8	5.4 ± 3.6	4.1 ± 4.7

Data are mean ± SD. S3 + 1: small size, 3 vs. 3 + offensive goalkeeper; S4: small size, 4 vs. 4; M4: medium size, 4 vs. 4; M5: medium size, 5 vs. 5; L5: large size, 5 vs. 5. Acc_{total}: total accelerations; Dec_{total}: total decelerations; HR_{avg}: average heart rate; HR_{peak}: peak heart rate; TD: total distance; V_{peak}: peak speed attained; RPE: rating of perceived exertion; RPF: rating of perceived enjoyment/fun. ^{a} denotes significant differences compared to S3 + 1; ^{b} to S4; ^{c} to M4; ^{d} to M5 ($p \leq 0.05$).

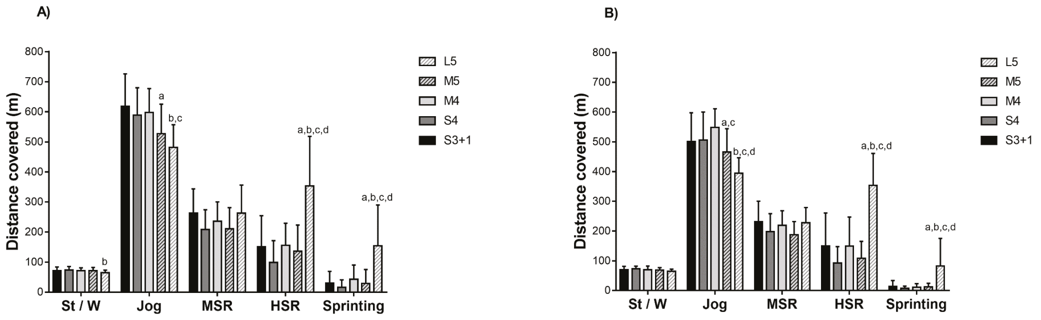

Figure 1. Distance covered in different speed zones in U9 (**A**) boy and (**B**) girl handball players by game formats. S3 + 1: small size, 3 v 3 + offensive goalkeeper; S4: small size, 4 v 4; M4: medium size, 4 v 4; M5: medium size, 5 v 5; L5: large size, 5 v 5. St/W: standing/walking; MSR: moderate-speed running; HSR: high-speed running. ^{a} denotes significant differences compared to S3 + 1; ^{b} to S4; ^{c} to M4; ^{d} to M5 ($p \leq 0.05$).

Girls covered more TD during L5 compared to S3 + 1, S4, and M5 ($p < 0.05$; ES = 0.9–2.1). In addition, the TD was moderately higher in M4 compared to M5 ($p = 0.043$; ES = 1.0 [0.4; 1.6]). Higher peak speed were reached during L5 compared to S3 + 1 ($p = 0.044$; ES = 1.0 [1.6; 0.4]). Girls covered more HSR and sprinting and performed more sprints in L5 compared to S3 + 1, S4, M4, and M5 ($p < 0.05$; ES = 0.8 to 2.9) (Table 1) (Figure 1B).

Furthermore, number of Acc_{total} and Dec_{total} were lower in L5 compared to S3 + 1, S4, and M4 ($p < 0.05$; ES = 0.6 to 1.8). In addition, M5 exhibited lower number of Acc_{total} and Dec_{total} than S3 + 1 and S4 ($p < 0.05$; ES = 0.8 to 1.5). The numbers of $Acc_{<1.5}$ and $Acc_{1.5–2.3}$ were lower during L5 compared to S3 + 1, S4, and M4 ($p < 0.05$; ES = 0.7 to 1.6). Conversely, the number of $Acc_{<1.5}$ was moderately higher in S4 compared to M5 ($p = 0.033$; ES = 0.8 (0.3; 1.3)), and the number of $Acc_{1.5–2.3}$ was largely higher in S3 + 1 than M5 ($p < 0.01$; ES = 1.4 (0.8; 1.9)). Notably, lower number of decelerations were observed during L5 compared to S3 + 1, S4, and M4 ($p < 0.05$; ES = 1.0 to 1.3). Furthermore, higher number of $Dec_{1.5–2.3}$, were observed in S3 + 1 compared to M5 and L5 ($p < 0.05$; ES = 0.9 to 1.3). Additionally, S4 showed higher number of $Dec_{1.5–2.3}$ than M5 ($p = 0.042$; ES = 0.9 (0.4; 1.3)). S3 + 1 showed higher number of $Dec_{>2.3}$ than M5 ($p = 0.019$; ES = 0.8 (0.3; 1.3)).

For girls, number of Acc_{total} and Dec_{total} were lower in L5 compared to S3 + 1, S4, and M4 ($p < 0.05$; ES = 1.2 to 2.5). In addition, M5 exhibited lower number of Acc_{total} than S3 + 1, S4, and M4 ($p < 0.05$; ES = 0.8 to 1.0). M5 had moderately lower number of Dec_{total} than M4 ($p = 0.047$; ES = 0.9 (0.3; 1.5)). Girls had lower number of $Acc_{<1.5}$ during L5 compared to S3 + 1, S4, M4, and M5 ($p < 0.05$; ES = 1.1 to 1.8). Similarly, during L5, girls had lower number of $Acc_{1.5–2.3}$ than S3 + 1, S4, and M4 ($p < 0.05$; ES = 1.1 to 2.1). In addition, $Acc_{1.5–2.3}$ had fewer efforts in M5 than in S3 + 1 and S4 ($p < 0.05$; ES = 0.8 to 1.4). In $Dec_{1.5–2.3}$, L5 had lower number of efforts than S3 + 1, S4, and M4 ($p < 0.05$; ES = 1.0 to 1.5). In addition, $Dec_{1.5-2.3}$ in S3 + 1 had higher number than M5 ($p = 0.002$; ES = 1.2 [0.6; 1.8]). Detailed representations of accelerations and decelerations are reported in Figures 2 and 3.

3.2. Heart Rate and Subjective Perceptions

Boys attained higher HR_{peak} in S3 + 1 compared to S4 ($p = 0.029$; ES = 0.9 (0.4; 1.4)) (Table 1). In addition, boys spent more time within 180–200 bpm in S3 + 1 than in S4 ($p = 0.045$; ES = 0.8 (0.3; 1.3)) (Figure 4). No significant differences were found between game formats in the RPEs and RPFs of boys ($p > 0.05$). Girls had higher times below 120 bpm during S3 + 1 compared to M4 and L5 ($p < 0.05$; ES = 1.3 to 1.6) (Table 1). In addition, girls spent more time between 120–160 bpm in M5 than S3 + 1 ($p = 0.028$; ES = 0.9 (0.3; 1.5)) (Figure 4). No significant differences were found between game formats in the RPEs and RPFs for girls ($p > 0.05$) (Table 1).

3.3. Technical Analysis

For the total number of shots, more shots occurred in S3 + 1 and S4 compared to M5 and L5 ($p < 0.05$; ES = 0.8 to 1.1). In contrast, no differences were observed for goals, successful shots, or duels in all the formats. For girls, the total amount of goals was higher in S3 + 1 than in M4, M5, and L5 ($p < 0.05$; ES = 0.9 to 1.3), as well as in S4 compared to M5 ($p = 0.029$; ES = 1.3 (0.3; 1.6)). In addition, situation S3 + 1 had more shots than M5 and L5 ($p < 0.05$; ES = 1.0 to 1.6). Furthermore, girls were less successful with shots in M5 than in S3 + 1 and S4 ($p < 0.05$; ES = 0.9 to 1.6) (Table 2).

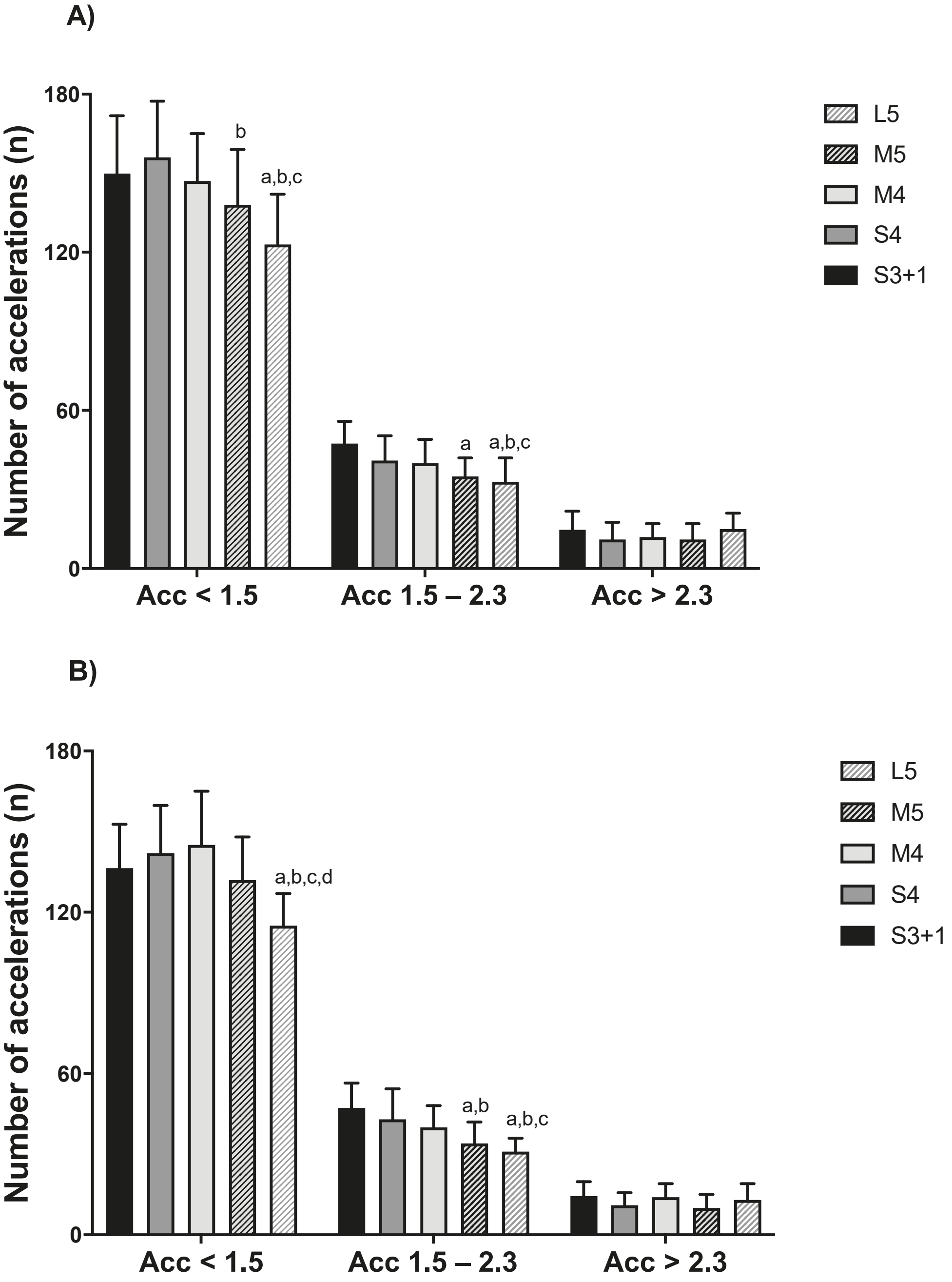

Figure 2. Number of accelerations in U9 (**A**) boy and (**B**) girl handball players by game formats. S3 + 1: small size, 3 v 3 + offensive goalkeeper; S4: small size, 4 v 4; M4: medium size, 4 v 4; M5: medium size, 5 v 5; L5: large size, 5 v 5. ^{a} denotes significant differences compared to S3 + 1; ^{b} to S4; ^{c} to M4; ^{d} to M5 ($p \leq 0.05$).

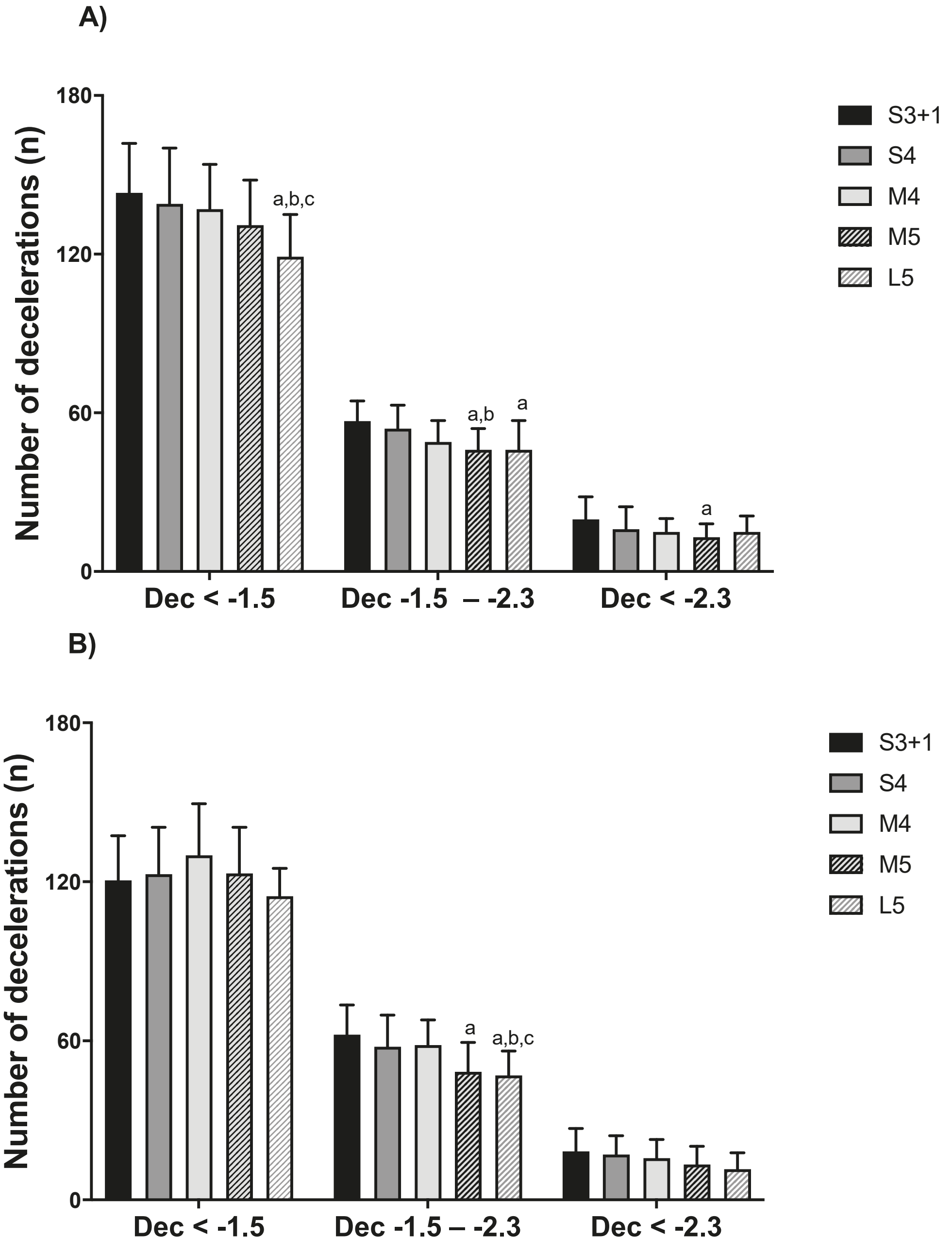

Figure 3. Number of decelerations in U9 (**A**) boy and (**B**) girl handball players by game formats. S3 + 1: small size, 3 v 3 + offensive goalkeeper; S4: small size, 4 v 4; M4: medium size, 4 v 4; M5: medium size, 5 v 5; L5: large size, 5 v 5. ^{a} denotes significant differences compared to S3 + 1; ^{b} to S4; ^{c} to M4 ($p \leq 0.05$).

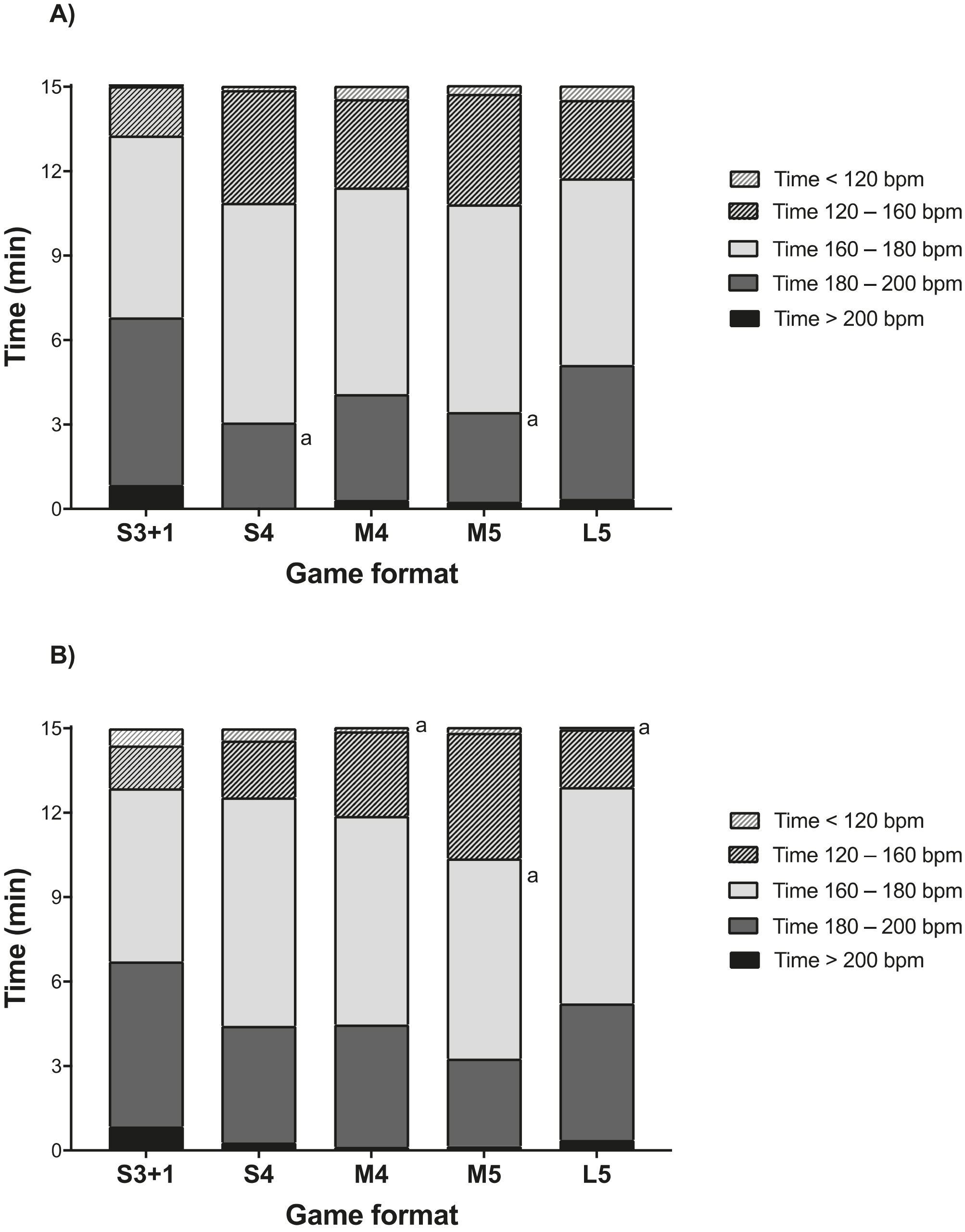

Figure 4. Heart rate distribution during U9 (**A**) boy and (**B**) girl handball games. S3 + 1: small size, 3 v 3 + offensive goalkeeper; S4: small size, 4 v 4; M4: medium size, 4 v 4; M5: medium size, 5 v 5; L5: large size 5 v 5. ^{a} denotes significant differences compared to S3 + 1 ($p \leq 0.05$).

Table 2. Differences in technical demands between game formats. Data are mean ± *SD*.

Variables	Sex	S3 + 1	S4	M4	M5	L5
Shots (counts)	Boys	7.0 ± 4.1	6.4 ± 3.9	4.9 ± 3.3	3.5 ± 2.6 ^{a,b}	3.2 ± 2.1 ^{a,b}
	Girls	7.4 ± 3.5	6.0 ± 5.2	4.7 ± 2.8	3.8 ± 3.0 ^{a}	2.8 ± 2.0 ^{a}
Goals (counts)	Boys	2.5 ± 2.4	2.2 ± 2.1	2.0 ± 2.0	1.1 ± 1.3	1.1 ± 1.0
	Girls	3.9 ± 2.9	2.4 ± 1.5	1.6 ± 1.4 ^{a}	0.7 ± 0.9 ^{b}	1.0 ± 1.3 ^{a}
Successful shots (counts)	Boys	35.2 ± 29.2	34.7 ± 23.9	38.0 ± 30.1	29.2 ± 32.0	32.2 ± 28.9
	Girls	53.7 ± 23.9	47.4 ± 41.3	35.3 ± 25.8	15.4 ± 22.5 ^{a,b}	31.0 ± 38.9
Duels (counts)	Boys	1.1 ± 1.2	0.7 ± 1.3	0.7 ± 1.1	0.5 ± 0.9	0.4 ± 0.6
	Girls	1.7 ± 2.8	1.6 ± 2.1	1.2 ± 1.7	0.6 ± 1.0	0.6 ± 1.2

Data are mean ± SD. S3 + 1: small size, 3 vs. 3 + offensive goalkeeper; S4: small size, 4 vs. 4; M4: medium size, 4 vs. 4; M5: medium size, 5 vs. 5; L5: large size, 5 vs. 5. ^{a} denotes significant differences compared to S3 + 1; ^{b} to S4.

3.4. Gender

The boys covered more TD in S3 + 1, S4, M5, and L5 compared to the girls ($p < 0.05$; ES = 0.8 to 0.9). Furthermore, the boys reached higher V_{peak} during S4 and M5 compared to the girls ($p < 0.05$; ES = 0.7 to 0.9). Moderate higher sprints were observed in the M4 format for boys compared to girls ($p = 0.020$; ES = 0.7 [0.2; 1.3]). Notably, the jog distance was higher for boys during S3 + 1, S4, M4, M5, and L5 compared to girls ($p < 0.05$; ES = 0.6 to 1.2). In addition, sprinting in M4 and L5 was higher for boys than girls ($p < 0.05$; ES = 0.8 to 0.5). Moreover, $\text{Acc}_{\text{total}}$ and $\text{Dec}_{\text{total}}$ were higher in S3 + 1 for boys compared to girls ($p < 0.05$; ES = 0.7 to 1.0). $\text{Acc}_{<1.5}$ was moderately higher during S4 in boys compared to girls ($p = 0.044$; ES = 0.6 (0.1; 1.2)). Notably, boys had higher numbers of decelerations during L5 compared to girls in $\text{Dec}_{>2.3}$ ($p = 0.021$; ES = 0.6 (0.2; 1.1)). Furthermore, S3 + 1 and S4 formats had more decelerations for boys compared to girls ($p < 0.05$; ES = 0.8 to 1.2). Conversely, in $\text{Dec}_{1.5\text{-}2.3}$, girls had more decelerations in M4 than boys ($p = 0.009$; ES = 0.9 (1.5; 0.4)).

The girls had higher $\text{Time}_{<120}$ in S3 + 1 and S4 compared to the boys ($p < 0.05$; ES = 0.7 to 1.9) (Table 1). In addition, $\text{Time}_{>200}$ in S4 was moderately higher for girls compared to boys ($p = 0.034$; ES = 0.7 (1.2; 0.1)). A detailed representation of the differences in activity profile, heart rate, subjective ratings, and technical involvement is reported in Figure 5.

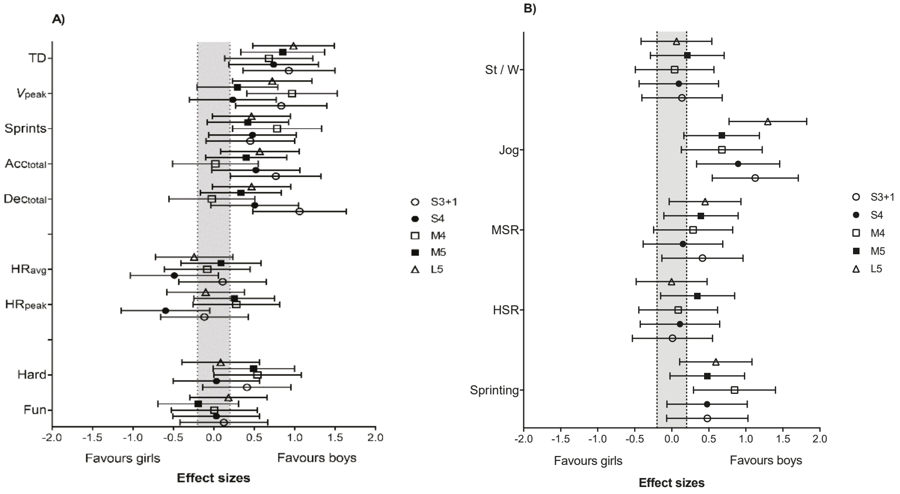

Figure 5. *Cont.*

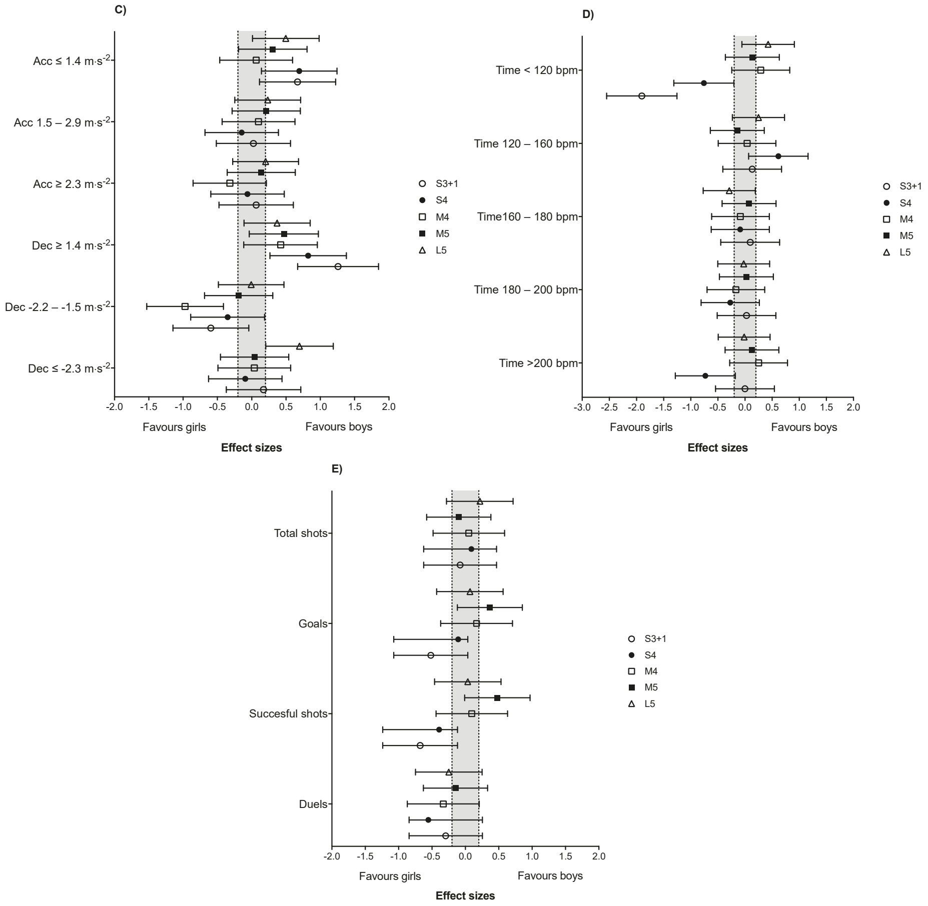

Figure 5. Differences in (**A**) overall physical and physiological demands, (**B**) activity profile, (**C**) accelerations and decelerations, (**D**) heart rate, and (**E**) technical demands between boys and girls during different U9 handball games. The forest plots are effect sizes (90% CI). S3 + 1: small size, 3 v 3 + offensive goalkeeper; S4: small size, 4 v 4; M4: medium size, 4 v 4; M5: medium size, 5 v 5; L5: large size, 5 v 5. St/W: standing/walking; MSR: moderate-speed running; HSR: high-speed running.

4. Discussion

This study provides the first detailed analysis of movement patterns and heart rates in U9 team handball for boys and girls, showing that the exercise intensity, heart rates, and technical involvement are high during small, medium, and large-sized games in all investigated formats. When comparing game formats, we observed higher distances covered and more sprints with L5 but a lower number of accelerations and decelerations compared to all the other formats. Notably, heart rates were similar between game formats. Irrespective of game format, boys covered 977–1320 m and girls covered 846–1124 m. For boys and girls, remarkably in the L5 format, TD, V_{peak}, sprints, HSR, and sprinting were higher, whereas St/W, JOG, $\text{Acc}_{\text{total}}$, $\text{Dec}_{\text{total}}$, $\text{Acc}_{<1.5}$, $\text{Acc}_{1.5\text{–}2.3}$, $\text{Acc}_{>1.5}$, $\text{Dec}_{<1.5}$, $\text{Dec}_{1.5\text{–}2.3}$, and $\text{Dec}_{>1.5}$ were lower than other formats and, on many occasions, significantly different. This may be because there is more room for sprinting and high-intensity running on larger pitches, which is supported by the greater distance covered with high-intensity running and higher V_{peak} during games on larger pitch sizes (40 × 20 m) compared with small pitches (20 × 13 m) in adult football players [25]. Interestingly, no differences were found between S4 and M4 in any variables (physical, physiological, subjective perception, and technical). As we already reported, other team sports showed that manipulating the player numbers and the pitch size can alter the exercise intensity (i.e., distance covered, jogging and walking, heart rate, and tackling, dribbling, goal attempts, and passes) during a game in different sports [8]. The forces generated while rapidly changing direction, stopping, and landing, as well as during jumping and shooting, may confer excellent osteogenic properties to team handball [26]. It is well known from cross-sectional studies that participation in sports activities is associated with markedly higher muscle mass and bone mineralization, as well as better coordination and postural balance [27,28], and a longitudinal intervention study with 8–10-year-old children has shown that participation in school-based small-sized ball games enhances the same parameters [29]. The mean HR was high for boys and girls, at 166–176 bpm and 165–175 bpm, respectively, in all game formats. A high HR during sports and, specifically, team handball match-play, irrespective of game format and gender, is important for the health profile of children [30]. Aerobic high-intensity training (>90% maximum HR) has been shown to be superior to moderate continuous training in improving cardiorespiratory fitness [31,32], which has been identified as a strong independent predictor of the risk of cardiovascular diseases and mortality [33]. Sports participation is an effective way to improve aerobic and anaerobic fitness, especially participation in high-intensity ball games [34]. For the $\text{Time}_{180–200}$ and $\text{Time}_{>200}$ in S3 + 1 format, young girl and boy team handball players spent more time above 180 bpm, which is not significantly different but working at a high intensity for more time could improve cardiorespiratory fitness positively [35]. No differences occurred in subjective perception between different game formats, in contrast with other studies [6,36] that found that larger courts felt more physically demanding. In our study, we had more goals and more shots in the small size pitch (S3 + 1, S4), as was also observed in a study by Randers and colleagues [7], where smaller pitches created more technical actions and may seem logical, as ball contacts are higher during a game with fewer players [37]. Interestingly, no differences were found in 1 v 1 duels in all the formats, that the players may try to score or shot faster in games with small size pitches. Involvement with many relevant activities is important in terms of motivation for children [38], as it helps the players to continue as active handball players. Maturation at this stage is still early, whereas it seems that the physiological load of the game is higher for boys than for girls, with many differences between them, as is supported by the work of Michalsik and colleagues [3] in the different distance zones, except for the TD, which females covered more of. A possible explanation is that boys have more self-confidence and perceived self-competence, making the game more demanding [39]. Only one significant difference was observed in favor of the girls in $\text{Dec}_{1.5–2.3}$, which had more decelerations in the M4 format. However, for physical loading between sexes, similar HR values were found, with only three comparisons, girls spent more time below 120 bpm in S3 + 1 and S4 compared to boys for $\text{Time}_{>200}$ in S4. Additionally, no significant differences were found for subjective perceptions or the technical analysis. In conclusion, having both genders mixed in the same format and game would possibly be very demanding for girls in terms of activity patterns at this age.

It is important to underline some limitations inherent to this study, Firstly, physical and physiological demands were compared across game formats of various pitch sizes and numbers of players, and thus, relative space per player was not constant. Secondly, maximum HR, maximal aerobic speed, and maximal sprinting speed were not assessed. The use of fixed HR and speed zones does not reflect the actual individual capacity, possibly resulting in under- or overestimating the real physical and physiological demands of the game. Although the technical analysis was carried out by experienced handball coaches, this analysis could be somewhat subjective. Thus, our technical analysis should be interpreted with caution. Finally, for logistical reasons, we were unable to describe the physical levels of the players. Future studies are warranted to use individualized HR and speed zones to accurately quantify the physical and physiological demands of youth team handball as well as physical evaluations of the players. In this context, the fitness component of max speed can be adopted in future studies as suggested by [40].

5. Conclusions

In summary, the HR and high-intensity distances are high in U9 team handball matches irrespective of the game format. The present data provide insight into how different game formats influence the physiological and the physical loading and evidence that various types of match-plays can contribute significantly to the improvement in the musculoskeletal and cardiovascular fitness of U9 boys because of high HRs and high-intensity running distances, along with multiple accelerations and specific actions with considerable impact. In all the game formats, physical loading seems similar but, interestingly, on the large pitch, the physiological load was higher. Playing with fewer players on smaller pitches resulted in minor changes to the physiological loading but elevated the technical involvement of players, which favors the use of smaller formats to emphasize technical demands. Several differences between girls and boys were found in U9 team handball players that should be considered when planning games for boys and girls separately or for mixed-gender games. The various game types could provide valuable information to coaches in the selection of players or training guidance. We would recommend the use of games with fewer players on smaller courts for U9 boys and girls since we believe that technical development is the most important factor at this age.

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Article

Will Next Match Location Influence External and Internal Training Load of a Top-Class Elite Professional European Soccer Team?

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Abstract: Background: The purpose of this study is to compare training load (TL) preceding a home versus away match in a top-class elite European team during the 2015–2016 season. Methods: Twenty elite outfield soccer players with a mean ± SD age, height and body mass of 25.9 ± 4.6 years, 183.1 ± 6.6 cm and 78.6 ± 6.6 kg, respectively, participated in this study. Total distance covered, high-speed running distance (HSRD), average speed (AvS), rating of perceived exertion (RPE) multiplied by training duration (s-RPE) and Hooper index (HI) were collected. Data from 24 weeks were analyzed through match-day minus/plus approach (MD-5, -4, -3, -2, -1, MD + 1). Results: All external TL variables indicated a decrease from MD-5 until MD-1 and then an increase to MD + 1 ($p < 0.01$). HI decreased from MD-5 to MD-1, but s-RPE increased until MD-3 and then decreased until MD + 1. When comparing TL data that preceded home matches versus away matches, for MD-5, HSRD and muscle soreness exhibited higher values when away match neared ($p < 0.05$). For MD-4 and MD-3, total distance, HSRD and AvS exhibited higher values closer to an away match than a home match ($p < 0.05$). For MD-1, total distances covered were higher closer to a home match than an away match ($p < 0.01$). For MD + 1, all HI items and AvS were higher when an away match was played ($p < 0.05$). Conclusions: This study confirms and provides evidence regarding the influence on internal and external TL data preceding home and away matches from a team that played in European competitions.

Keywords: soccer training; s-RPE; Hooper index; GPS; match day; match location

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1. Introduction

Several situational variables (e.g., competition stage, match location, quality of opposition and match status or match outcome) impact a sports team's performance [1]. Soccer is dominated by strategic/tactical factors; therefore, it is reasonable to suggest that situational variables influence team and player performance [2–6]. Match location (playing home or away) has been identified as one of the most important situational variables that dictate possession patterns [7,8]. Playing a home match implies stronger interaction with team possession than playing an away match [4,6,9]. In addition, other studies have revealed that indicators such as stress and sleep are influenced by match location [10,11].

Furthermore, soccer science has begun to focus more on delimiting success indicators in soccer. Nevertheless, soccer science in general is inconclusive due to small sample size, unstandardized analysis procedures and lack of consideration of the complexity of soccer as an unpredictable and dynamic sport. Even so, there are useful variables for quantifying, modeling and possibly adjusting internal and external training load (TL). One way to control internal TL involves multiplying the duration of training sessions by the rating of perceived exertion (s-RPE), also known as training impulse [12–17]. Another way to control internal TL is the wellbeing status provided by the Hooper index (HI) questionnaire that measures the perception of fatigue, stress, delayed onset muscle soreness (DOMS) and sleep quality [18,19].

Recently, both methods were used to control internal TL [19–22]. Nobari et al. [19] found highest values of weekly acute, chronic and strain s-RPE were verified in the mid-season and the lowest values in the early season; the highest values of accumulated weekly fatigue, stress, and DOMS were observed in the late season, and the lowest values of sleep and stress were found in the early season, while the lowest values of fatigue and DOMS were observed in the mid-season. Clemente et al. [21] found that the relationship between s-RPE and HI indicates significant and negative small-to-moderate correlations in the weeks with two matches, but not in the weeks with only one match. On the other hand, Oliveira et al. [22] showed minor variations regarding HI scores across 10 mesocycles and in days prior to the match. In fact, only the day following the match revealed increases in HI scores. This last finding was also corroborated by Oliveira et al. [20].

Based on a previous study, a combined analysis of contextual effects on TL, determined by s-RPE, different running distances and wellbeing status, accumulated within a match-to-match microcycle, can provide more rounded information to improve understanding of the demands of match play [20].

To the best of our knowledge, only two studies about training content have attempted to assess the difference between playing a home or an away soccer match for internal TL of elite professional European soccer teams [11,23]. Abbott et al. [11] analyzed the influence of these situational match variables on subjective wellbeing status (fatigue, DOMS, quality sleep, stress and mood) in under-23 soccer players after several matches throughout a season of English Premier League 2 and found that subjective wellbeing does not differ before the match ($p > 0.05$). However, on the first and third days following the match, stress and mood were ≥20% lower after playing away from home ($p < 0.05$). Meanwhile, Brito et al. [23] analyzed situational variables of subjective wellbeing in under-19 players from a first league club in France and found that subjective wellbeing was not affected by match location. However, subjective wellbeing was only assessed the day before the match, and as the authors acknowledged, this might not be the most suitable time to assess the influence of these variables on match-to-match fluctuations in wellbeing. Thus, the present study is the first to explore whether match location affects the training sessions that precede a home or away match (regarding internal and external TL variables) in a team that plays European competitions through the full season.

Therefore, the main purpose of this study is to compare internal and external TL preceding a home versus away match. A secondary purpose was to determine if there were differences between starters and non-starters in a top-class elite European team during the 2015–2016 season.

2. Materials and Methods

2.1. Experimental Approach to the Problem

TL data were collected over 39 weeks during the 2015–2016 season. All elite players competed in four official competitions throughout the season, including the European Competition, the national league and two national cups from their own country. For the purposes of the present study, only main team sessions were considered. Only data from the training sessions were considered. Data from rehabilitation or recuperation were excluded. The total minutes of each training session comprised a warm-up, a main phase and a slow-down phase, in addition to stretching. Data that preceded 12 home matches and 12 away matches were analyzed. All matches were national league matches. Training data collection for this study was carried out at the soccer club's outdoor training pitches. To analyze data, only weeks with one match were included, and the approach in relation to the number of days away from the competitive match fixture (i.e., match day minus (MD-)) was used [20,22]. The team typically trained five days per week (MD-5, MD-4, MD-3, MD-2, MD-1), plus one day after the match (MD + 1). Due to the different week schedules, there were some weeks with a day off on MD + 1, and for that reason, in some weeks, MD-5 was the first training day of the week. The number of MD minus/plus is identified in the results section (Table 1).

Table 1. Comparison of MD- for training load data that preceded home versus away matches for squad average, mean ± SD.

	Home	**Away**	**ES (Home vs. Away)**
MD-5 (n = 24)	**n = 12**	**n = 12**	
DOMS (au)	3.530 ± 0.239 ^{a,b,c,d}	3.878 ± 0.256 ^{a,b,c,d}	−1.41 (−2.07, −0.69) *
Sleep (au)	3.093 ± 0.142 ^{c,d,e}	2.820 ± 0.166 ^{e}	1.77 (1.01, 2.46)
Fatigue (au)	3.577 ± 0.245 ^{a,c,d}	3.722 ± 0.246 ^{a,b,c,d,e}	−0.59 (−1.21, 0.05)
Stress (au)	2.599 ± 0.0136	2.466 ± 0.181	0.83 (0.17, 1.46)
HI (au)	12.893 ± 0.557 ^{c,d,e}	12.886 ± 0.651 ^{a,b,c,d,e}	0.01 (−0.61, 0.63)
Duration (min)	56.642 ± 2.296 ^{a,b,c,d,e}	57.807 ± 2.275 ^{a,b,c,d,e}	−0.51 (−1.13, 0.13)
s-RPE (au)	190.658 ± 24.086 ^{a,b,c}	180.746 ± 19.385 ^{a,b,c,e}	0.45 (−0.18, 1.07)
Total Distance (m)	7050.871 ± 168.175 ^{a,c,d,e}	7210.571 ± 120.153 ^{a,c,d,e}	−1.09 (−1.73, −0.41)
HSRD (m)	254.122 ± 19.128 ^{d,e}	316.044 ± 27.984 ^{b,c,d,e}	−2.58 (−3.36, −1.70) *
AvS (m/min)	129.597 ± 6.448 ^{a,b,c,d,e}	129.416 ± 5.051 ^{a,b,c,d,e}	0.03 (−0.59, 0.65)
MD−4 (n = 20)	**n = 10**	**n = 10**	
DOMS (au)	2.848 ± 0.196 ^{e}	2.824 ± 0.194 ^{e}	0.12 (−0.50, 0.74)
Sleep (au)	2.984 ± 0.141 ^{e}	2.927 ± 0.154 ^{e}	0.39 (−0.25, 1.00)
Fatigue (au)	2.854 ± 0.185 ^{e}	2.710 ± 0.193 ^{c,e}	0.76 (0.11, 1.39)
Stress (au)	2.552 ± 0.176	2.471 ± 0.169	0.47 (−0.17, 1.09)
HI (au)	11.238 ± 0.530 ^{c,d}	10.928 ± 0.575 ^{e}	0.56 (−0.08, 1.18)
Duration (min)	81.083 ± 1.020 ^{d,e}	77.346 ± 1.078 ^{e}	3.56 (2.51, 4.47) *
s-RPE (au)	355.150 ± 25.845 ^{d,e}	338.452 ± 27.881 ^{d,e}	0.62 (−0.03, 1.24)
Total Distance (m)	6156.369 ± 94.723 ^{b,c,d,e}	6519.533 ± 123.547 ^{c,d,e}	−3.30 (−4.17, −2.29) *
HSRD (m)	252.113 ± 18.286 ^{d,e}	273.032 ± 17.485 ^{c,d,e}	−1.17 (−1.81, −0.48)
AvS (m/min)	76.034 ± 1.209 ^{b,d}	84.475 ± 1.783 ^{c,d,e}	−5.54 (−6.77, −4.09) **
MD-3 (n = 24)	**n = 12**	**n >= 12**	
DOMS (au)	2.929 ± 0.181 ^{e}	2.822 ± 0.194 ^{e}	0.57 (−0.07, 1.19)
Sleep (au)	3.011 ± 0.167 ^{e}	2.919 ± 0.529 ^{e}	0.23 (−0.39, 0.85)
Fatigue (au)	2.975 ± 0.191 ^{e}	2.793 ± 0.208 ^{e}	0.91 (0.24, 1.54)
Stress (au)	2.546 ± 0.144	2.253 ± 0.187 ^{c}	1.76 (1.00, 2.45) **
HI (au)	11.461 ± 0.547 ^{e}	10.786 ± 0.621 ^{e}	1.15 (0.46, 1.80)
Duration (min)	80.978 ± 1.126 ^{d,e}	78.534 ± 0.928 ^{e}	2.37 (1.52, 3.12) *
s-RPE (au)	392.009 ± 22.746 ^{c,d,e}	368.139 ± 30.510 ^{d,e}	0.89 (0.22, 1.52)
Total Distance (m)	6643.648 ± 112.012 ^{c,d,e}	6864.267 ± 65.982 ^{c,d,e}	−2.40 (−3.16, −1.55) *
HSRD (m)	236.208 ± 13.133 ^{d,e}	238.649 ± 15.622 ^{d,e}	−0.17 (−0.79, 0.46)
AvS (m/min)	82.181 ± 1.287 ^{d}	87.575 ± 1.169 ^{c,d,e}	−4.39 (−5.43, −3.17) **
MD-2 (n = 24)	**n = 12**	**n = 12**	
DOMS (au)	2.980 ± 0.203 ^{e}	3.079 ± 0.191 ^{e}	−0.50 (−1.12, 0.14)
Sleep (au)	2.672 ± 0.163 ^{e}	2.787 ± 0.149 ^{e}	−0.74 (−1.36, −0.08) *
Fatigue (au)	2.942 ± 0.217 ^{e}	3.090 ± 0.193 ^{e}	−0.72 (−1.35, −0.07) *
Stress (au)	2.475 ± 0.160	2.438 ± 0.165	0.23 (−0.40, 0.84)
HI (au)	11.111 ± 0.608 ^{e}	11.393 ± 0.553 ^{e}	−0.49 (−1.10, 0.15)
Duration (min)	77.704 ± 0.684 ^{d,e}	78.933 ± 0.477 ^{e}	−2.08 (−2.81, −1.28)
s-RPE (au)	309.385 ± 22.746 ^{c,d,e}	319.927 ± 23.016 ^{d,e}	−0.46 (−1.08, 0.18)
Total Distance (m)	5672.056 ± 66.924 ^{d,e}	5772.040 ± 57.580 ^{d,e}	−1.60 (−2.28, −0.86)
HSRD (m)	202.866 ± 9.509 ^{d,e}	208.496 ± 12.475 ^{d,e}	−0.51 (−1.13, 0.13)
AvS (m/min)	73.035 ± 1.041 ^{d}	73.167 ± 0.841 ^{d,e}	−0.14 (−0.76, 0.48)

Table 1. *Cont.*

	Home	Away	ES (Home vs. Away)
MD-1 (*n* = 24)	***n* = 12**	***n* = 12**	
DOMS (au)	2.914 ± 0.170 ^{e}	2.834 ± 0.220 ^{e}	0.41 (−0.23, 1.02)
Sleep (au)	2.601 ± 0.148 ^{e}	2.713 ± 0.164 ^{e}	−0.72 (−1.34, −0.06)
Fatigue (au)	2.887 ± 0.185 ^{e}	2.828 ± 0.222 ^{e}	0.29 (−0.34, 0.91)
Stress (au)	2.398 ± 0.150	2.515 ± 0.197	−0.67 (−1.29, −0.02)
HI (au)	10.801 ± 0.512 ^{e}	10.889 ± 0.619 ^{e}	−0.15 (−0.77, 0.47)
Duration (min)	86.379 ± 0.651 ^{e}	82.954 ± 1.303 ^{e}	3.33 (2.31, 4.20) *
s-RPE (au)	218.543 ± 15.538 ^{e}	221.074 ± 13.389 ^{e}	−0.17 (−0.79, 0.45)
Total Distance (m)	3644.602 ± 62.053 ^{e}	3452.107 ± 66.846 ^{e}	2.98 (2.03, 3.82) **
HSRD (m)	69.503 ± 6.994	68.431 ± 5.338	0.17 (−0.45, 0.79)
AvS (m/min)	42.245 ± 0.775 ^{e}	41.877 ± 1.044 ^{e}	0.40 (−0.23, 1.02)
MD + 1 (*n* = 20)	***n* = 10**	***n* = 10**	
DOMS (au)	4.048 ± 0.265	4.377 ± 0.267	−1.24 (−1.89, −0.54) *
Sleep (au)	3.737 ± 0.156	4.005 ± 0.230	−1.36 (−2.02, −0.65)
Fatigue (au)	4.158 ± 0.250	4.444 ± 0.250	−1.14 (−1.79, −0.45) *
Stress (au)	2.526 ± 0.179	2.687 ± 0.201	−0.85 (−1.47, −0.18)
HI (au)	14.469 ± 0.684	15.513 ± 0.699	−1.51 (−2.18, −0.78) *
Duration (min)	26.687 ± 3.098	16.179 ± 0.769	4.66 (3.39, 5.74) **
s-RPE (au)	86.238 ± 23.532	25.922 ± 2.432	3.61 (2.54, 4.53) *
Total Distance (m)	4421.407 ± 114.412	4308.190 ± 82.567	1.13 (0.45, 1.78)
HSRD (m)	103.066 ± 16.503	77.741 ± 8.651	1.92 (1.14, 2.63)
AvS (m/min)	102.210 ± 16.029	273.645 ± 11.738	−12.20 (−14.65, −9.27) **

MD- = match day minus (5, 4, 3, 2, 1); MD + 1 = match day plus 1; DOMS = delayed onset muscle soreness; au = arbitrary units; HI = Hooper Index; min = minutes; m = meters; s-RPE = session rating of perceived exertion; HSRD = high-speed running distance; AvS = average speed; ES = effect size. ^{a} denotes difference from MD-4. ^{b} denotes difference from MD-3. ^{c} denotes difference from MD-2. ^{d} denotes difference from MD-1. ^{e} denotes difference from MD + 1. All, $p < 0.05$. * significant differences between home vs. away ($p < 0.05$). ** significant differences between home vs. away ($p < 0.01$).

2.2. Participants

The sample consisted of four central defenders (CDs), four wide defenders (WDs), five central midfielders (CMs), four wide midfielders (WMs) and three strikers (ST) of an elite European soccer team that plays in the UEFA Champions League. The players exhibited a mean ± SD age, height and mass of 25.85 ± 4.55 years, 183.06 ± 6.64 cm and 78.56 ± 6.64 kg, respectively. Height and weight were collected through a scale and stadiometer (SECA 220, Germany, Hamburg) to the nearest 0.01 kg and 0.1 cm, respectively. Inclusion criteria are described by Oliveira et al. [20] and mean that participants had regular participation with a minimum of 80% weekly training sessions. Participants also had to complete at least 60 min in one match in the first half of the season and one match in the second half of the season. For further analysis, we added other inclusion criteria to analyze MD + 1 and MD-5 by dividing starters and non-starters. Players were considered starters if they participated in three consecutive matches for at least 60 min, while the other players were considered non-starters [20]. All participants were familiarized with the training protocols and signed informed consent prior to the investigation. This study was conducted according to the requirements of the Declaration of Helsinki and was approved by the Ethics Committee of Polytechnic Institute of Santarém (252020Desporto).

2.3. External Training Load—Training Data

Each player's physical activity during each training session was monitored using portable global positioning system (GPS) units (Viper pod 2, STATSports, Belfast, UK). This device provides position velocity and distance data at 10 Hz frequency. It was used across the upper back between the left and right scapula through a custom-made vest that allows a better satellite reception for the GPS antenna. This system has previously been determined to be valid and reliable to measure linear, multidirectional and soccer-specific activities [24]. Thirty minutes before use, all devices were turned on in order to acquire satellite signals and to provide synchronization between the GPS clock and the satellite's atomic clock [21]. After data collection, the Viper PSA software (STATSports, Belfast, UK) was used to download data and to clip the entire training session (i.e., from the beginning of the warm-up to the end of the last organized drill). Players wore the same GPS device for each training session to avoid interunit error. The following variables were assessed: total duration of training session (minutes), total distance and high-speed running distance (HSRD, above 19 km/h).

2.4. Internal Training Load—Training Data

The perceptions of fatigue, stress, DOMS and quality of sleep were assessed through the HI [18] 30 min before the beginning of training sessions. The scale of HI uses 1–7 points, in which 1 is very, very low and 7 is very, very high (for stress, fatigue and muscle soreness levels) and 1 is very, very bad and 7 is very, very good (for sleep quality). Then, the summation of the four categories provides the total HI. In addition, RPE, on a scale of 0–10 [25] was collected 30 min after the end of the training session. Then, it was multiplied by the session duration to generate a session RPE (s-RPE) [12–17].

2.5. Statistical Analysis

The SPSS version 22.0 (SPSS Inc., Chicago, IL, USA) for Windows statistical software package was used to analyze the data. To describe and characterize the sample, descriptive statistics were used. Shapiro–Wilk and Mauchly's tests were performed to determine normality and sphericity, respectively. Once the variables reached normal distribution, repeated-measures ANOVA with a Bonferroni post hoc was used (Shapiro–Wilk > 0.05) to compare the days prior to the competitive match, as well as match location. ANOVA Friedman and Mann–Whitney tests were used for the variables for which normal distribution had not been obtained to compare different moments and different player positions. Independent sample *t*-test was used to compare data from starters and non-starters. Results were significant in the interaction ($p \leq 0.05$). The Cohen's d effect-size (ES) statistic was calculated to determine the magnitude of effects by the difference of two population means which are then divided by the standard deviation from the data, and it was assessed using the following criteria: <0.2 = trivial, 0.2–0.6 = small, 0.6–1.2 = moderate, 1.2–2.0 = large, and >2.0 = very large effect [26].

3. Results

We analyzed physical performance in the weeks that preceded the 24 analyzed matches (12 home and 12 away matches over the entire season).

Descriptive results and comparisons of match day minus for TL data that preceded home or away matches and comparisons of TL data that preceded home versus away matches for squad average are presented in Table 1. Figures 1 and 2 displayed a graphical representation of Table 1 through mean and standard deviation (SD).

3.1. Comparison of Match Day Minus Preceding Home or Away Matches

In general, and regardless of match location, based on internal TL data that preceded home and away matches, all categories from HI and the total HI scores were higher on MD + 1 than all of MD-(5, 4, 3, 2, 1), and the scores decreased from MD-5 to MD-1. Moreover, s-RPE values increased until MD-3 and then decreased until MD + 1. External TL total distance, HSRD and AvS values decreased from MD-5 to MD-1 and then increased to MD + 1.

For data preceding home matches, the main results indicate that stress (from HI questionnaire) does not differ for all MD-(5, 4, 3, 2, 1) or for MD + 1. For MD-5 vs. MD-1, all variables exhibited differences, with the exception of s-RPE. When comparing MD-5 vs. MD + 1, sleep, HI (total), duration, s-RPE, total distance, HSRD and AvS exhibited differences. When comparing MD-4 vs. MD-1, all variables were different with the exceptions of DOMS, sleep and fatigue. When comparing MD-4 vs. MD + 1, all variables were different, except for total HI score. When comparing MD-3 and MD-2 vs. MD-1, all variables exhibited differences, except for every category of HI scores. Moreover, when comparing MD-3 and MD-2 vs. MD + 1, all variables differed, except for AvS. Lastly, when comparing MD-1 vs. MD + 1, all variables except HSRD exhibited differences.

For data preceding away matches, the main results indicate that stress does not differ for any of the MD-(5, 4, 2, 1) but differs between MD-3 and MD + 1. When comparing MD-5 vs. MD-1, all variables were different, except sleep. When comparing MD-5 vs. MD + 1, all variables exhibited differences, except for DOMS. When comparing MD-4 vs. MD-1, only s-RPE, total distance, HSRD and AvS differed. When comparing MD-4 vs. MD + 1, all variables were different, except stress. When comparing MD-3 vs. MD-1, all variables exhibited differences. When comparing MD-3 vs. MD + 1, only s-RPE, total distance, HSRD and AvS differed. When comparing MD-2 vs. MD + 1, all variables differed, except for stress. When comparing MD-2 vs. MD + 1, only s-RPE, total distance, HSRD and AvS differed. When comparing MD-1 vs. MD + 1, all variables exhibited differences, except stress and HSDR.

Finally, Table 2 presents differences between starters vs. non-starters regarding MD + 1 and MD-5. Only data regarding home matches presented significant differences in DOMS ($p = 0.018$), stress ($p = 0.030$) and HI ($p = 0.030$) for MD + 1.

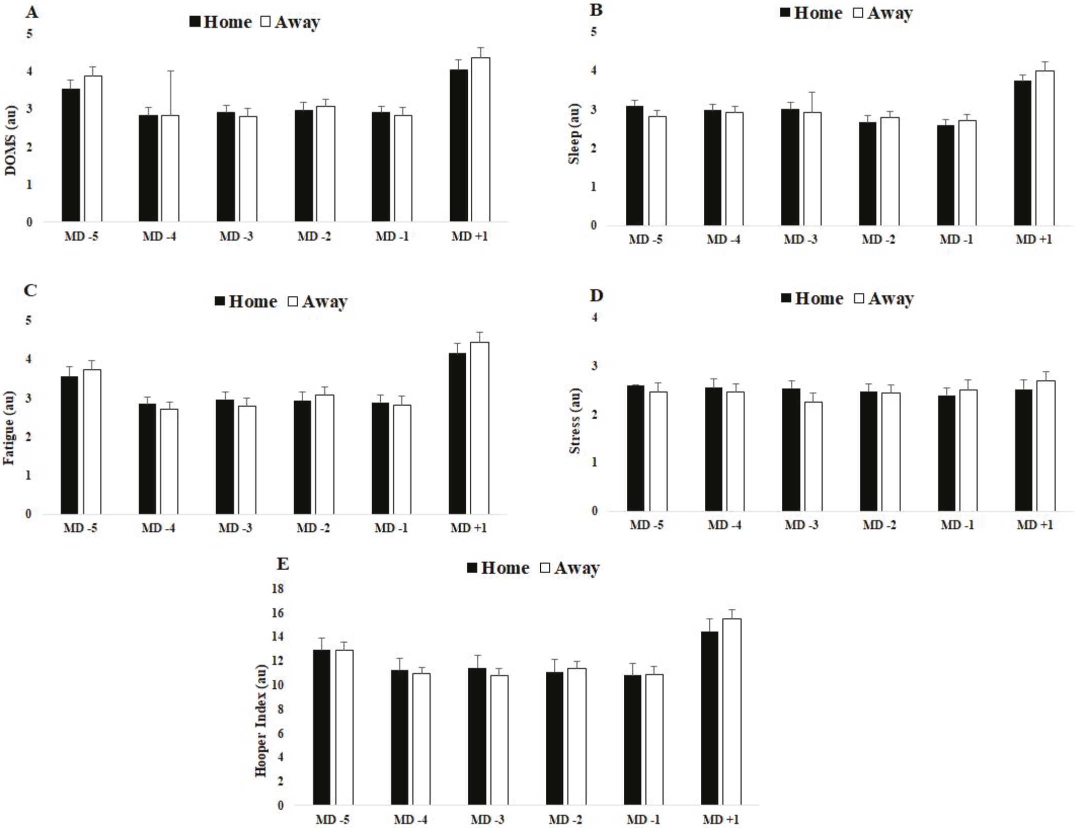

Figure 1. Differences between match day minus/plus preceding home and away matches for (**A**) DOMS, (**B**) sleep, (**C**) fatigue, (**D**) stress and (**E**) Hooper index. Data presented by mean ± SD.

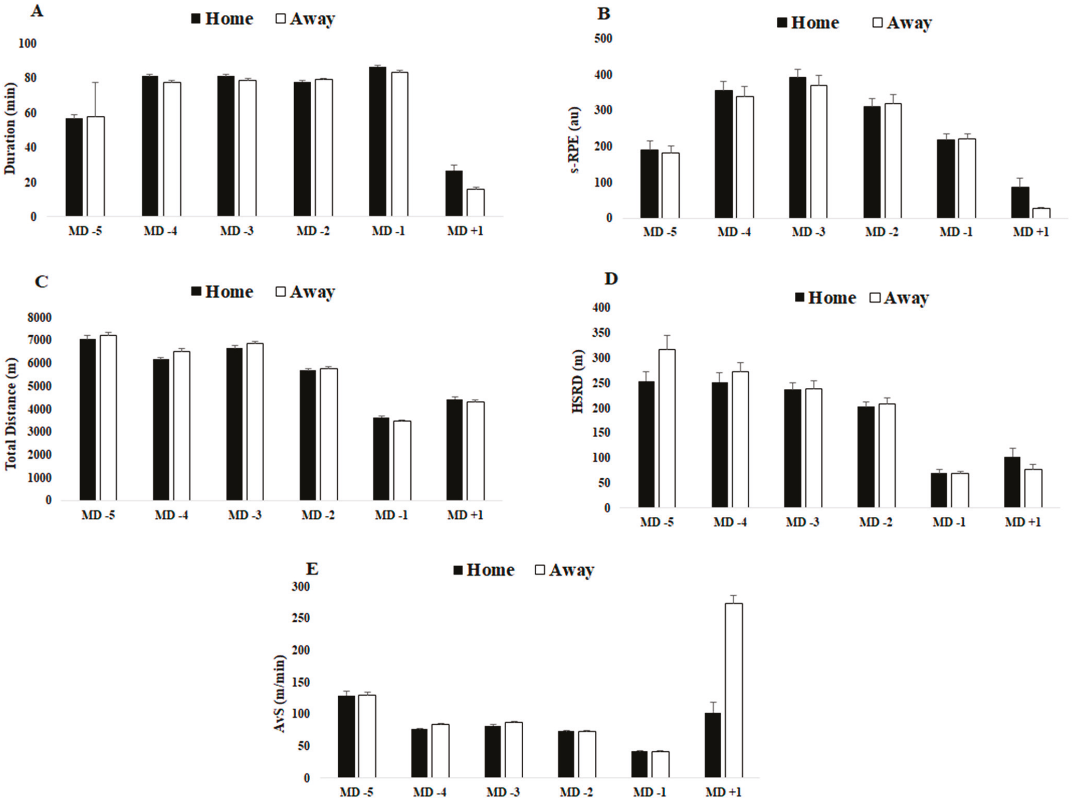

Figure 2. Differences between match day minus/plus preceding home and away matches for (**A**) duration, (**B**) s-RPE, (**C**) total distance, (**D**) HSRD and (**E**) AvS. Data presented by mean ± SD.

3.2. Comparison of Match Location

When comparing TL data that preceded home matches versus away matches, for MD-5, it was observed that total distance, HSRD and DOMS from the HI questionnaire exhibited higher values, while s-RPE was lower when closer to an away match than a home match.

For MD-4 and MD-3, external TL variables, such as total distance, HSRD and AvS, exhibited higher values when an away match was nearer, although all internal TL variables exhibited higher values when a home match was nearer.

For MD-2, all external and internal TL variables presented higher values closer to an away match than a home match, except for stress.

For MD-1, duration of training sessions and total distance covered were higher closer to a home match than an away match.

For MD + 1, all scores from the HI questionnaire and AvS were higher after playing an away match than a home match, although the duration of the training sessions, s-RPE, total distance and HSRD were lower after playing an away match than a home match.

Figures 3 and 4 displayed a graphical representation of Table 2 through mean and SD.

Table 2. Comparison of TL between starters and non-starters for home and away matches on MD-5 and MD + 1; mean ± SD.

MD-5	**Home (Starter, *n* = 10)**	**Home (Non-Starter, *n* = 10)**	**Away (Starter, *n* = 10)**	**Away (Non-Starter, *n* = 10)**
DOMS (au)	3.907 ± 0.990	3.236 ± 0.934	4.052 ± 0.997	3.739 ± 1.248
Sleep (au)	3.148 ± 0.666	3.035 ± 0.751	2.991 ± 0.578	2.701 ± 0.778
Fatigue (au)	3.909 ± 0.988	3.227 ± 0.903	4.038 ± 0.918	3.448 ± 1.129
Stress (au)	2.485 ± 0.966	2.666 ± 0.879	2.387 ± 0.873	2.577 ± 1.035
HI (au)	13.449 ± 2.552	12.308 ± 2.594	13.468 ± 2.351	12.465 ± 3.526
Duration (min)	52.599 ± 12.598	60.536 ± 7.727	54.550 ± 4.946	62.228 ± 14.944
s-RPE (au)	216.723 ± 143.317	171.020 ± 36.071	161.122 ± 55.633	212.840 ± 132.008
Total Distance (m)	7242.072 ± 526.893	6811.405 ± 997.150	7258.627 ± 619.855	7203.919 ± 411.725
HSRD (m)	226.664 ± 114.584	271.157 ± 165.186	338.507 ± 136.427	306.065 ± 149.409
AvS (m/min)	144.588 ± 33.356	114.324 ± 23.714	134.108 ± 14.039	122.215 ± 31.009
MD + 1				
DOMS (au)	4.621 ± 0.991 [a]	3.513 ± 0.911	4.664 ± 1.013	4.145 ± 1.313
Sleep (au)	3.950 ± 0.652	3.539 ± 0.971	3.800 ± 0.788	4.207 ± 1.174
Fatigue (au)	4.625 ± 0.917 [a]	3.685 ± 0.868	4.469 ± 0.962	4.193 ± 1.012
Stress (au)	2.733 ± 0.919	2.354 ± 0.967	2.602 ± 1.065	2.798 ± 1.180
HI (au)	15.930 ± 2.242 [a]	13.087 ± 3.089	15.753 ± 2.487	15.343 ± 4.009
Duration (min)	21.685 ± 8.076	30.543 ± 20.128	16.725 ± 3.854	16.075 ± 3.399
s-RPE (au)	46.111 ± 34.241	122.407 ± 151.091	29.309 ± 12.157	23.254 ± 10.022
Total Distance (m)	4215.586 ± 258.536	4649.747 ± 678.602	4435.604 ± 341.846	4260.829 ± 144.671
HSRD (m)	66.486 ± 29.941	139.718 ± 113.176	75.039 ± 40.146	84.345 ± 58.732
AvS (m/min)	140.265 ± 89.796	74.532 ± 46.093	275.079 ± 53.178	272.742 ± 54.309

MD-5 = match day minus 5; MD + 1 = match day plus 1; DOMS = delayed onset muscle soreness; au = arbitrary units; HI = Hooper index; min = minutes; m = meters; s-RPE = session rating of perceived exertion; HSRD = high-speed running distance; AvS = average speed. [a], denotes difference from home (non-starter), all $p < 0.05$.

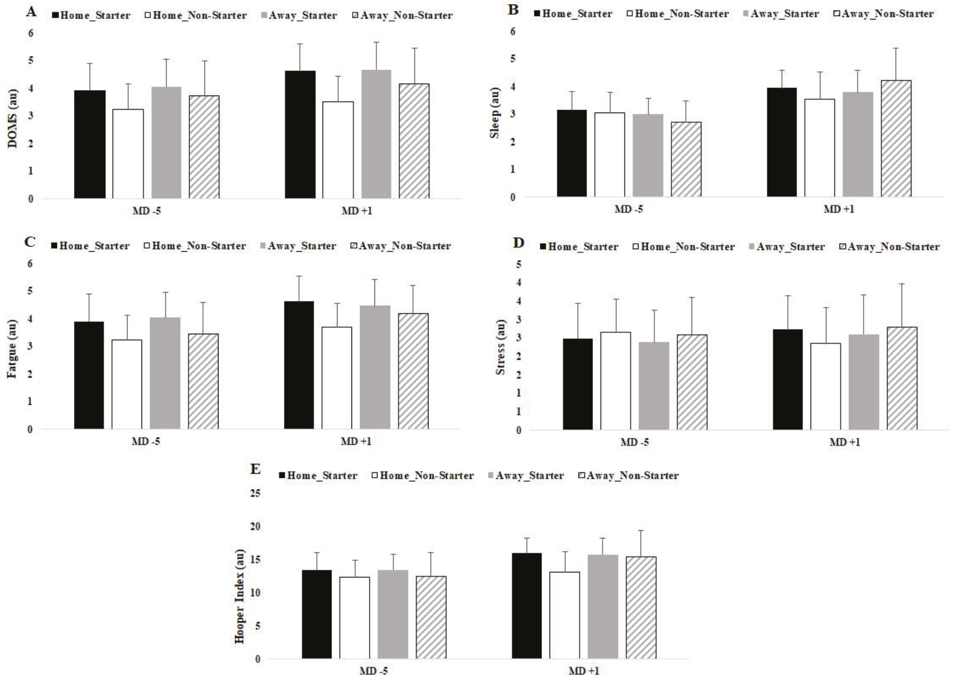

Figure 3. Differences between match-day minus/plus preceding home and away matches by player positions for (**A**) DOMS, (**B**) sleep, (**C**) fatigue, (**D**) stress and (**E**) Hooper index. Data presented by mean ± SD.

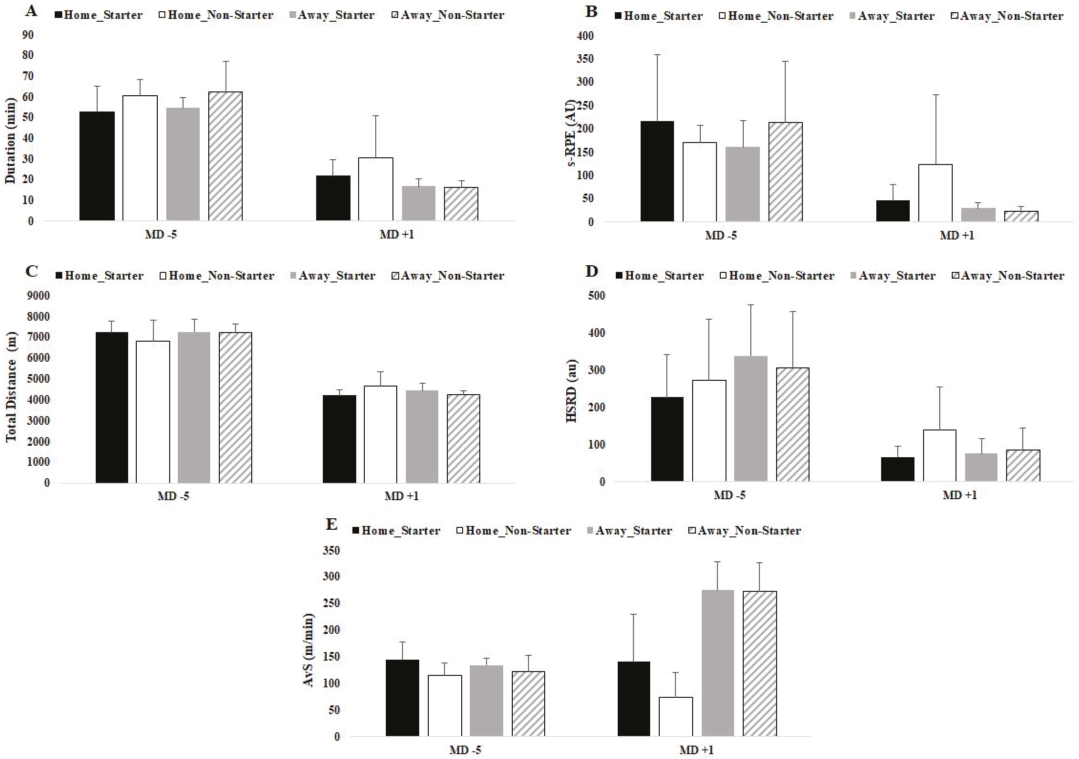

Figure 4. Differences between match day minus/plus preceding home and away matches for (**A**) duration, (**B**) s-RPE, (**C**) total distance, (**D**) HSRD and (**E**) AvS. Data presented by mean ± SD.

4. Discussion

The purpose of the present study was to quantify the internal and external TL employed by a top European soccer team during a full season to compare match day minus for TL that precedes a home or away match, as well as compare TL that precedes a home match versus TL that precedes an away match.

4.1. Comparison of Match Day Minus Preceding Home or Away Matches

In general, the first finding is a decrease for all variables on MD-1, which is in accordance with several other studies [27–29].

For internal TL, s-RPE revealed similar results regardless of match location when compared to other studies that found a progressive increase in this variable until MD-3, with a subsequent decrease until MD-1 [27–29]. Regarding MD + 1, s-RPE was higher than on MD-1 but lower than on MD-(5, 4, 3, 2) as home matches neared, while s-RPE was lower than on all MD-(5, 4, 3, 2, 1) for away matches. These results can be attributed to the recovery training sessions that occurred the day following the match.

In addition, HI scores revealed few variations in the days prior to each match, with the highest values being reported on the day after a match, which supports the claim that matches represent the most demanding workload of each week [28]. Moreover, MD-5 had higher values for DOMS, fatigue, sleep and total HI than MD-(4, 3, 2, 1), although these MD-(4, 3, 2, 1) are similar when home or away matches approach all variables. Moreover, these results are in accordance with those reported by Haddad et al. [30], who suggested that fatigue, stress, DOMS and sleep are not major contributors to perceived exertion during traditional soccer training without excessive TL. However, these findings also oppose the results of Clemente et al. [19,21], who found that the relationship between s-RPE and HI is both significant and negative in the weeks that contained two official matches, but not in the weeks with only one match.

Furthermore, for external TL variables, our study reveals that MD-5 has the highest TL session with lower duration and that TL was successively reduced until MD-1 even with higher training durations. A possible justification for this result could be associated with a higher intensity training in the beginning of the week and a consequent reduction as the next match approaches. However, Owen et al. [29] reported that, on MD-3, external TL variables were higher than on MD-(4, 2, 1). Moreover, Malone et al. [31] noted a progressive increase in total distance until MD-3 and a subsequent decrease until MD-1. A possible explanation for this difference could be that the study [29] was conducted during a competitive six-week mesocycle training period and that the other study [27] was conducted over the course of three separate weekly microcycles from the beginning, half and end of the season.

Specifically, the major difference occurred on MD+1, and the results were significant despite the short training duration (~26 min) after home matches. For external TL, AvS was the second highest on MD+1. On the other hand, despite the short training duration (~16 min) after away matches, the AvS was the highest compared to the other days. A possible explanation for this result could be the need to compensate for the short training duration and, therefore, an increment in total distance covered, especially for non-starters [32,33]. As in previous studies, the inclusion criteria adopted for this study included players that completed at least 60 min in one match in the first half of the season and one match in the second half of the season, regardless of whether they were starters [32,33]. This could possibly explain a greater effort by non-starter players on the day after the match, along with the fact that four CDs, four WDs, five CMs and four WMs were included for analysis, but usually only two players from each position play. All these arguments may influence the data collected.

Regardless of match location, the results for MD + 1 can be associated with a high-intensity training session. Moreover, it is important to acknowledge that an in-season match-day-minus training comparison was analyzed using mean values and that the microcycles/weeks have different patterns. For example, some microcycles had training days after match days and some did not.

4.2. Comparison of Match Location

The rationale to compare TL data preceding home versus away matches is based on previous research [1,6], which has found evidence of multiple home advantage effects on technical, tactical and strategic behaviors in professional soccer. Thus, home matches increase ball possession compared to away matches [4,6]. Moreover, home teams tend to employ a more offensive strategy, performing a higher number of attacking actions (goals scored, shots on goal, passes, crosses and so on), while more defensive behaviors (interceptions, clearances, etc.) were evident in less advanced pitch positions when playing away [7,8]. Although these findings only regard data from matches, our study also observed some influences in training sessions due to match location.

S-RPE remains similar during MD-(5, 4, 3, 2, 1) regardless of match location, but it is significantly higher on the day following a home match. In opposition to MD + 1, Abbott et al. [11] have found that s-RPE is similar for home and away matches. It is not clear why this is the case, because external TL was found to be significantly higher on the day following an away match. However, some studies have also reported that s-RPE did not reflect external TL [24,34]. Ferraz et al. [35] noted that RPE may be a physiological and volatile construct that could differ according to the cognitive focus of the player.

Regarding MD-1, HI scores are in accordance with two studies [11,23]. Both stated that match location does not influence subjective wellbeing status. Moreover, our results are in line with other studies that determined there is no difference in player mood or stress between home and away matches [10,36].

For MD + 1, all scores from the HI were higher after an away match than a home match. These results are not corroborated by Abbott et al. [11], who found that sleep quality was lower when an away match was played. On the other hand, the stress values are in accordance with Abbott et al. [11], who also found higher values of stress if the match was played away vs. at home. In the days following an away match, our findings could be related to air travel [36], although this study is not in line with ours, because it reported that air travel had minimal influence on perceived fatigue, soreness, sleep quality and stress in six elite Australian soccer players 1 and 2 days after an away match. The authors found that soreness and stress were higher after home than away matches. Some explanations for these different findings could be associated with the methods used for data collection. Fowler et al. [36] measured these effects 2 days after the match and analyzed players from an elite professional squad in Australia.

Other factors that could affect stress on the day following an away match include travel, unfamiliarity with surroundings, habit disruption, changes in food provision, pressure from away supporters and sleep loss [37].

Furthermore, sleep quality was lower in the present study after away matches, which may be because the players went to sleep later and/or had to travel a further distance to get home, both of which could negatively influence perceived sleep quality [38].

Regarding external TL variables, for MD-5, it was observed that total distance and HSRD covered increased closer to an away match than a home match. For MD-4 and MD-3, external TL variables, such as total distance, HSRD and AvS, exhibited higher values nearer an away match than a home match. For MD-2, all external variables exhibited higher values closer to an away match than a home match. It is not clear why this happened, and the extant literature neither confirms nor denies our results. Thus, it appears that external TL is more intense between MD-5 and MD-2 as an away match approaches because, on MD-1, duration of training sessions and total distance covered are greater than when a home match approach. We speculate that this could be associated with not having to travel (such as in the case of an away match), in which case coaches apply more TL because they know that players will have time to recover. Moreover, the higher values between MD-5 and MD-2 when an away match approaches could be associated with more defensive behaviors (interceptions, clearances, and so on) [7,8]. Based on this knowledge, coaches try to apply a greater stimulus in a training session in order to achieve better results.

For MD + 1, AvS was higher after an away than a home match, but duration of training sessions, total distance and HSRD were lower after an away than a home match. In general, the training session after a match has a lower duration. That fact can lead to a training session with exercises that achieve HSRD, but with a lower total distance covered. However, our study presents some differences regarding match location that we cannot address.

Although it was not a purpose of this study, we have provided Figures 5 and 6 with average week TL data regarding home and away matches as a tool to support coaches in their TL week planning when a home or away match approaches.

Based on the statement of Barret et al. [39], there is a need for further investigation into what influences the results obtained by RPE to better understand how and if this helps inform practitioners of either mental or physical fatigue. For example, situations such as scoring a goal, opportunities to score a goal, interceptions, tackles, a good set play, a turnover win, increased possession or the ability to block an attack or even the non-technical/tactical training type of exercises may influence the perceived exertion of a player. In addition, HI scores can also be influenced in a similar manner. Nonetheless, this study reinforces the use of HI scores, especially on the day following a match.

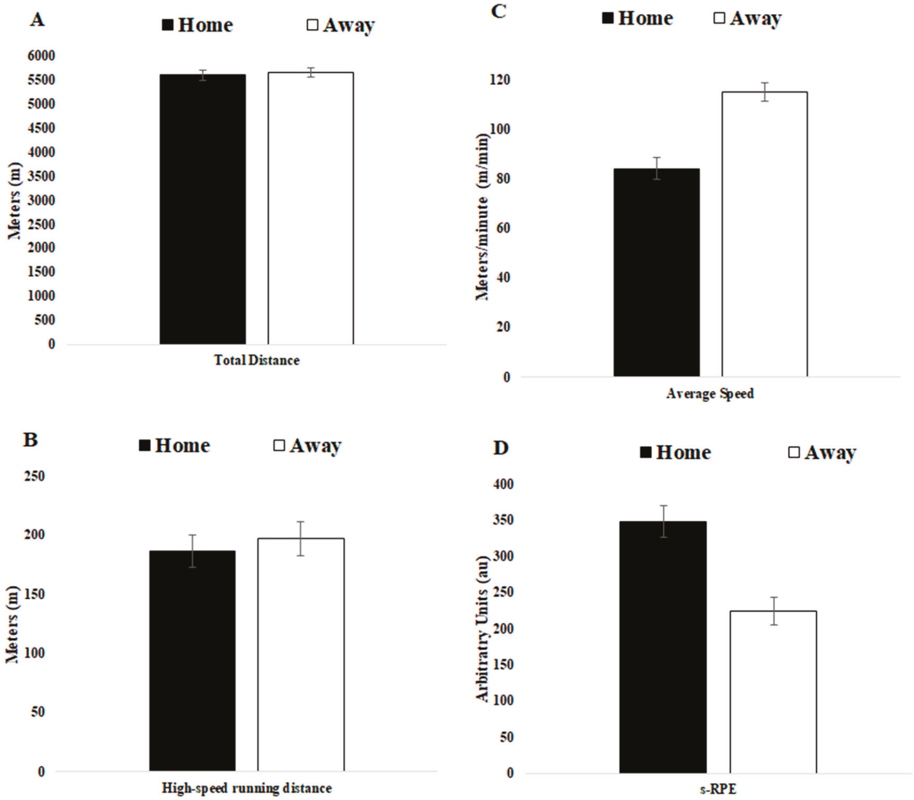

Figure 5. Average week training load regarding home and away matches for (**A**) total distance, (**B**) high-speed running distance, (**C**) average speed and (**D**) s-RPE.

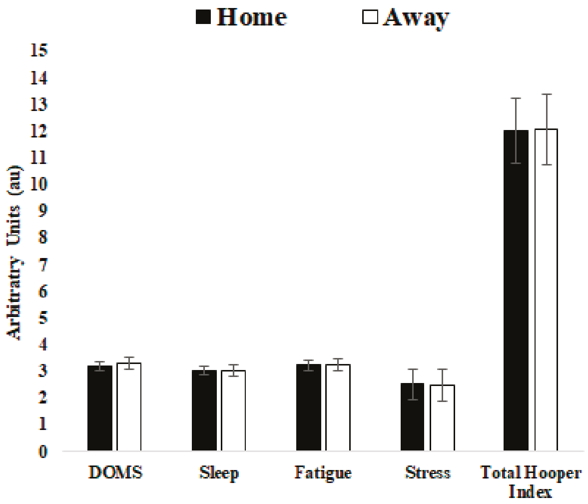

Figure 6. Average week training load regarding home and away matches for DOMS, sleep, fatigue, stress and total Hooper index.

Furthermore, this study has some limitations that should be addressed. First, only one team was analyzed. Secondly, the team played in European matches and thus may not be representative of the customary training demands of other domestic teams that did not play in European matches [40] or those from different continents/countries [41] because the team manager and coach may have been influenced by different managerial and coaching philosophies [42].

Moreover, future research should consider different analyses of the season (e.g., to include weeks with two or three matches) and other contextual variables like match result [11,20,23] and level of opponent [11,23].

5. Conclusions

This study confirms and provides evidence regarding the match location influence on internal and external TL data preceding home and away matches from a team that played in European competitions.

From a practical perspective, the findings of the present study can help to guide coaches for better TL periodization when a home or an away matches approaches for weeks with one match. For instance, when an away match approaches, it was shown that on MD-5, total distance and HSRD were higher. MD-4 showed higher values for all external variables. MD-3 showed higher values for total distance and AvS. Moreover, it was revealed that all HI scores and AvS were higher on MD + 1.

On the other hand, when a home match approaches, MD-1 showed higher values of total distance while MD + 1 showed higher values for s-RPE, total distance and HSRD.

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Article

Segmental Phase Angle and Body Composition Fluctuation of Elite Ski Jumpers between Summer and Winter FIS Competitions

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Abstract: (1) Background: The purpose of this study was to observe segmental phase angle (PhA) and body composition fluctuation of elite ski jumpers. (2) Methods: In the study, 12 professional ski jumpers took part. Body composition was estimated with segmental multi-frequency bioelectrical impedance analysis. Repeated ANOVA was used to check the parameters' variability in time. The symmetry between the right and left side of the body was verified with the *t*-test for dependent samples. Pearson's linear correlation coefficient was calculated. (3) Results: The most stable parameter was body weight. An increase in the visceral fat area was noted, the fat-free mass dropped, and significant changes were noted in the internal and external cell water parameters. Parameters connected with water between the right and left side of the body were symmetrical. Significant correlation between PhA values and body parameters with regard to fat tissue and PhA values of the legs was noticed when PhA was measured at 50 kHz. (4) Conclusions: PhA could be considered as a ski jumper body symmetry monitoring tool. The described relationship may be useful for the assessment of body fat change, which, in the case of jumpers, is crucial. Moreover, our data suggest that segmental PhA evaluation could be a good solution for ski jumpers as a confirmation if lowered body mass and low BMI are still healthy and increase the chance for longer jumps and good performance.

Keywords: body symmetry; ski jumpers; segmental phase angle; visceral fat area; BIA; winter sports; nutritional status

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1. Introduction

1.1. Importance of Body Composition for Ski Jumpers

The body composition and nutritional status of ski jumpers belong to the factors that are essential for the explosiveness required in ski jumping performance. Due to gravitational reasons, lower body mass index (BMI) definitely increases the chance for longer jump but is not a sufficient factor [1,2]. For good performance, the most important is the ability to very rapidly produce a great power output during the jump, which is achieved through a combination of the muscular strength, power, body coordination, and balance of the athlete [3,4]. Therefore, an adequate nutritional status of ski jumpers provides a chance to maintain low body weight simultaneously with a properly balanced lean-to-fat tissue ratio. For ski jumpers it is essential to monitor body composition at each stage of their preparation for competitions and during the season.

1.2. The Bioelectrical Impedance Analysis (BIA)

BIA remains a proper tool for this purpose. BIA is non-invasive and easy to perform and serves as a valuable tool for the evaluation of body composition and the assessment of nutritional status in either clinical patients, healthy population, or athletes [5–8]. BIA provides body composition comparable with other methods such as dual-energy X-ray absorptiometry (DXA) and hydrostatic weighing [9–13]. In addition, BIA is a good tool for ski jumpers, as it can be used to control the endurance of the training process in order to protect against the harmful effects of excessive endurance exercises that are part of the training to prepare jumpers for competitions [14,15]. According to recent studies, raw bioelectrical impedance parameters are useful predictors of total and extracellular pools, cellular hydration, and fluid distribution in athletes [16,17].

1.3. Meaning of the Phase Angle (PhA) Parameter

PhA, which can be estimated from the electrical properties of body tissue, seems to play an important role in evaluating the changes in water distribution and monitoring the hydration status of athletes regardless of sport discipline [10,18–20]. The PhA concept is based on the changes in resistance and reactance as an alternating current passes through the evaluated tissues. A phase shift occurring as part of the current is stored in the resistive compartments of cellular membranes [21]. Although BIA predictions of body composition often rely on population-specific equations, the PhA is estimated directly without an additional conversion to specific body parameters. Therefore, the authors highlight that the measurement of PhA depends on several biological factors, such as the quantity of cells with their respective cell membranes, cell membrane integrity, and related permeability and the amounts of extracellular and intracellular fluids [22–25]. PhA reflects the relative contributions of fluid (resistance) and cellular membranes (reactance) of the human body and is positively associated with reactance and negatively associated with resistance. Decreased cell integrity or cell death is suggested by lower PhA, while intact cell membranes are suggested by higher PhA [26,27]. That is why this parameter is considered a general marker of health, reflecting body cell mass and constituting one of the best markers of cell membrane function [28–30]. PhA is strongly recommended by the European Society for Clinical Nutrition and Metabolism (ESPEN) as a prognostic nutritional status measure [31]. There are considerable differences between PhA across various populations, although they share similar features in relation to age, sex, and BMI [32–34]. PhA values have a similar pattern that starts from infants, increases progressively up to the teenage phase, stabilizes during adult ages, and then decreases progressively in the elderly [35–37]. Among healthy individuals, the PhA for the whole body ranges from 5° to 7.5° [32,38]. Among trained athletes, this value rises and may reach the 8.5° [18,39] to 9.5° [40] range. A large variability in the whole-body PhA values is observed for the same sport and between various sports [41,42], but the availability of data concerning the assessment of segmental PhA is still limited [43]. Segmental (five compartments: trunk, lower and upper limbs) evaluation could be useful for monitoring the condition of the athlete preparing for a competition and for assessing differences among athletes [15,44]. As bioimpedance analysis allows us to adjust the nutrition programme within trainings and prevent unhealthy reduction of fat among ski jumpers, the aim of this study was to observe the segmental PhA and body composition fluctuations between pre-season summer training and winter competition season in the group of elite ski jumpers who represented Poland in the Ski Jumping World and Continental Cup. Moreover, our aim was to analyse the usefulness of different frequencies that are offered by segmental bioimpedance analysis. To our knowledge, this is the first study which analyses this parameter in a group of ski jumpers.

2. Materials and Methods

2.1. Study Group

Twelve members of the Polish National Team in ski jumping, world-class performers, and leaders and medallists of the Four Hills Tournament, Ski Jumping World Cup and

Continental Cup, participated in the study. Their mean age was 21.7 (SD: 3.2; ranging from 17 to 29) years. All participants represented Poland in the summer and winter international competitions according to FIS competition schedule 2016/2017. The athletes were under dietician supervision, and their diet was adjusted to individual needs. The subjects were excluded from the study if they had taken medicine that might affect hydration status in the seven days prior to the test. The study was carried out in accordance with the guidelines featured in the Declaration of Helsinki. The Polish Ski Association and the athletes signed informed consent prior to the study entry, and the study protocol was approved by the Ethical Committee of the Jagiellonian University, Krakow, Poland (No. 122/6120/103/2016).

2.2. Measurements and Conditions

All anthropometric measurements were performed by the same operator at an ambient temperature of 22–24 °C, between 07:30 and 08:40 a.m., after fasting for at least 8 h and with an empty bladder. Body weight was measured with a medical weight scale (SECA 711), and the result was rounded to the nearest 0.1 kg. Individuals were measured barefoot, wearing minimal, light clothing. The BMI (in kg/m^2) was calculated as body weight divided by the square meter of the height. Body composition and fluid distribution were measured with a direct segmental multi-frequency bioelectrical impedance analysis (DSM-BIA) using an impedance-meter InBody S10 (Biospace Corp., Seoul, Korea). InBody S10 is a Food and Drug Administration-approved portable version of the multi-frequency bioelectrical impedance plethysmograph body composition analyser that enables measurement in the supine position, eliminating the gravity effect of body fluid when standing. InBody S10 makes use of eight tactile electrodes: two are in contact with the palm and thumb of each hand, and two with the anterior and posterior aspects of the sole of each foot. The electrical current flows through the trunk from hand (finger) to foot (ankle) and from ankle to finger. This equipment has previously been shown to have high test–pretest reliability and accuracy and is a valid tool for the assessment of whole-body composition and for segmental lean mass measurements when validated against DXA [45]. Unlike conventional BIA equipment, which often takes only partial measurements and therefore relies upon formulas to estimate whole-body composition, the DSM-BIA technique employs the assumption that the human body is composed of five interconnected cylinders and takes direct impedance measurements from the various body compartments. An eight-point tactile electrode system is used, which separately measures the impedance of the subject's trunk, arms, and legs at six different frequencies (1 kHz, 5 kHz, 50 kHz, 250 kHz, 500 kHz, and 1000 kHz) for each of the body segments. The spectra of electrical frequencies are used to predict the intracellular water (ICW) and extracellular water (ECW) compartments of the total body water (TBW) in the various body segments. Low-level frequencies rely on the conductive properties of extracellular fluid, whereas at high-level, the conductive properties of both ICW and ECW are instrumental. LBM is estimated as TBW (ICW+ECW)/0.73. FM is calculated as the difference between total body weight and LBM. TBW is calculated from the resistivity index Ht^2/R and weight using the published bioimpedance equation of Kushner and Schoeller, modified by the manufacturer's empirical constants [46,47]. The electrical current flows through cell membranes acting as a capacitor and resulting in a phase shift known as the geometrical phase angle, which is calculated as the arctangent of the ratio of X_c to R (converted to degrees) [48]. The values of PhA measured at 5 kHz, 50 kHz, and 250 kHz were taken for further considerations and calculated from the raw impedance values using the software supplied by Biospace Ltd. The measurement started with the preparation of the participants to accurately capture the impedance and PhA values. The participants were maintained in the supine position for 15 min on a non-conducting surface to avoid the effects of gravity-induced water movement. Metal and electronic devices were removed before measurement to avoid interference in the electrical current flow. The arms were slightly abducted, with elbows pronated (palms down) at about 15 degrees, and the legs were slightly abducted to the shoulder width to ensure the proper route of the current, and the skin was cleaned using wet electrolyte tissue paper to increase current conduction.

All measurements were taken at six time points:

- time point 1: (resting time) (June 2016)—2 days after completion of spring strength-endurance training series;
- time point 2—before summer FIS Grand Prix (July 2016);
- time point 3—after summer competitions (August 2016);
- time point 4, 5 (October and November 2016, respectively);
- time point 6—during the period of winter FIS Ski Jumping (World and Continental) Cup 2016/2017 (January 2017).

As a result of the measurements, the following parameters were obtained and analysed in this article: body mass (kg), body height (cm), BMI (kg/m^2), total body water (TBW), intracellular body water (ICW), extracellular body water (ECW), ECW:TBW ratio (e_t), body cell mass (BCM), % body fat (PBF), fat (kgBF), visceral fat area (VFA), skeletal muscle mass (SMM), fat-free mass (FFM), segmental body water, segmental ECW:TBW ratio, segmental 5 kHz PA (X5 Pha), segmental 50 kHz PA (X50 Pha) and 250 kHz PA (X250 Pha). Segmental means five compartments: right arm (RA), left arm (LA), trunk (TR), right leg (RL), and left leg (LL), separately.

2.3. Statistical Analysis

All studied parameters were described using the mean ± standard deviation (SD) as their distributions were mostly symmetrical. Repeated ANOVA was used to check their variability in time, as standardized residuals were approximately normally distributed. Post hoc tests as well as polynomial contrasts were applied to assess the shape of changes and differences between time points. Symmetry between the right and left side of the body in segmental body water and other parameters was verified with the *t*-test for dependent samples. To investigate the effect size, Cohen's *d* parameter was measured. A Cohen's *d* of ±0.2 is considered a 'small' effect size, ±0.5 a 'medium' effect size, and ±0.8 a 'large' effect size. Pearson's linear correlation coefficient, which determines the level of dependence between the analysed variables, was calculated. This way, variables that are significantly associated with each other were determined. For ease of interpretation, the result was presented in the form of a colour map, in which the values of the correlation coefficients are arranged on a colour scale: from dark blue, denoting the maximum positive correlation value, i.e., +1, through white, indicating no correlation 0, to dark red, indicating the maximum negative correlation value, i.e., −1. The discussion focused on Pearson's correlation results above 0.6.

3. Results

The BMI did not change significantly during the study period, and the mean BMI value was 19.6 (SD: 0.56; range: 18.5–21.3 kg/m^2). The basic anthropometric measurements and general characteristics of the participants based on BIA and segmental PhA for the whole time of observation are described in Table 1 and Appendix A.

3.1. Body Weight and Body Composition Fluctuation during the Period of Observation

The most stable parameter during the study period was body weight. Changes in the amount of fat and in fat-free mass were noted (as % or kilograms). In general, fat tissue content rose, and the most pronounced change was observed for visceral fat area ($p_{1–6} < 0.013$). Fat-free mass, due to lowered amounts of body cell mass and skeletal muscle mass, dropped ($p_{1–6} < 0.009$). The increased body fat (% and kg) between the first and the last time point was statistically significant ($p_{1–6} < 0.002$ in both cases). The differences between the time points for chosen parameters are presented in Figure 1a–c.

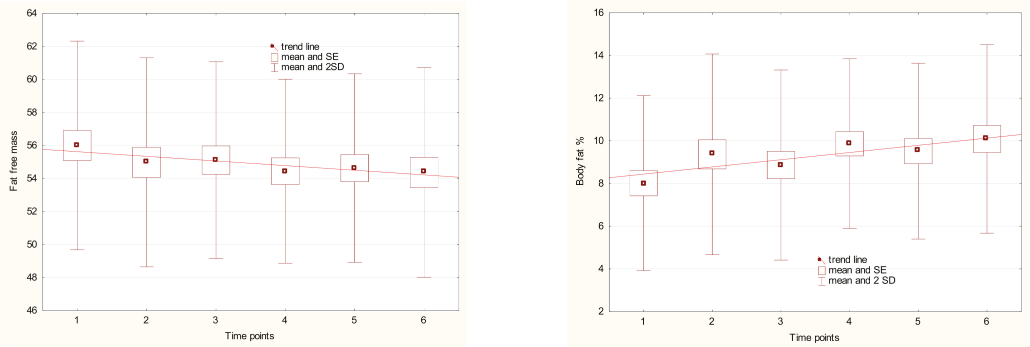
Table 1. General characteristics of the participants based on BIA and segmental PhA measurements.

Parameter	Mean	SD	Min	Max
Height [m]	1.76	0.033	1.70	1.80
Weight [kg]	60.47	2.489	56.40	66.47
BMI [kg/m^2]	19.58	0.570	18.54	21.28
ICW (intracellular body water)	25.48	1.409	23.50	29.00
ECW (extracellular body water)	14.80	0.739	13.60	16.60
TBW (total body water)	40.28	2.115	37.10	45.6
h2oRA (water content, right arm)	2.29	0.177	1.97	2.70
h2oLA (water content, left arm)	2.27	0.168	1.92	2.70
h2oTR (water content, trunk)	18.77	0.975	17.00	20.90
h2oRL (water content, right leg)	6.93	0.461	6.36	8.10
h2oLL (water content, left leg)	6.93	0.456	6.32	8.10
e_t_Total (ECW:TBW ratio; total)	0.37	0.004	0.36	0.40
e_tRA (ECW:TBW ratio; right arm)	0.37	0.004	0.36	0.40
e_tLA (ECW:TBW ratio; left arm)	0.37	0.004	0.36	0.40
e_tTR (ECW:TBW ratio; trunk)	0.37	0.005	0.36	0.40
e_tRL (ECW:TBW ratio; right leg)	0.37	0.005	0.36	0.40
e_tLL (ECW:TBW ratio; left leg)	0.37	0.005	0.36	0.40
BCM (Body Cell Mass) in kg	36.45	2.040	33.20	41.50
SMM (Skeletal Muscle Mass) in kg	31.18	1.855	28.20	35.80
FFM (Fat-Free Mass) in kg	54.92	2.968	49.90	62.30
Fat in kg	5.61	1.287	2.20	8.00
PBF (Percentage of body fat)	9.29	2.187	3.40	13.60
VFA (Visceral Fat Area) in cm^2	14.84	6.611	5.00	30.00
X5PhaRA (5 kHz PA; right arm)	2.58	0.220	2.00	3.00
X5PhaLA (5 kHz PA; left arm)	2.47	0.240	1.90	3.00
X5PhaTR (5 kHz PA; trunk)	3.85	0.294	3.10	4.70
X5PhaRL (5 kHz PA; right leg)	3.07	0.443	2.30	6.00
X5PhaLL (5 kHz PA; left leg)	2.97	0.279	2.30	3.50
X50PhaRA (50 kHz PA; right arm)	6.23	0.438	5.20	7.10
X50PhaLA (50 kHz PA; left arm)	6.00	0.512	4.70	7.00
X50PhaTR (50 kHz PA; trunk)	9.45	0.974	7.60	12.70
X50PhaRL (50 kHz PA; right leg)	7.11	0.509	6.10	8.20
X50PhaLL (50 kHz PA; left leg)	6.98	0.526	5.90	8.10
X250PhaRA (250 kHz PA; right arm)	6.11	0.624	5.00	7.80
X250PhaLA (250 kHz PA; left arm)	5.93	0.677	4.80	7.60
X250PhaTR (250 kHz PA; trunk)	9.34	3.511	4.00	20.70
X250PhaRL (250 kHz PA; right leg)	4.75	0.438	3.90	6.20
X250PhaLL (250 kHz PA; left leg)	4.55	0.471	3.80	6.00

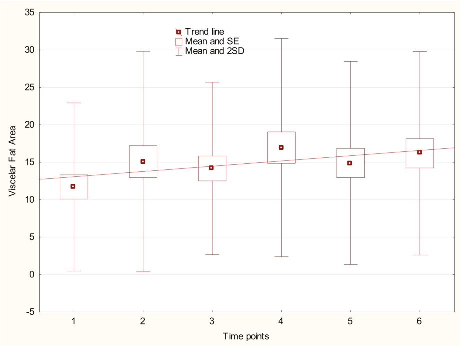
The total body water decreased for water parameters, ICW and TBW, whereas the parameter of ECW to TBW increased, with statistically significant differences (between the first and the last time point) of $p_{1–6} < 0.005$, $p_{1–6} < 0.011$, and $p_{1–6} = 0.001$, respectively (Figure 2a–c).

Statistically significant changes in the parameter of water content were for both legs, between first and last measurements: $p_{1–6} < 0.002$ for right leg and $p_{1–6} < 0.017$ for the left leg (Figure 3a,b).

Water content in the legs was still lower compared with the first time point. It should be highlighted that this drop was associated with lower intracellular water content, while extracellular water content was unchanged. The highest water content was measured in the trunk, and the amount was three times greater than that in the legs. The lowest water content was noted in the arms—9 times lower than that in trunk. During the whole observation time, the amount of water between the right and the left side of the body was symmetrical for each compartment and for the ratio of extracellular body water to total body water.

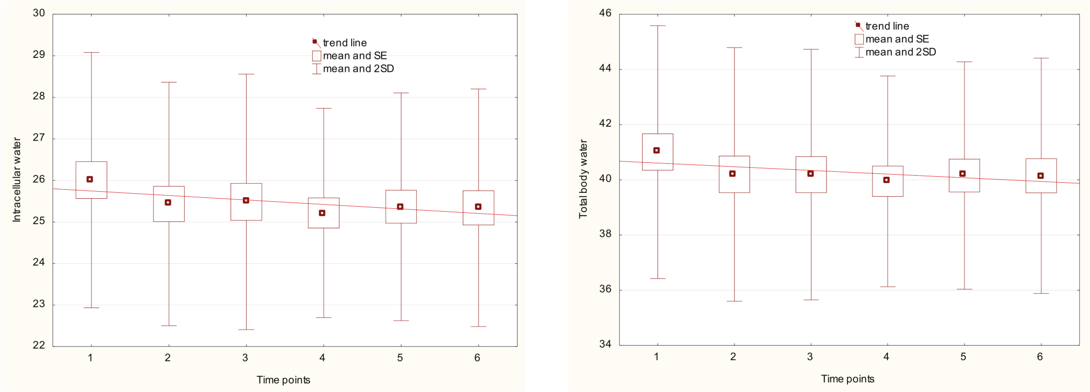


(**a**) Changes in fat–free mass (**b**) Changes in body fat in percentage



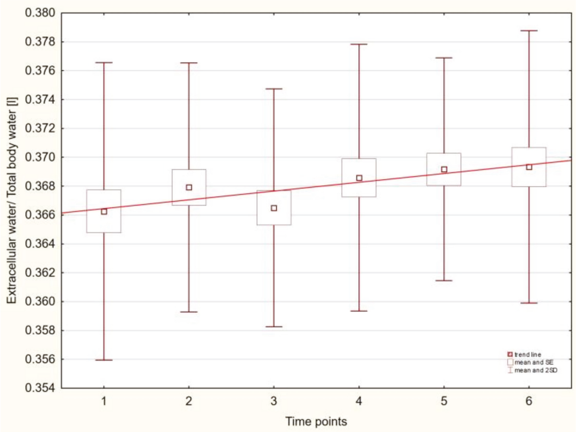
(**c**) Changes in visceral fat area

Figure 1. Changes in fat– free mass content (**a**), percentage of body fat (**b**), and visceral fat area (**c**) with respect to time points.



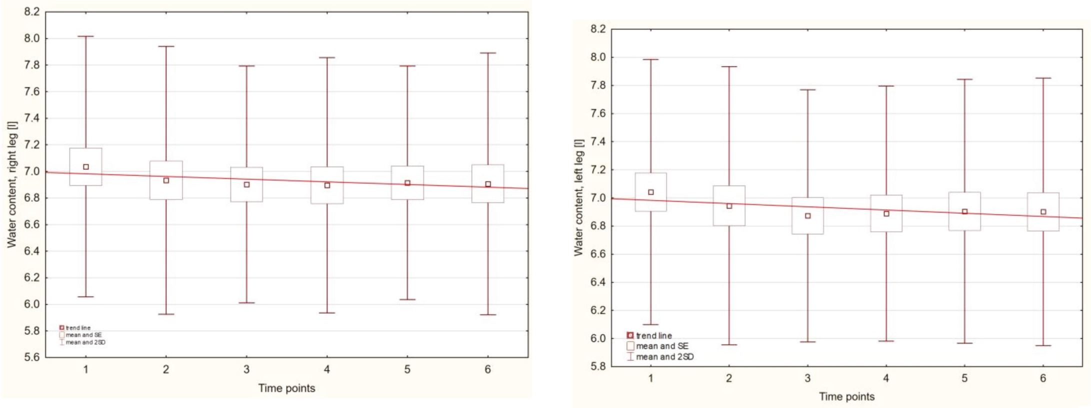
(**a**) Intracellular body water content (**b**) Total body water content

Figure 2. *Cont.*



(**c**) Extracellular to total body water ratio

Figure 2. Changes in intracellular body water content (**a**), total body water content (**b**), and the ratio of extracellular body water to total body water (**c**) with respect to time points.



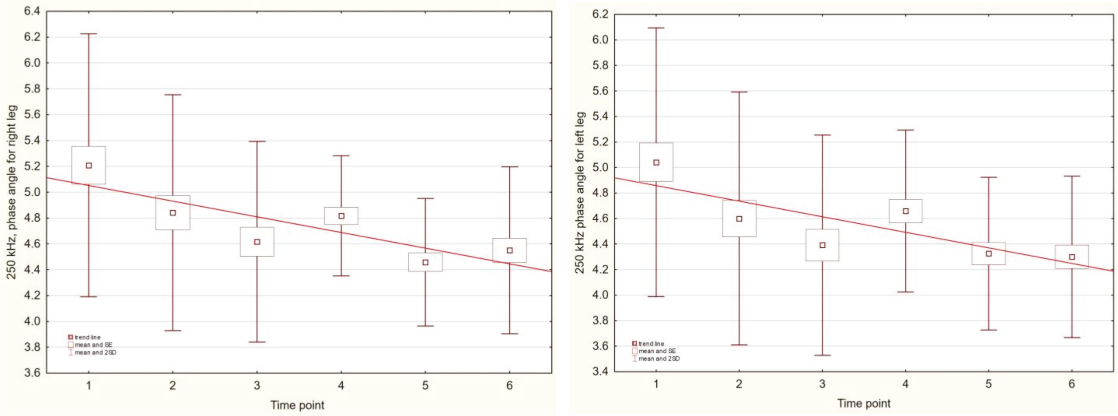
(**a**) Changes of body water content in the right leg

(**b**) Changes of body water content in the left leg

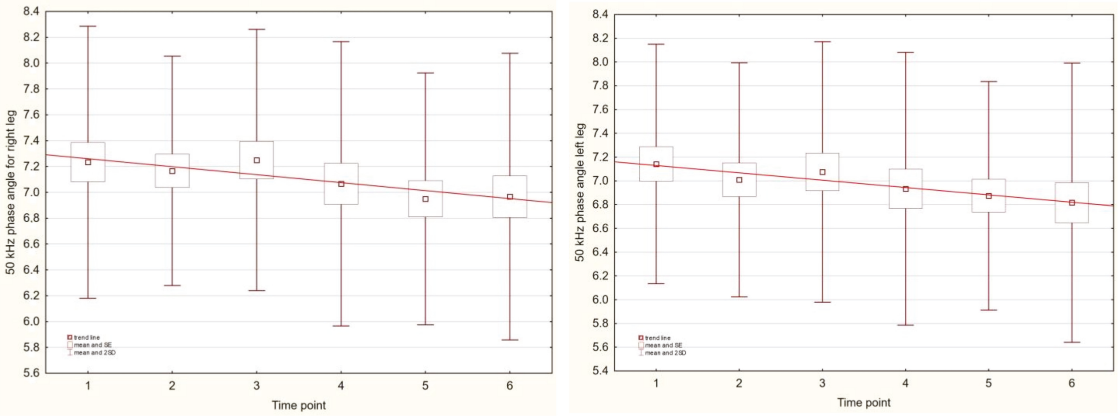
Figure 3. Changes of body water content in the right (**a**) and the left (**b**) leg with respect to time points.

3.2. Phase Angle Fluctuation during the Period of Observation

Fluctuation in PhA values for 5, 50, and 250 kHz was observed between time points. Regardless of frequency, the highest value of PhA was for a trunk. Higher frequency was related with higher PhA values for all compartments. For both the lower limbs, the highest values of PhA were observed when using a frequency of 50 kHz, and the lowest when using 5 kHz. For all the time points, the PhA values measured with a frequency of 5 kHz for the right side of the body (arms and legs) were slightly higher than those for the left side. The highest PhA values for all body compartments (including the trunk) were noted in the third time point, that is, the end of August 2016. For a frequency of 50 kHz between each time point, substantial differences were noticed, but when comparing the starting time point and the last measurement, the differences were only observed for the right arm and the right leg. For the highest frequency (250 kHz), all body compartments had the highest PhA values in the first time point, and for subsequent time points the PhA values were dropping. For both legs, 250 kHz and 50kHz were dropping systematically, as depicted in Figure 4a–d.



(**a**) Changes in phase angle for the right leg at 250 kHz (**b**) Changes in phase angle for the left leg at 250 kHz



(**c**) Changes in phase angle for the right leg at 50 kHz (**d**) Changes in phase angle for the left leg at 50 kHz

Figure 4. Changes in the phase angle value for both legs with respect to kHz frequency and time points.

3.3. Right-to-Left Body Side Symmetry

The results of a test analysing the significance of the differences between the right and left body parts during the study period are presented in Table 2. The upper limb PhA values for 5, 50, and 250 kHz were significantly higher for the right side of the body than those for the left, while the ECW:TBW (e_t) ratio indicated significantly higher values for the left side of the body (for the left arm as well as the left leg). The changes in the analysed parameters at different time points were inconsiderable with respect to symmetry. In the arms, the dominance of the right side of the body was visible, and PhA values were higher. The test failed to confirm the differences between the right and the left side of the body with respect to total water content and phase angle for the legs at all three frequencies.

Table 2. Differences between left and right body parts with respect to total body water, the ratio of extracellular body water to total body water, and the phase angle at 5 kHz, 50 kHz, and 250 kHz.

	Mean	SD	95% Confidence Interval	Statistical Significance *p*	Effect Size	
					Cohen's *d*	95%CI
h2oRA–h2oLA	0.006	0.0491	−0.025–0.037	0.688	—	
h2oRL–h2oLL	−0.006	0.0675	−0.049–0.037	0.770	—	
e_tRA–e_tLA *	−0.001	0.0017	−0.002–−0.0001	0.041	−0.65	[−0.91, −0.40]
e_tRL–e_tLL *	−0.003	0.0024	−0.004–−0.001	0.003	−1.22	[−1.54, −0.92]
5kHzPhaRA–5kHzPhaLA *	0.150	0.1679	0.043–0.257	0.010	0.65	[0.40, 0.91]
5kHzPhaRL–5kHzPhaLL	0.100	0.2132	−0.035–0.235	0.132	—	
50kHzPhaRA–50kHzPhaLA *	0.292	0.1975	0.166–0.417	0.000	1.22	[0.92, 1.54]
50kHzPhaRL–50kHzPhaLL	0.092	0.1832	−0.025–0.208	0.111	—	
250kHzPhaRA–250kHzPhaLA *	0.150	0.1382	0.062–0.238	0.003	1.07	[0.78, 1.37]
250kHzPhaRL–250kHzPhaLL	0.167	0.3114	−0.031–0.365	0.091	—	

* No significant difference in body symmetry between right and left body parts.

3.4. Correlation Analysis for Measured Parameters

Significant correlation between PhA values and body parameters with regard to fat tissue and PhA values of the legs was noticed when PhA was measured at 50 kHz. A higher VFA parameter meant a lower PhA value for both legs ($r > -0.75$), and PhA values for the legs inversely correlated with body fat ($r = -0.63$ and $r = -0.61$; for the right and the left leg, respectively). The results of the correlation analysis are shown in Figure 5.

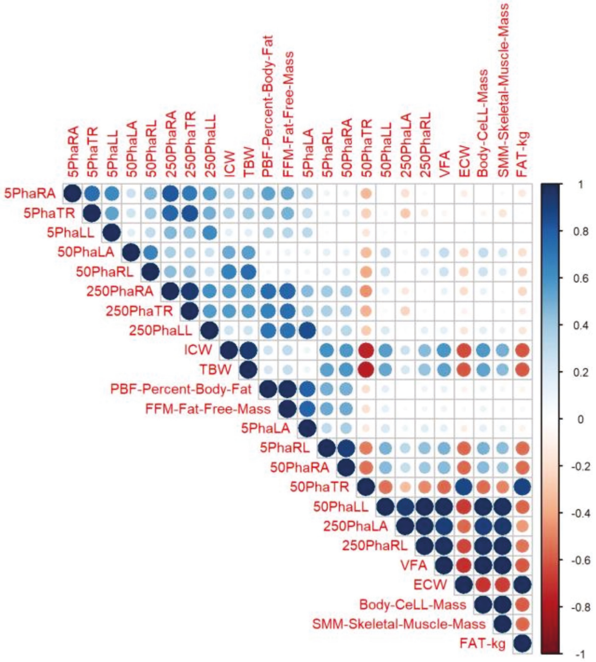


Figure 5. Visual representation of Pearson's correlation coefficient for the measured parameters. More intense colours mean stronger correlation (from dark blue to light blue, positive correlation; from dark red to light red, negative correlation).

4. Discussion

Ski jumping can be classified as a speed–strength sport discipline as it requires strength, power, good balance, space orientation, and reaction abilities from professional ski jumpers [49]. For better performance, ski jumpers need to keep a body weight that can enhance their performance, and for this reason, the BMI of ski jumpers is low. As highlighted by Muller, although low weight belongs to performance determinants, it should be considered that very low weight can cause severe performance setbacks due to decreased jumping force, general weakness, reduced ability to cope with pressure, and increased susceptibility to diseases (e.g., anorexia nervosa) [50]. The BMI values of ski jumpers are changing: in 1970, the mean BMI was about 23.6 kg/m^2, while in the first decade of the twenty-first century, a mean BMI of 19.4 kg/m^2 was observed [2,15]. The mean BMI calculated in the present study (19.6 kg/m^2) remains comparable and did not change significantly during the seven months of observation. This fact is inconsistent with Rønnestad's observation, according to which the body weight of ski jumpers is reduced from pre-season to the end of the competitive season in internationally competing ski jumpers [51]. During the study period, the amount of fat tissue (visceral fat content) increased from 8.2% to 10.1%, which still adheres to the values recommended for ski jumpers and athletes of other sports in which body weight restrictions are required due to gravitational reasons, e.g., high/long jumping, long-distance running, jockeying, mountain running, and sport climbing [52]. Considering the good results of these jumpers in winter season 2016/2017, we can assume that this increased fat content should not be treated as an additional obstacle. BIA predictions of body composition depend on population-specific equations. The PhA value is not an independent variable, and circumstances such as different types of segmental analysis (e.g., foot-to-hand or direct segmental in standing position) change the results. Moreover, several biological factors, such as the quantity of cells, cell membrane integrity, and related permeability and the amounts of extracellular and intracellular fluids, affect the measured value [22–24]. Therefore, making comparisons of our results with other studies should be interpreted with caution. According to our results, the segmental analysis of phase angle indicated a negative statistically significant correlation between PhA for both the lower limbs ($r > -0.75$; measured at 50 kHz) and visceral fat, and only for 50 kHz frequency, PhA correlated for both legs with percentage of body fat ($r = -0.63$ and $r = -0.61$; for the right and the left leg, respectively). Our results correspond with a study by Siddiqui and co-workers [9] which indicated that PhA can be predicted from visceral fat, although the study was not based on sportsmen population and the average amount of fat in the study group was 22% (two times greater than in our population), while another study showed that the PhA of the trunk is significantly correlated with percentage of body fat [53]. During the seven months of observation, the amount of fat-free mass decreased by 1.63 kg; this decrease was caused by a decrease in skeletal muscle mass and accompanied by a decrease in the amount of body water. This change is due to the first measurement (baseline time point) being done just after the period of training, mainly composed of gym exercises, aimed at strengthening the muscles, which was followed by a resting period. Subsequent trainings preparing for the summer season are not connected exclusively with physical exertion. The change was probably partially associated with differences in body water content that fluctuate between seasons (summer and winter) [54,55]. During the study period, the water content was changing, and a decrease in water content was noticed with the most intensive drop between summer and autumn. The differences between ECW/TBW parameters were visible only when 50 kHz and 250 kHz frequencies were analysed. Though changes in the proportion of water content may be evidence of malnutrition, according to the literature, these changes are probably associated with the increase in visceral fat content and change in the type of exercise [21,56]. It is worth highlighting that the most pronounced changes are associated with the lower limbs, probably because the legs are the most metabolically active body parts of ski jumpers [3,57]. As the literature data associated with water monitoring in each body segment, as well as detailed studies monitoring body parameters in regular time spans during the training of ski jumpers, are scanty, our results cannot be compared with other studies, to draw firm conclusions. The BIA method and PhA value are an accepted marker of cells' healthiness and an important tool in assessing nutritional status in any situation, being superior to anthropometric and biochemical methods [58]. On the basis of the literature, it is known that when a drop in BMI is not accompanied by a decrease in PhA, we can assume that there is no threat of undernutrition. In constitutionally lean people and ballet dancers, despite lower BMI, phase angle is not decreased. The explanation of this fact is body composition—less fat and more muscle mass as a result of workout [43,59]. For ski jumpers who practice lower BMI simultaneously with a lower percentage of body fat, the same tendency may be expected. Higher BMI is associated with increasing PhA in more cells, but only up to a BMI of 30 kg/m^2. Interestingly, at BMI > 40 kg/m^2, an inverse relationship with PhA is observed. This has been attributed to increased tissue hydration or a pathological fluid overload [23]. Our data suggest that in the case of phase angle monitoring among ski jumpers, 50 kHz can be more useful than other frequencies, as this PhA value is correlated, for both legs, with VFA and percentage of body fat, with the following tendency: the lower the PhA value, the higher the fat proportion. The described relationship may be useful for a rough assessment of body fat change, which, in the case of jumpers, is crucial. Moreover, our data suggest that phase angle could be potentially useful in monitoring the symmetry of ski jumpers' legs.

4.1. Practical Application

From a practical point of view, at the present time the measurement of PhA, especially PhA monitoring at 50 kHz, is a promising approach to evaluate muscle quality in athletes and the nutritional status and healthiness of body cells, which should be controlled at all stages of the ski jumper's preparation by BIA. We have to agree that there are more precise methods for the evaluation of body composition, such as DXA, but still they are invasive and cannot be repeated frequently, while BIA is non-invasive and fast and provides reliable results, as long as the measurement conditions are always the same and there are no ambient factors that could affect the amount of body water.

4.2. Strengths and Limitations

The main strength of the present work is that it presents a detailed analysis and description of a specific, selected population of high-performing ski jumpers at different time points throughout their training season. The main limitation of our study remains the very small number of participants, though we aimed to focus on a specific group of Olympic ski jumpers. Moreover, there are limited studies reporting changes in DSM-BIA parameters during a training season, which makes comparisons more difficult and lowers the strength of our conclusions.

5. Conclusions

For ski jumpers, the differences in body composition of each compartment are the result of special training, and the segmental MFBIA seems to be a good tool to monitor these changes repeatedly during the season to ensure that lowered body mass is the consequence of a fat mass decrease and low BMI is still healthy and increases the chance for longer jumps and good performance. Therefore, segmental PhA values can help monitor progress and healthiness during the training season in terms of body fat content, visceral fat area, water content, and body symmetry. In addition, we suggest that for ski jumpers, PhA monitoring at 50 kHz can be more useful than at other frequencies. Although further studies are needed to scrutinize how changes, observed during the study, fluctuate over time, the results of the measurements are still informative, at least regarding the information about intact cell membranes. Understanding BIA as a tool that monitors body components, including segmental phase angle, during ski jumpers' training remains an open area for research.

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Institutional Review Board Statement: The study was conducted according to the guidelines featured in the Declaration of Helsinki. The Polish Ski Association and the athletes signed informed consent prior to the study entry, and the study protocol was approved by the Ethical Committee of the Jagiellonian University, Krakow, Poland (No. 122/6120/103/2016).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Restrictions apply to the availability of this data. Data become the property of the Polish Ski Association and are available from the corresponding author with the permission of Polish Ski Association.

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Conflicts of Interest: The authors have no conflict of interest relevant to this article.

Appendix A

Table A1. Fluctuation in the analysed parameters (table).

Changes in Analysed Parameters during the Whole Time of Observation								
	Time Point							
	1	2	3	4	5	6	p	p for Pairwise Comparisons
	Value ± SD	Value ± SD	Value ± SD	Value ± SD	Value ± SD	Value ± SD		
BMI	19.71 ± 0.63	19.63 ± 0.60	19.51 ± 0.63	19.60 ± 0.41	19.45 ± 0.45	19.57 ± 0.73	0.295	
ICW	26.01 ± 1.54	25.43 ± 1.47	25.48 ± 1.54	25.22 ± 1.26	25.37 ± 1.37	25.34 ± 1.43	<0.001	$p_{12} = 0.009$; $p_{13} = 0.013$; $p_{14} = 0.001$; $p_{15} = 0.007$; $p_{16} = 0.005$
ECW	15.00 ± 0.79	14.77 ± 0.86	14.71 ± 0.75	14.73 ± 0.68	14.79 ± 0.72	14.81 ± 0.75	0.022	$p_{12} = 0.027$; $p_{13} = 0.002$; $p_{14} = 0.010$; p for quadratic trend: <0.001
TBW	41.01 ± 2.29	40.20 ± 2.30	40.19 ± 2.27	39.95 ± 1.91	40.16 ± 2.06	40.15 ± 2.13	0.005	$p_{12} = 0.011$; $p_{13} = 0.005$; $p_{14} = 0.002$; $p_{15} = 0.013$; $p_{16} = 0.011$; p for linear trend: 0.022
h2oRA	2.31 ± 0.18	2.29 ± 0.2	2.28 ± 0.2	2.26 ± 0.16	2.31 ± 0.18	2.32 ± 0.18	0.021	$p_{14} = 0.026$; $p_{36} = 0.020$; $p_{45} = 0.005$; $p_{46} = 0.002$; p for quadratic trend: 0.001
h2oLA	2.3 ± 0.19	2.27 ± 0.2	2.24 ± 0.18	2.25 ± 0.15	2.28 ± 0.15	2.28 ± 0.16	0 .103	
h2oTR	18.89 ± 1.05	18.79 ± 1.14	18.64 ± 1.08	18.64 ± 0.87	18.82 ± 0.92	18.86 ± 0.94	0.083	
h2oRL	7.04 ± 0.49	6.93 ± 0.5	6.9 ± 0.45	6.90 ± 0.48	6.92 ± 0.44	6.91 ± 0.49	0.016	$p_{12} = 0.040$; $p_{13} = 0.022$; $p_{14} = 0.002$; $p_{15} = 0.030$; $p_{16} = 0.002$ p for linear trend: 0.007
h2oLL	7.04 ± 0.47	6.94 ± 0.49	6.87 ± 0.45	6.89 ± 0.45	6.90 ± 0.47	6.90 ± 0.48	0.003	$p_{12} = 0.038$; $p_{13} = 0.005$; $p_{14} = 0.001$; $p_{15} = 0.030$; $p_{16} = 0.017$ p for linear trend: 0.032
e_t	0.366 ± 0.005	0.368 ± 0.004	0.367 ± 0.004	0.369 ± 0.005	0.369 ± 0.004	0.369 ± 0.005	<0.001	$p_{12} = 0.017$; $p_{14} = 0.006$; $p_{15} < 0.001$; $p_{16} = 0.001$; $p_{25} = 0.006$; $p_{35} < 0.001$; $p_{36} = 0.032$ p for linear trend: <0.001
e_tRA	0.367 ± 0.005	0.369 ± 0.004	0.369 ± 0.003	0.370 ± 0.004	0.371 ± 0.003	0.371 ± 0.004	<0.001	$p_{12} = 0.019$; $p_{14} = 0.005$; $p_{15} = 0.001$; $p_{16} = 0.005$; $p_{35} = 0.002$; $p_{36} = 0.002$; p for linear trend: <0.001
e_tLA	0.369 ± 0.005	0.371 ± 0.005	0.370 ± 0.004	0.371 ± 0.004	0.372 ± 0.003	0.372 ± 0.005	0.001	$p_{12} = 0.011$; $p_{14} = 0.019$; $p_{15} = 0.008$; $p_{16} = 0.017$; $p_{23} = 0.025$; $p_{34} = 0.010$; $p_{35} = 0.003$; $p_{36} = 0.036$; p for linear trend: 0.014
e_tTR	0.365 ± 0.006	0.368 ± 0.004	0.366 ± 0.004	0.368 ± 0.005	0.369 ± 0.004	0.369 ± 0.005	<0.001	$p_{12} = 0.006$; $p_{14} = 0.003$; $p_{15} = 0.004$; $p_{16} = 0.001$; $p_{23} = 0.022$; $p_{34} = 0.004$; $p_{35} = 0.001$; $p_{36} = 0.002$; p for linear trend: <0.001
e_tRL	0.366 ± 0.006	0.366 ± 0.005	0.366 ± 0.005	0.367 ± 0.006	0.368 ± 0.005	0.368 ± 0.006	0.038	$p_{15} = 0.046$; $p_{25} = 0.046$; $p_{35} = 0.015$; $p_{36} = 0.026$; p for linear trend: 0.026
e_tLL	0.369 ± 0.005	0.369 ± 0.005	0.368 ± 0.005	0.370 ± 0.006	0.370 ± 0.005	0.370 ± 0.006	0 .156	
BCM	37.23 ± 2.18	36.48 ± 2.12	36.59 ± 2.06	36.11 ± 1.93	36.23 ± 1.97	36.03 ± 2.16	<0.001	$p_{12} = 0.019$; $p_{13} = 0.019$; $p_{14} < 0.001$; $p_{15} = 0.002$; $p_{16} = 0.007$; $p_{34} = 0.031$; p for linear trend: 0.005
SMM	31.89 ± 1.98	31.22 ± 1.94	31.32 ± 1.89	30.88 ± 1.74	30.98 ± 1.77	30.81 ± 1.97	<0.001	$p_{12} = 0.019$; $p_{13} = 0.018$; $p_{14} = 0.001$; $p_{15} = 0.002$; $p_{16} = 0.007$; $p_{34} = 0.029$; p for linear trend: 0.004
FFM	56.00 ± 3.16	54.98 ± 3.17	55.11 ± 2.98	54.44 ± 2.79	54.63 ± 2.85	54.37 ± 3.17	<0.001	$p_{12} = 0.025$; $p_{13} = 0.016$; $p_{14} = 0.001$; $p_{15} = 0.002$; $p_{16} = 0.009$; p for linear trend: 0.005
FAT	4.87 ± 1.15	5.67 ± 1.41	5.36 ± 1.34	5.93 ± 1.15	5.76 ± 1.22	6.09 ± 1.30	<0.001	$p_{12} = 0.009$; $p_{14} = 0.001$; $p_{15} = 0.005$; $p_{16} = 0.002$; $p_{34} = 0.025$; $p_{36} = 0.011$ p for linear trend: 0.003
PBF	8.02 ± 2.05	9.37 ± 2.35	8.87 ± 2.23	9.87 ± 1.99	9.52 ± 2.06	10.09 ± 2.21	<0.001	$p_{12} = 0.009$; $p_{14} = 0.001$; $p_{15} = 0.004$; $p_{16} = 0.002$; $p_{34} = 0.012$; $p_{36} = 0.007$; p for linear trend: 0.002
VFA	11.71 ± 5.61	15.10 ± 7.36	14.18 ± 5.76	16.96 ± 7.29	14.9 ± 6.77	16.19 ± 6.79	0.002	$p_{12} = 0.032$; $p_{14} = 0.002$; $p_{16} = 0.013$; $p_{34} = 0.038$; $p_{45} = 0.009$; p for linear trend: 0.024
5PhaRA	2.64 ± 0.24	2.62 ± 0.24	2.66 ± 0.19	2.53 ± 0.27	2.50 ± 0.16	2.55 ± 0.20	0.059	
5PhaLA	2.49 ± 0.27	2.47 ± 0.27	2.53 ± 0.26	2.43 ± 0.28	2.44 ± 0.17	2.46 ± 0.21	0.547	
5PhaTR	3.77 ± 0.34	3.88 ± 0.35	3.98 ± 0.23	3.83 ± 0.26	3.85 ± 0.25	3.79 ± 0.33	0.177	
5PhaRL	2.99 ± 0.24	2.99 ± 0.28	3.21 ± 0.23	3.02 ± 0.32	3.01 ± 0.22	3.23 ± 0.92	0.355	
5PhaLL	2.89 ± 0.24	2.97 ± 0.28	3.16 ± 0.22	2.94 ± 0.32	2.93 ± 0.23	2.93 ± 0.34	0.004	$p_{13} < 0.001$; $p_{23} = 0.024$; $p_{34} = 0.002$; $p_{35} = 0.005$; $p_{36} = 0.017$; p for quadratic trend: 0.011
50PhaRA	6.40 ± 0.50	6.23 ± 0.45	6.29 ± 0.40	6.23 ± 0.44	6.08 ± 0.38	6.15 ± 0.48	<0.001	$p_{12} = 0.012$; $p_{14} = 0.031$; $p_{15} = 0.001$; $p_{16} = 0.004$; $p_{25} = 0.010$; $p_{35} < 0.001$; $p_{36} = 0.037$; $p_{45} = 0.034$; p for linear trend: 0.001

Table A1. *Cont.*

Changes in Analysed Parameters during the Whole Time of Observation

	Time Point						***p***	***p* for Pairwise Comparisons**
	1	**2**	**3**	**4**	**5**	**6**		
	Value ± SD	**Value ± SD**	**Value ± SD**	**Value ± SD**	**Value ± SD**	**Value ± SD**		
50PhaLA	6.11 ± 0.61	5.97 ± 0.56	6.09 ± 0.49	6.03 ± 0.54	5.87 ± 0.44	5.93 ± 0.49	0.014	$p_{15} = 0.013$; $p_{35} = 0.002$; $p_{36} = 0.014$; $p_{45} = 0.037$;
50PhaTR	9.82 ± 1.02	8.98 ± 0.56	10.03 ± 1.06	9.27 ± 0.91	9.28 ± 0.70	9.34 ± 1.22	0.005	$p_{23} < 0.001$; $p_{35} < 0.003$; $p_{34} = 0.005$; $p_{36} = 0.012$; $p_{12} = 0.012$
50PhaRL	7.23 ± 0.53	7.17 ± 0.44	7.25 ± 0.51	7.07 ± 0.55	6.95 ± 0.49	6.97 ± 0.55	<0.001	$p_{15} = 0.008$; $p_{16} = 0.001$; $p_{25} = 0.017$; $p_{26} = 0.018$; $p_{35} = 0.001$; $p_{36} = 0.008$; *p* for linear trend: 0.001
50PhaLL	7.14 ± 0.50	7.01 ± 0.49	7.08 ± 0.55	6.93 ± 0.57	6.88 ± 0.48	6.82 ± 0.59	<0.001	$p_{12}<0.039$; $p_{14} = 0.001$; $p_{15} = 0.001$; $p_{16} = 0.001$; $p_{25} = 0.039$; $p_{26} = 0.019$; $p_{35} = 0.013$; $p_{36} = 0.021$ *p* for linear trend: <0.001
250PhaRA	6.70 ± 0.76	6.00 ± 0.48	6.14 ± 0.45	6.07 ± 0.46	5.75 ± 0.45	5.98 ± 0.73	<0.001	$p_{12} < 0.005$; $p_{13} < 0.026$; $p_{14} = 0.001$; $p_{15}<0.001$; $p_{16} = 0.011$; $p_{35} = 0.018$; $p_{45} = 0.012$ *p* for linear trend: 0.001
250PhaLA	6.55 ± 0.79	5.83 ± 0.55	6.03 ± 0.51	5.88 ± 0.57	5.53 ± 0.49	5.79 ± 0.75	<0.001	$p_{12} < 0.008$; $p_{14} = 0.002$; $p_{15} < 0.001$; $p_{16} = 0.011$; $p_{25} = 0.037$; $p_{25} = 0.012$; $p_{45} = 0.008$ *p* for linear trend: 0.001
250PhaTR	12.43 ± 4.22	6.89 ± 1.68	10.48 ± 2.64	8.23 ± 3.10	8.48 ± 2.80	9.53 ± 3.74	<0.001	$p_{12} < 0.001$; $p_{14} < 0.001$; $p_{15} = 0.006$; $p_{23} = 0.007$; $p_{25} = 0.022$; *p* for quadratic trend: 0.017
250PhaRL	5.21 ± 0.51	4.84 ± 0.46	4.62 ± 0.39	4.82 ± 0.23	4.46 ± 0.25	4.55 ± 0.32	<0.001	$p_{13} = 0.001$; $p_{14} = 0.004$; $p_{15} < 0.001$; $p_{16} < 0.001$; $p_{25} = 0.011$; $p_{26} = 0.020$; $p_{34} = 0.028$; $p_{45} = 0.001$; $p_{46} = 0.015$ *p* for linear trend: <0.001
250PhaLL	5.04 ± 0.53	4.60 ± 0.50	4.39 ± 0.43	4.66 ± 0.32	4.33 ± 0.30	4.30 ± 0.32	<0.001	$p_{13} = 0.002$; $p_{14} = 0.003$; $p_{15} < 0.001$; $p_{16} < 0.001$; $p_{25} = 0.033$; $p_{34} = 0.023$; $p_{45} = 0.007$; $p_{46} = 0.003$ *p* for linear trend: <0.001

Index of abbreviations: Total body water (TBW), intracellular body water (ICW), extracellular body water (ECW), ECW:TBW ratio (e_t), body cell mass (BCM), % body fat (PBF), fat (kgBF), visceral fat area (VFA), skeletal muscle mass (SMM), fat-free mass (FFM), segmental body water (h2o), segmental ECW:TBW ratio (e_t), segmental 5 kHz phase angle (PA) (5 Pha), segmental 50 kHz PA (50 Pha), and 250 kHz PA (250 Pha). Segmental means 5 compartments: right arm (RA), left arm (LA), trunk (TR), right leg (RL), and left leg (LL), respectively.

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Article

Dose-Response Relationships between Training Load Measures and Physical Fitness in Professional Soccer Players

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Abstract: The aim of this cohort study was two-fold: (i) to analyze within-group changes of final velocity in a 30-15 intermittent fitness test (V_{IFT}), final velocity in a Vameval test ($V_{vameval}$), 20-m sprint and countermovement jump (CMJ); (ii) to explore the relationships between V_{IFT} and Vvameval outcomes and their changes with internal and external loads. Twenty-two professional soccer players (mean ± SD; age 27.2 ± 3.4 years, height 174.2 ± 3.6 cm, body mass 69.1 ± 6.4 kg, and body fat 10.4 ± 4.1%, 3.1 ± 1.5 years in the club) participated in this study. External and internal loads were obtained using global positioning system, heart rate and rate of perceived effort (sRPE) after each training session. Players were assessed in CMJ, 20-m sprint, Vameval and 30-15 intermittent fitness test, before and after the observed period. Very large relationships were observed between V_{IFT} and Vameval for pre- ($r = 0.76$), post ($r = 0.80$) and pooled-data ($r = 0.81$). $V_{vameval}$ showed less sensitivity (−22.4%, [−45.0 to 9.4]), ES −0.45 [−1.05 to 0.16]) than V_{IFT}. ΔV_{IFT} had unclear associations with all sRPE, but had moderate correlations with objective internal and external measures, while, $\Delta V_{vameval}$ varied between large and very large relationships with all sRPE, but had unclear associations with all other selected training loads. Objective internal and external loads may be used to track aerobic power related changes from V_{IFT}.

Keywords: football; performance; athletic performance; sports training; internal load; external load

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1. Introduction

In sports context, dose-response relationships are simply referred to the magnitude of a biological response, depending on the exposure to a given training stimulus after a certain time-period [1]. In that sense, it has been suggested that chronic exposures to training loads are associated with more resilient athletes that are capable of sustaining greater acute training loads, without higher injury risks [2,3]. Despite that, the principles of training such as individualization, progression and overload, must be carefully followed for ensuring that athlete's dose-responses are adequate and have the desired effects on them [4]. Considering that in professional soccer teams, coaches typically follow a one-size-fits-all soccer practice, the above-mentioned training principles may not be adequately imposed [5].

The dose-response relationship is highly dependent on different determinants of player's physical fitness levels, as the same stimuli might be perceived higher or lower for one athlete, and not for others. Given that, the response of a given dose is certainly different between athletes, resulting in within-team variations [6]. Usually, training is quantified through different methods, depending on teams' different budgets. For instance, the external loads (imposed stimulus) are commonly quantified via global position systems (GPS) in soccer [7]. The internal loads (response to a given imposed stimulus) can be quantified via objective measures such as heart rate (HR), and biochemical markers [8,9]. On the other hand, internal loads can also be quantified via subjective measures, such as session-rate of perceived exertion (sRPE), and perceived level of exertion for respiratory and leg musculature efforts [10,11], and its associated indices [12]. Both, internal and external load measures have been consistently researched for their meaningful associations, although providing different information for sports scientists and coaches [8,9].

The imposed training loads may be perceived differently between players and produce different adaptations. For those reasons, it is of paramount importance to establish associations between internal (objective and subjective) and external training load measures with the different determinants of player's physical fitness responses. In fact, considering the subjective measures of internal load quantification and its relationships with possible performance changes during intermittent-based field tests, such as the 30-15 intermittent fitness test (30-15IFT), it was previously revealed strong associations exist between sRPE and VIFT measure [13].

Moreover, negative associations between cumulative lower limb perceived load exertions and countermovement jump performance changes has been documented [9]. Considering the objective internal load measures such as HR variables, contradictory evidence has been documented [13,14]. Despite that, strong associations between HR measures (training impulse, TRIMP) and aerobic performance, as well as field tests performance improvements has been revealed [14]. Also, considering the different commonly used TRIMP methods, it was revealed that despite the Bannister's TRIMP method significantly correlated with sRPE, it was not associated to aerobic fitness adaptations [15].

Furthermore, quantifying training and match activity is now facilitated by the use of GPS systems that enables coaches to extract information about weekly distance- and accelerometry-based measures [16,17]. Given that, using these metrics to analyze their dose-relationships with physical fitness of soccer players is a topic of interest. However, there is a lack of studies supporting these associations [8,18,19].

In fact, one of the few studies that analyzed external load dose-response relationships, found large associations between the weekly time spent above maximal aerobic speed (MAS) and adaptations in aerobic fitness [8]. However, unclear correlations were found between different high-intensity running thresholds and MAS [8]. Similarly, a study conducted on eleven professional soccer players, revealed unclear relationships between very high-intensity running, total distance and changes in V_{IFT} [19]. Interestingly, the same study [19], revealed large relationships between accumulated new body load (NBL) and aerobic changes. Also, a similar accelerometry metric (player load), had demonstrated associations with variations in different fitness determinants [18].

As mentioned earlier, there are conflicting evidence surrounding the dose-response relationships between internal loads and physical fitness changes, and there are still a lack of studies analyzing dose-response relationships using different external load measures in adult professional soccer players. For instance, one of the studies that analyzed external loads dose-response relationships used a sample of amateur soccer players [18], while another study used a sample of youth soccer players [8]. Moreover, only one study, to the best of our knowledge, was conducted on professional adult soccer players [19], but only testing the effects on 30-15IFT and not in other determinants of performance as sprinting or vertical jump.

As the training process may be reflected by a highly within- and between-players variation in terms of responses to the imposed loads, it is of interest to understand the relationships between both internal (objective and subjective) loads and external (distance-based and accelerometry-based) loads with possible changes in different levels of fitness parameters. Despite some studies testing the effects of specific load parameters in fitness changes, no study has been included both internal and external load demands, and also analyzed relationships with different fitness tests that are tested for their relationship (e.g., 30-IFT and Vameval). This can be interesting, particularly to identify how tests can be related in their changes, and how load can be associated with that. For those reasons, the purposes of the present study were: (i) to analyze the within-group changes of V_{IFT}, Vameval, 20-m sprint and CMJ; and (ii) to explore the relationships between V_{IFT} and Vameval tests as well as their changes (i.e., ΔV_{IFT} and ΔVameval) with accumulated training load indices. We hypothesize that beneficial changes will occur after the cohort in the fitness performance, while sRPE will be the measure with a better dose-response relationship since represents both dimensions of load (internal and external).

2. Materials and Methods

2.1. Experimental Approach to the Problem

An observational analytic cohort design was implemented in this study. First fitness assessments of the players were conducted one week prior to the beginning of 2018/2019 pre-season, between 24th June and 1st July and second test was performed immediately after preparation phase between 19 and 26 August. All the materials were the same and the environmental conditions were almost similar during fitness assessments (indoor track, ambient temperature and relative humidity, ranging between 22 and 26 °C and 45 and 52% respectively). For each assessment, temperature and relative humidity were collected two times, and the mean value was registered. However ambient temperature and relative humidity varied greatly over the training data collection phase, ranging between 25 and 32 °C and 55 and 76%, respectively). For each training, temperature and relative humidity were collected two times, and the mean value was registered. Training intervention was implemented from 2 July to 18 August. Training time in the morning and afternoon were between 10:00–12:00 and 17:00–20:00, respectively. During training intervention phase, which lasted 47 days, the external and internal loads were obtained using global positioning and HR monitoring systems, respectively. The sRPE was also collected after each training session. All players involved in the study were professional and were familiar with the GPS system and sRPE methods.

2.2. Participants

Twenty-two professional soccer players (mean ± SD; age 27.2 ± 3.4 years, height 174.2 ± 3.6 cm, body mass 69.1 ± 6.4 kg, and body fat 10.4 ± 4.1%, 3.1 ± 1.5 years in the club), all members of a professional club competing in the 2018/2019 season of Qatar Stars League (Qatar First Division), participated in this study. Sample was chosen in convenience, as well as the sample size. The inclusion criteria were (i) participation in all assessments and training sessions, (ii) absence of injuries, physical constrains, or illnesses exhibited during sessions occurred in the period and two weeks prior to the data collections; and (iii) absence of signals of fatigue on assessment days. Players were daily monitored for the training load parameters; thus, the follow-up was ensured by daily collecting information from the players. None of the included players had an illness or chronic clinical conditions, all of them were professional and fully dedicated to the team. All players were informed of the experimental procedures and related risks and gave informed consent before commencing the study. The study protocol was approved by the Scientific Committee of School of Sport and Leisure (Melgaço, Portugal) with the code number CTC-ESDL-CE00118. The study followed the ethical standards of the Declaration of Helsinki.

2.3. Fitness Assessment

Assessments included anthropometric assessments conducted on the first day. On the following day, the players were evaluated in countermovement jump, 20-m sprinting test, followed by Vameval test. The 30-15IFT was performed three days after. Training intervention included 47 days (morning or evening sessions) including five friendly matches, six days off and six recovery sessions. To avoid bias in data collection, the players were familiarized with the testing protocols and the instruments of load monitoring were individualized. Additionally, the observers during fitness assessment were blind to the study protocol to minimize the risk of bias. Aiming to minimize the effects of confounders variables, before assessment periods the players had rest for 48-h and had similar patterns of dietary and supplementation and sleep routines.

2.3.1. The 30–15 Intermittent Fitness Test

The 30-15IFT consisted of 30 s of running interspersed by 15 s of walking for recovery. Players were required to run between two lines positioned 40-m apart and return. The test started at 8 km·h^{-1} followed by 0.5 k/h increments every 30 s. At every 30 s, a beep sounded to signal the start of the 15 s of recovery. During the 15 s of recovery the athletes had to stay within the 3-m limits outlined between each line of cones and wait for a new beep to start the next 30 s run. Players were told to complete as many stages as possible, and the test was ended when the players could not maintain the required running speed or could not reach the 3-m zone before the beep on three consecutive times. The test final outcomes were HR_{max} (bpm) and the V_{IFT} (km·h^{-1}) score, which was determined by the final velocity reached in the last running lap [20].

2.3.2. Vameval Test

The Vameval is a cardiorespiratory fitness test that consists in a progressive incremental running until exhaustion. The athletes were required to run in a circular setup with 31.85-m radius with cones placed every 20-m. The test started at 8 km·h^{-1} followed by 0.5 km·h^{-1} increments every minute. After the start, the athletes had to maintain the correct running pace as indicated by the audio recording, so that they were in line with each of the placed cones when the beep sounded. If athletes were 1-m behind a cone when a beep sounded, they were given one fault. At the second warning the test stopped. The test final outcomes were the total time in minutes and seconds to complete the test, and MAS (km·h^{-1}). To calculate MAS, firstly an VO_2max estimate was calculated (3.5 × velocity of the last lap). Then MAS was calculated as the estimated VO_2max divided by 3.5 [21]. The $V_{vameval}$ (km·h^{-1}) was determined by the final velocity reached in the last running lap.

2.3.3. The Sprinting Tests

To measure sprint performance, the 20-m sprint test, including the 5-m, 10-m and 15-m split times, was conducted. To assess sprinting times and split times, two pairs of timing gates (Smart Speed, Fusion Sport, Queensland, Australia) were used. Before the test started, a standardized sprint specific warm up was completed. A 20-m straight line was marked by a cone at the beginning (0-m) and at the end (20-m) of the space outlined for the test. The athletes started from a static position with one foot in front of the other, with the front foot behind the starting line. The athletes were instructed to start the test after a "3,2,1, go" verbal signal was made. After the signal was made, the athletes had to maximally accelerate and reach the ending line as fast as possible. Each athlete completed three 20-m sprint trials interspersed with 3 min of rest. The total time in seconds to complete each 20-m sprint was recorded.

2.3.4. Countermovement Jump

For the CMJ free arms was used allowing them to do arm swings [22]. The CMJ tests were performed on a force plate (Force Decks v1.2.6109, Vald Performance, Albion, Australia). Players were told to start from a standing position and were allowed to do a knee flexion at their comfortable depth before the jump take off. During the flight phase, the athletes had to maintain hip, knee and ankle extension and jump as high as possible. Also, players were instructed to try to land with the tip toes in the same place they took off. Three maximal trials were made and the jump heights (cm) were registered for further analysis.

2.4. Training Load Monitoring

2.4.1. Internal Load

For the internal load objective measures, HR data were recorded using Bluetooth HR sensors (Polar H10, Polar-Electro, Kempele, Finland, recorded in 5-s intervals) synchronized to a portable 10-Hz VX Sport 350 GPS units (VX Sport, Wellington, New Zealand). HR measures including HR_{avg}, Edwards'TRIMP, and Bannister'TRIMP were analyzed following each session. The HR_{max} of each individual was extracted from maximal field-based test 30–15 Intermittent Fitness Test. The test seems to be valid for extracting the HR_{max} [23]. For internal load subjective measures, approximately 30 min after each training session the Foster's 10-point scale of the rate of perceived exertion (RPE) was applied [24]. The athletes were asked about how hard the training session was, and they had to score from 1 to 10, were 1 corresponds to "very light activity" and 10 corresponds to "maximal exertion". The athletes scored the RPE individually without the presence of other athletes. Moreover, the athletes rated their perceived level of exertion separately for respiratory (sRPE[R]) and leg musculature (sRPE[M]) efforts, as previously detailed [10,11]. Also, they were allowed to score the RPE in decimals (e.g., 1.5). The subjective internal load was then obtained by multiplying each athlete's RPE score by the total duration of the soccer training session in minutes to determine the session-RPE (sRPE), expressed in arbitrary units (A.U.) [25].

2.4.2. External Load

External load measures were recorded during all sessions using portable 10-Hz VX Sport GPS units (VX Sport), which was previously considered a valid and reliable GPS device [26]. The external load measures included in this study were total distance (TD), high-speed running (HSR, distance >19.8 $km \cdot h^{-1}$), sprint distance (SD, $\geq$25.2 $km \cdot h^{-1}$) and mechanical work (MW) that summed the numbers of acceleration and deceleration efforts above and below 2.2 $m \cdot s^2$ thresholds.

2.5. Statistical Analysis

The results are presented in text, table and figures as Mean ± SD or 90% confidence intervals (CI) where specified. Normality of the sample and homogeneity was preliminary tested and confirmed in the Kolmogorov-Smirnov and Leven's test, respectively ($p > 0.05$). Within-group changes in changes of V_{IFT}, $V_{vameval}$, 20-m sprint and CMJ were expressed as percentage changes and standardized differences as Cohen's d (effect size, ES, 90% CI) [27]. No missing data occur in within group analysis. Between-group differences in changes of V_{IFT}, $V_{vameval}$ tests was also expressed based on Cohen's d (effect size, ES, 90% CI) [27]. Magnitude-based inference approach was used for interpreting data [28]. Threshold values for ES were <0.2: trivial; 0.20–0.59: small; 0.60–1.19: moderate; >1.2: large [28]. Probabilities were calculated to indicate whether the true change was lower than, similar to, or higher than the smallest worthwhile change (SWC) [29]. The scale of probabilities was as follows: 25–75%: possible; 75–95%: likely; 95–99%: very likely; >99%: almost certain [29]. The probabilities were used to make a qualitative probabilistic mechanistic inference about the true effect: if the probabilities of the effect being substantially positive and negative were both >5%, the effect was reported as unclear; the effect was otherwise clear and reported as the magnitude of the observed value. Person correlation coefficient was also used to measure the association between V_{IFT} and $V_{Vameval}$ outcomes as well as their changes (i.e., ΔV_{IFT} and $\Delta V_{vameval}$) with accumulated training load indices. The correlation coefficient (r, 90% confidence limits, CL) was ranked as trivial (<0.1), small (0.1–0.29), moderate (0.3–0.49), large (0.5–0.69), very large (0.7–0.89) and nearly perfect (0.9–0.99) [28]. The statistical procedures were conducted in propre-designed Excel spreadsheets [30].

3. Results

The results showed almost certainly moderate changes in VIFT, $V_{Vameval}$, and CMJ following training intervention (Table 1). An almost certain large improvement was also observed in 20-m sprint in players (Table 1).

Table 1. Within-group changes in physical fitness tests.

Group	Pre	Post	% Difference (90% CL)	Standardized Difference (90% CL)	% Greater/Similar/Lower (90% CL)
				Rating	Probability
V_{IFT} (km.h^{-1})	17.8 (1.4)	19.0 (1.4)	6.8 (5.4; 8.2)	0.8 (0.64; 0.96) Moderate	100/0/0 Almost certain
$V_{Vameval}$ (km.h^{-1})	16.5 (1.5)	17.5 (1.5)	5.7 (4.2; 7.2)	0.6 (0.4; 0.7) Moderate	100/0/0 Almost certain
20-m sprint (s)	3.0 (0.0)	2.9 (0.0)	−2.8 (−3.9; −1.6)	−1.1 (−0.6; −0.6) Large	0/0/100 Almost certain
CMJ (cm)	46.7 (3.3)	49.7 (3.9)	5.5 (3.9; 7.2)	0.7 (0.5; 0.9) Moderate	100/0/0 Almost certain

V_{IFT}: The maximal speed reached at the end of 30–15 Intermittent Fitness Test, Vameval: The maximal speed reached at the end of the Vameval test, CMJ: Countermovement jump, CL: Confidence limits.

Very large relationships were observed between changes V_{IFT} and $V_{Vameval}$ for pre-, post- and pooled-data (Figure 1).

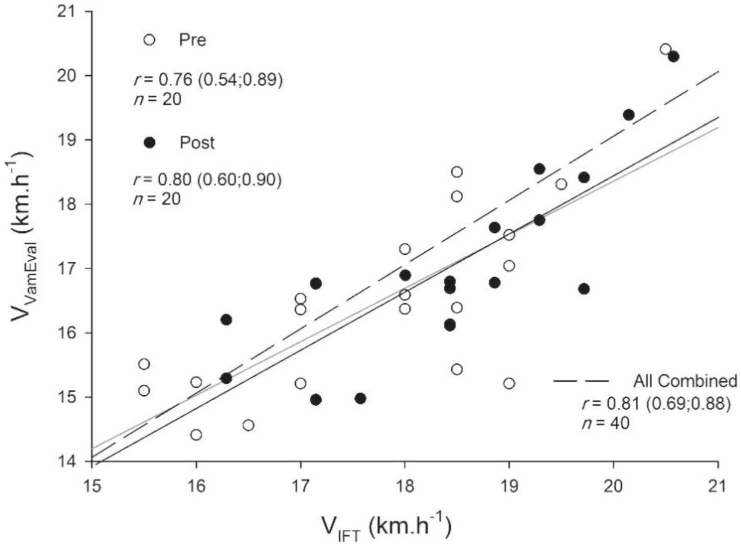

Figure 1. Relationships between V_{IFT} and $V_{Vameval}$ tests for pre−, post− and pooled-data.

$V_{Vameval}$ showed likely smaller changes (i.e., sensitivity) (−22.4%, [−45.0 to 9.4]), ES −0.45 [−1.05 to 0.16]) compared to VIFT following training intervention (Figure 2).

When analyzing dose-response relationships between ΔV_{IFT} and $\Delta V_{Vameval}$ and training load indices, ΔV_{IFT} revealed trivial unclear associations with sRPE and its differential versions (i.e., respiratory and muscular sRPE) but showed moderate correlations with all other selected measures (Figure 3). In contrast, $V_{Vameval}$ showed large to very large relationships with sRPE and its differential versions but revealed unclear trivial-to-small associations with all other selected training load measures (Figure 3).

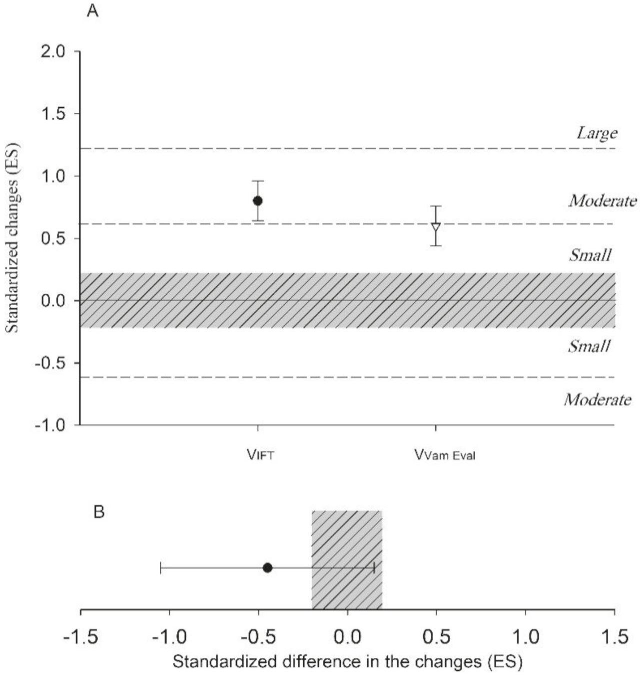

Figure 2. Relationships and sensitivities of V_{IFT} and $V_{Vameval}$ to training. (**A**) Within-group changes and (**B**) between-group changes in V_{IFT} and $V_{Vameval}$.

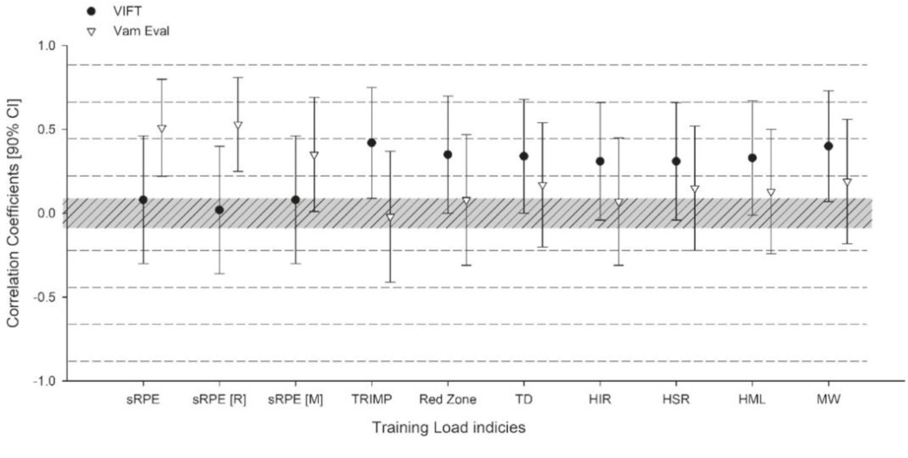

Figure 3. Dose-response relationships between V_{IFT} and $V_{Vameval.}$ with selected training load measures. Notes: sRPE; session-ratings of perceived exertion, sRPE (R); respiratory session-ratings of perceived exertion, sRPE (M); muscular session-ratings of perceived exertion, TRIMP; training impulse, Red Zone; time spent >85% of HR_{max}, TD; total distance, HIR; high-intensity running, HSR; high-speed running, HML; high-metabolic load, MW; mechanical work (number of accelerations and decelerations >3 $m{\cdot}s^2$).

4. Discussion

The aims of the present study were to analyze the within-group changes of V_{IFT}, $V_{Vameval}$, 20-m sprint and CMJ after training intervention, and to explore the relationships between V_{IFT} and $V_{Vameval}$ tests, and their changes, with accumulated training load indices. The main findings revealed that although there were very large relationships between changes of V_{IFT} and $V_{Vameval}$ measures, the V_{IFT} was the most sensitive to track small changes. While V_{IFT} showed unclear associations with both sRPE measures, it showed moderate relationships with all external and objective internal loads. On the other hand, $V_{Vameval}$ showed large-to-very large associations with both sRPE measures, but not with any external and objective internal loads.

Within-group changes (pre-post) of V_{IFT}, $V_{Vameval}$, and CMJ showed almost certain moderate improvements, and almost certainly large improvements for the 20-m sprint test were revealed after training intervention. This finding may be related to the fact that the analyzed training intervention period was from the beginning until the end of the preparation phase where greater training volumes usually ensured. In fact, some studies suggest that the overall physical fitness parameters tend to increase after the pre-season period [31,32]. However, some caution should be given to this, as some controversies has been documented regarding this topic. For instance, in contrast with our findings, no significant changes for sprint performance were found after the pre-season period [33]. Indeed, other study conducted on 19 professional Spanish soccer players revealed no significant differences for CMJ performance from the beginning of pre-season to 4-weeks after the beginning of in-season [9]. However, that study revealed significant sprint time improvements, similar to our results [9]. These setbacks may be related to the different methodologies used, considering the type of population, observational periods and the testing protocols used.

The V_{IFT} and $V_{Vameval}$ measures showed very large associations between them, with V_{IFT} being the most sensitive measure. Previous research has documented similar associations between the 30-15IFT test and the Yo-Yo Intermittent Recovery test (YYIRT), with similar sensitivity [34]. The greater sensitivity of V_{IFT} to track small changes may be due to the fact that the 30-15IFT is more dependent to aerobic power, while the Vameval test is more related to aerobic endurance. Also, the Vameval test is done in a circular fashion, while the 30-15IFT characteristics and the test final outcome (V_{IFT}) are more soccer specific [35]. For those reasons, using the 30-15IFT and V_{IFT}, seem to be more useful for tracking even the smallest but worthwhile changes in performance than the Vameval test and its related $V_{Vameval}$.

Surprisingly, the dose-response relationships between V_{IFT} and $V_{Vameval}$ changes and internal and external loads revealed to be somewhat complex. Although meaningful correlations between 30-15IFT and Vameval tests, it seems that they might have different dose-response relationships with training loads. In the present study, only $V_{Vameval}$ presented strong associations with all sRPE measures, while V_{IFT} showed no relationships with any of the internal subjective measures. In contrast, a study conducted on twelve professional soccer players, revealed that soccer practice volume and the accumulated subjective measures of training loads had strong associations with increases in higher velocities completed during the 30-15IFT [13]. Interestingly, it was previously revealed no relationships between sRPE, sRPE [R] and sRPE [M] with changes in aerobic fitness [9].

As mentioned before, contradictory evidence has been documented regarding the relationships between objective internal load measures and changes in field tests performances [13,14]. In fact, no relationships were found between HR measures and changes in 30-15IFT test performance, which is in contrast with our findings [13]. Conversely, other study conducted on eighteen professional soccer players, revealed large-to-very large associations between TRIMP and the yo-yo intermittent recovery 1 test performance [14]. Similarly to our results, Rabbani et al. [19] revealed that both Bannister's and Edward's TRIMP showed large relationships with changes at the final speed reached on 30-15IFT. However, methodological differences between the above-mentioned studies must be highlighted, as some used field tests and others used laboratory tests.

Moreover, our study demonstrated moderate relationships between V_{IFT} and all external loads, while $V_{Vameval}$ did not show any associations. Similar to our results, a recent study conducted on 11 professional soccer players, revealed large dose-response relationships between NBL and changes in high-intensity intermittent running capacity assessed via 30-15IFT and its related V_{IFT} [19]. Although that same study [19], revealed no associations between TD and high-intensity running (HIR), and very high-intensity running (VHIR) metrics with changes in V_{IFT}, which is in contrast with our results. Also, other study [8] revealed a lack of relationships between the overall external metrics and changes in aerobic fitness performance.

These differences might be related to the fact that the two above-mentioned studies [8,19], analyzed the dose-relationships during in-season period, while in the present study our observations were from pre-season period to only 4 weeks of the beginning of the season. However, it should be noted that only moderate relationships were found between V_{IFT} and all external loads. Also, MW was the metric the strongest associations compared to all other external loads, reinforcing the statement regarding the usefulness of HR-based and MW-based metrics for tracking changes in high-intensity intermittent running performance in professional soccer players [19].

The present study had its limitations. One of the main limitations is related to the small sample size, which makes any generalizations based on the results difficult. However, considering that the sample is from professional players, is almost impossible to have larger samples. Other study limitation can be related with variation in environmental conditions occurred during the period of intervention. Another limitation is the fact that only a brief period during the initial phase of the season was analyzed. These limitations may influence the results, since no dose-response relationship was analyzed in the later stage of the season, and possibly different results can be found. Future studies should analyze a more longitudinal period to make better generalizations.

Considering the lack of studies and the conflicting evidence surrounding the dose-relationships between internal and external loads with physical fitness changes, the present study revealed some interesting findings. As practical implications, this study suggests that despite field tests may show relationships between them, it does not mean that they present similar dose-response relationships with internal and external training loads. Therefore, different dimensions of load may produce different impact in fitness of players. However, conclusions should be interpreted carefully, since the limitations and small sample may affect the generalizability of the findings.

5. Conclusions

The present study revealed significant improvements of V_{IFT}, $V_{Vameval}$, CMJ and 20-m sprint tests after the training intervention. Despite very large relationships between V_{IFT} and $V_{Vameval}$, the V_{IFT} showed great sensitivity to track small changes. Also, these two measures revealed dose-response relationships with different dimensions of training load quantification. Objective internal and external load measures seem to be better suited for tracking V_{IFT} changes. While subjective internal loads are better suited to track changes in aerobic endurance from $V_{Vameval}$, at least during the initial phases of the season. For those reasons, coaches and practitioners should use objective internal and external loads to track aerobic power related changes from V_{IFT}.

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Article

Can Rules in Technical-Tactical Decisions Influence on Physical and Mental Load during Soccer Training? A Pilot Study

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Abstract: This study aimed to analyze the effects of rules limitations in pass decisions during soccer tasks on physical and mental load reported by players. Participants were 40 semiprofessional Spanish soccer players ($M_{\text{age}} = 22.40$, $SD = 2.25$) from two male teams. Two training sessions with four tasks (same tasks with different score system: two maintaining ball possession games with goalkeepers, and two maintaining ball possession games) in counterbalanced order between teams were completed. To achieve a goal during limitation tasks, a minimum number of players had to participate in the passes before the goal. Internal (perceived effort and heart rate) and external physical load (distances), mental load (validated adaptation of the NASA-TXL) and fatigue (VASfatigue) were quantified. Paired t-test and magnitude-based inference were conducted. The results showed significantly higher mean speeds ($p < 0.01$), effort perception ($p < 0.001$), and mental fatigue (very likely positive) during possession games with restrictions. Additionally, performance satisfaction obtained significantly higher values with goalkeepers and pass restrictions (very likely positive). External physical load showed no significant differences between situations. The influence of mental fatigue on internal load and the complexity of the tasks could explain these results. Coaches can use this information to manipulate the training load in ecological conditions.

Keywords: monitoring; soccer constraints; small-sided games; training interventions; training load

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1. Introduction

Specific soccer strategies such as the number of players involved, the scoring system, or the size and orientation of the pitch could vary according to the coach's objectives during training tasks [1]. Although these changes have usually been designed for technical-tactical objectives, this also allows the intentional manipulation of the training load by coaches in ecological conditions [2]. Thus, knowledge about the effects of these soccer strategies on training load can optimize the training process [3–5]. One frequently used strategy is to include constraints in pass decisions; however, no study has assessed the effect of rules in pass decisions on physical and mental load during soccer tasks. This study proposed to examine the effects of this strategy on load during soccer training tasks.

Within the current soccer training approach, physiological, psychological, and technical-tactical elements are interrelated [6] to obtain greater specific adaptations in ecological conditions [7]. In this approach, coaches use constraints to enhance their training objectives, i.e., the maintaining ball possession games (MBPG), where teams have to achieve a certain number of consecutive passes, producing different player responses in comparison with the same tasks with goalkeepers and regular goals (MBPG-G) [8]. This is an example of how coaches could manipulate the load through the use of task constraints [9,10], such as an unbalance in the number of players for each team, specific rules in games and tasks, or modifying the field dimensions. These coaches' modifications can differentiate task characteristics, demands, and training goals [9]. Therefore, to control the load caused by these types of tasks, it is necessary to know the specific influence of each constraint on mental and physical load [5]. This information allows a correct distribution and application of the training load [11,12].

It has been shown that larger pitch size increases the physical load of the soccer tasks in terms of total distance and heart rate [3,13,14]. Additionally, the presence of jokers decreases the physical load with higher values of walking time [15,16], whereas the presence of goalkeepers increases the distance covered during tasks [17]. However, the condition in which each player can perform a maximum number of touches on the ball decreases the walking time and distance compared to normal touch conditions [15,18]. On the contrary, to our knowledge, few studies [10,19–21] have analyzed the influence of these soccer-specific strategies on mental load and fatigue, although, it is demonstrated that mental fatigue decreases specific soccer performance during small-sided Games. Specifically, mental fatigue increases the number of soccer technical errors [22], impairs the spatial distribution (distances between players) [23], and decreases the physical performance and accuracy of technical-tactical decisions [4,24,25]. In this regard, it has been shown that awarding an extra point (at the beginning) or a double extra point (in the final minutes) when the points were obtained in certain time intervals produces higher levels of mental load than the habitual scores [10]. Additionally, the MBPG-G score system showed higher values in the mental load than the MBPG [19]. Furthermore, coaches' active participation through the use of general encouragement increases mental fatigue compared to tasks where coaches adopt a passive attitude [20]. In addition, the time constrains to achieve the goal modifying the score of training matches and tasks duration also increases mental fatigue [21].

However, to our knowledge no previous studies have analyzed the influence of added rules in pass decisions (e.g., all players must touch the ball to score a valid goal) on physical and mental load, although this strategy is frequently used during soccer tasks. First, we hypothesize (1) that the restrictions in pass decisions will increase the internal and external physical load of the soccer tasks. To justify this hypothesis, we highlight that previous studies that used constraints like the limitation of ball touches or unbalance have observed an increase in one vs. one duels, the distance covered, and Rated Perceived Exertion Scale (RPE) values [15,26,27]. Additionally, in our opinion, to achieve the objectives during pass limitations tasks, players must optimize the space and increase the speed of the ball, which can increase the physical demands [27]. Secondly, we hypothesize (2) that the mental load and mental fatigue of the soccer tasks will increase with the use of the constraint in pass decisions. This assumption is based on previous studies reporting increases in the attention level [5] and cognitive demands in highly-complex environments [10] or decreases in the motivation levels [28] due to the frustration caused by worse performance. Moreover, the increases in mental fatigue (2) could have negative effects on physical performance (1) [29,30].

We consider that the present study could contribute information about how restrictions in pass decisions may affect the training load. This information can increase the control of the load changes produced by this frequently used constraint, so it can be important for coaches and practitioners. This study aimed to analyze the effects of rules in pass decisions on the physical and mental load and fatigue of soccer training tasks.

2. Materials and Methods

2.1. Participants

Participants were 40 semi-professional soccer players from two Spanish male teams (M_{age} = 22.90, SD = 5.60) belonging to the Third Spanish League (n = 20) and the u-18 First Spanish League (n = 20). All of them participated voluntarily in the study. The two teams performed four training sessions per week (ranging between 90 to 100 min), and all players had a minimum soccer experience of 14 years. Respect to the inclusion criteria of the players, we consulted previous experts [24,25]. The criteria for players' inclusion were:

(1) players who regularly attended training sessions, and (2) players optimally accustomed to demanding training sessions, without recent injuries. According to these criteria, eight players (three players belonging to the senior team and five players belonging to the u-18 team) were excluded.

2.2. Instruments

2.2.1. Polar Team Pro System (Polar Electro, Finland)

To analyze mean and peak heart rate, mean and peak speed, distance/minute, and the number of sprints (accelerations over 2.8 m/s^2), the Polar Team Pro, a global position system (GPS) was used. This technology is based on a signal concentration system of different Polar brand sensors, designed for the control and monitoring of physical activity in collective sports like soccer or basketball. This technology has been validated [31,32] and used in previous studies that registered the physical load of soccer tasks [10,19] and is currently one of the most used instruments for the quantification of the physical load in this context [33].

2.2.2. Rate of Perceived Exertion

The Rated Perceived Exertion Scale (RPE) was used to quantify the perception of effort by soccer players. This instrument has been used to control the internal physical load, through the registration of the player's exhaustion level after a physical or sports activity. The RPE includes values ranging from 0 (*not at all tired*) to 10 (*maximum exhaustion*), and its use and accuracy in soccer tasks has been proved [34].

2.2.3. NASA-Task Load Index

To analyze the mental load, an adaptation of the NASA-Task Load Index (NASA-TLX) was used. The original NASA- TXL is one of the most used scales in organizational psychology. Specifically, this adaptation asked about specific soccer-related mental and physical effort, time pressure, performance satisfaction, general effort, unsafety, and interaction. This instrument includes values from 0 (*no load*) to 10 (*maximum load*) for each item described. The validity of this instrument in soccer has been demonstrated in previous studies [10,19] and it was validated [35,36]. The internal consistency (obtained by the mean value of these two times) of this scale was acceptable (Cronbach's alpha = 0.75) with adequate temporal stability (test–retest r = 0.90).

2.2.4. Visual Analog Scale (VASfatigue)

The Visual Analogue Scale 100 (VAS100) was used to quantify the mental fatigue perception of the players [37]. Originally, this procedure established a scale that includes values from 0 (*no fatigue perceived*) to 100 (*maximum fatigue perceived*) and players indicated their general fatigue perception. Participants were instructed to "Please mark the point in the line that represents your current state of mental fatigue." The accuracy of this scale has been proven in soccer samples for the purpose described herein [38].

2.3. Study Design and Procedures

All research procedures were conducted in accordance with the Declaration of Helsinki (World Medical Association, 2013) and had the approval of Ethics Committee for Research with Human Beings. (approval number: 93/2020). All participants were informed about the objective of the study and signed informed consent.

Two training sessions (A and B) with four tasks were completed by each team. This intervention was carried out at the mid-season phase (from January to March in the Spanish national competitions). The first experimental session was developed three days after the last match (on Wednesday), whereas the next match was played three days after the first experimental session had finished. The second experimental session was performed exactly one week after (also on Wednesday) the first session was performed, with the same pre- and post-match rest days, as explained. These training sessions included the same type of task with a modification in the score system constraint: Tasks 1 and 2 were MBPG, whereas Tasks 3 and 4 were MBPG-G. A restriction in pass decisions was included in one of each type of task per session (one MBGP and MBPG-G with pass limitations and one MBPG and MBPG-G without pass limitations per session). The manipulation of the limitation in pass decision was implemented by the next condition: a minimum number of players (at least three jokers, in this case) had to participate in the passes before achieving the goal (goal was not valid if this condition was not met). Additionally, to control the residual effects, the tasks were presented in counterbalanced order (see Table 1) between the teams (Team 1: Session A–B; Team 2: B–A). The inter-task rest time was two minutes between T1–T2, and T2–T3, and four minutes between T3–T4, and T4–T5. The inter-task time was used by the players to complete the VAS-100, the adaptation of the NASA-TXL, and RPE. The sample had previously experience with these instruments, as they completed an initial measure, which was not taken into account for the investigation, and this ensured that the scales were understood.

Table 1. Design of the investigation. Task description and order.

Tasks	Description	Order
T1	Possession. 6 + 2 vs. 6 + 2. Field 40 × 20 m. Jokers located in lateral areas of the pitch. Jokers must not pass the ball to each other. Each 5-consecutive passes = 1 goal. 10 min long. Jokers switched every 2.5 min.	The first task in Session A, and the second task in Session B
T2	Possession. 6 + 2 vs. 6 + 2. Field 40 × 40 m. Jokers located in lateral areas of the pitch. Jokers must not pass the ball to each other. Each 5-consecutive passes = 1 goal that was only valid if at least 3 jokers participated. 10 min long. Jokers switched every 2.5 min.	The second task in Session A, and the first task in Session B
T3	Match 6 + 2 vs. 6 + 2. Field 40 × 40 m. Jokers located in lateral areas of the pitch. Match with Goalkeeper. Normal goal. 10 min long. Jokers switched every 2.5 min.	The third task in Session A, and the fourth task in Session B
T4	Match 6 + 2 vs. 6 + 2. Field 40 × 40 m. Jokers located in lateral areas of the pitch. Match with Goalkeeper. Normal goal, but only valid if at least 3 jokers participated. 10 min long. Jokers switched every 2.5 min.	The fourth task in Session A, and the third task in Session B

Note: T1 = Task 1, T2 = Task 2, T3 = Task 3, T4 = Task 4.

2.4. Data Analysis

The statistical program SPSS 25.0 (2017) and Hopkins' (2017) specific pre-post crossover spreadsheet were used to analyze the data obtained [39]. Data were expressed as mean and standard deviation values for all variables described. A paired t-Test was performed for each variable and pair of tasks (e.g., mental load in Task 1 of Session A and Task 2 of Session B compared with mental load in Task 2 of Session A and Task 1 of Session B). Significant levels were set at 0.1%, 1%, and 5%. Additionally, the magnitude of change in terms of effect sizes (ES) [40], was calculated with the spreadsheet named [37]. The ES were classified as: trivial (<0.2), small (0.2–0.6), moderate (0.6–1.2), large (1.2–2.0) and very large (>2.0) [41]. Magnitude-based inferences (MBI), using the confidence intervals, were used to determine the possible benefit, like positive or negative changes, of the mental and physical load and fatigue between tasks. The smallest worthwhile change (SWC) to assess the change for variables between tasks was set at an ES of 0.2 [41]. Moreover, a qualitative analysis of the changes was performed: 0.5% to 5%, very unlikely; 5% to 25%, unlikely; 25% to 75%, possibly; 75% to 95%, likely; 95% to 99.5%, very likely; and > 99.5%, most likely [42]. The use of these two types of statistical analysis (*p*-values and MBI) is based on Holgado et al.'s affirmation according to previously reported data about the statistical negative effects of mental fatigue on physical performance or the fatigue that could have been caused by statistical errors [43].

3. Results

3.1. Internal Physical Load

The comparison between internal physical load values is shown in Table 2. Significant differences were found in peak heart rate and RPE during MBPG between the two conditions, with higher values in MBPG tasks with the use of pass constraint. For internal physical load values, no significant differences were found for MBPG-G between normal and pass restriction conditions. These results agree with the results shown by the MBI between these two conditions.

Table 2. Internal physical load results between pairs of tasks.

		T1–T2		**T3–T4**	
Variables		**NOPR**	**PR**	**NOPR**	**PR**
Mean Heart Rate	*M SD*	156.30 ± 12.43	158.13 ± 13.40	157.75 ± 12.74	158.33 ± 13.91
	t(*p*)	−1.45(0.16)		−0.30(0.76)	
	ES	0.14		0.04	
	%Change	1.17		0.32	
	%+/trivial/-QI	91/0/9		60/0/40	
		Unclear		Unclear	
Peak Heart Rate	*M SD*	175.63 ± 11.09	178.70 ± 11.27	179.25 ± 10.57	181.48 ± 15.62
	t(*p*)	−3.16(**)		−1.54(0.13)	
	ES	0.27		0.20	
	%Change	1.75		1.31	
	%+/trivial/-	100/0/0		93/0/7	
	QI	Most Likely +ive		Unclear	
RPE	*M SD*	5.95 ± 1.52	6.43 ± 1.17	6.89 ± 1.21	7.18 ± 1.15
	t(*p*)	−4.69(***)		−1.09(0.28)	
	ES	0.33		0.15	
	%Change	8.07		3.34	
	%+/trivial/-	100/0/0		85/0/15	
	QI	Most Likely +ive		Unclear	

Note. T1 = Task 1, T2 = Task 2, T3 = Task 3, T4 = Task 4. NOPR = no pass restriction, PR = pass restriction. ES = effect size, QI = qualitative inference, +ive = positive. *** $p < 0.001$, ** $p < 0.01$.

3.2. External Physical Load

Table 3 presents the results of external physical load. Distance/minute and mean speed presented significant changes in the MBPG score system. In this case, distance/minute showed higher values without pass limitations, whereas the mean speed was higher in MBPG with pass limitations. No significant differences in the MBPG-G score system was observed in these variables between the two conditions. The results obtained by the MBI analysis supported the findings with unclear changes in peak speed and number of sprints for MBPG and all variables during the MBPG-G.

Table 3. External physical load results between pairs of tasks.

		T1–T2		**T3–T4**	
Variables		**NOPR**	**PR**	**NOPR**	**PR**
Distance/Minute	*M SD*	104.10 ± 17.13	96.58 ± 17.06	94.05 ± 19.11	91.10 ± 17.34
	t(*p*)	3.87(***)		0.97(0.34)	
	ES	−0.44		−0.12	
	%Change	−7.22		−2.83	
	%+/trivial/-	0/0/100		23/0/77	
	QI	Most Likely–ive		Unclear	
Peak Speed	*M SD*	22.04 ± 2.04	21.93 ± 2.69	22.65 ± 2.56	23.62 ± 2.73
	t(*p*)	0.29(0.77)		−1.46(0.15)	
	ES	−0.08		0.35	
	%Change	4.04		4.28	
	%+/trivial/-	31/0/69		92/0/8	
	QI	Unclear		Unclear	
Mean Speed	*M SD*	5.95 ± 1.52	6.43 ± 1.17	5.90 ± 1.17	5.72 ± 1.06
	t(*p*)	3.56(**)		0.91(0.37)	
	ES	0.33		−0.08	
	%Change	8.07		−2.67	
	%+/trivial/-	100/0/0		23/0/77	
	QI	Most Likely +ive		Unclear	
Sprints Number	*M SD*	1.15 ± 1.42	1.60 ± 1.85	1.80 ± 1.77	1.88 ± 1.83
	t(*p*)	−2.26(*)		−22(0.82)	
	ES	−0.04		−0.27	
	%Change	39.13		−16.11	
	%+/trivial/-	45/0/55		16/0/84	
	QI	Unclear		Unclear	

Note. T1 = Task 1, T2 = Task 2, T3 = Task 3, T4 = Task 4. NOPR = no pass restriction, PR = pass restriction. ES = effect size, QI = qualitative inference, +ive = positive, –ive = negative. *** $p < 0.001$. ** $p < 0.01$, * $p < 0.05$.

3.3. Mental Load and Fatigue

Finally, descriptive values and the comparison of pairs of tasks for mental variables are presented in Table 4. According to the *p*-value analysis, only time pressure in the MBPG showed significant changes, with higher values in the limitation tasks. However, according to the MBI analysis, mental effort and fatigue for MBPG and performance satisfaction during MBPG-G showed very or most likely changes with higher values in tasks with pass limitations. Mental effort represents the real mental resources that the players use to achieve the goal and it produces mental fatigue Thus, the relation between these variables is clear. The rest of the mental variables (unsafety and interaction) compared for these two types of tasks did not show relevant differences (either with *p*-values or MBI analysis), although all results were higher for these variables in pass limitation conditions, both in the MBPG and the MBPG-G score system.

Table 4. Mental load and mental fatigue results between pairs of tasks.

		T1–T2		**T3–T4**	
Variables		**NOPR**	**PR**	**NOPR**	**PR**
Mental Effort	*M SD*	57.50 ± 18.74	61.63 ± 17.07	62.75 ± 17.58	64.13 ± 18.15
	t(*p*)	−2.50(0.17)		−0.77(0.45)	
	ES	0.16		0.05	
	%Change	7.52		2.20	
	% (+/trivial/-)	96/0/4		72/0/28	
	QI	Very Likely +ive		Unclear	
Time Pressure	*M SD*	56.00 ± 16.26	61.88 ± 16.20	60.25 ± 17.02	61.75 ± 18.14
	t(*p*)	$-3.85(^{***})$		−0.64(0.55)	
	ES	0.26		0.16	
	%Change	12.62		2.49	
	% (+/trivial/-)	100/0/0		92/0/8	
	QI	Most Likely +ive		Unclear	
Performance Satisfaction	*M SD*	60.50 ± 15.22	62.25 ± 16.60	61.75 ± 18.21	64.50 ± 19.34
	t(*p*)	−1.22(0.23)		−1.15(0.26)	
	ES	0.04		0.21	
	%Change	1.34		4.45	
	% (+/trivial/-)	67/0/33		99/0/1	
	QI	Unclear		Very Likely +ive	
Unsafety	*M SD*	32.63 ± 22.10	34.25 ± 22.83	38.38 ± 25.30	41.63 ± 26.15
	t(*p*)	−0.96(0.34)		−0.75(0.46)	
	ES	0.11		0.18	
	%Change	8.72		8.47	
	% (+/trivial/-)	94/0/6		94/0/6	
	QI	Unclear		Unclear	
Interaction	*M SD*	56.75 ± 17.30	59.75 ± 18.64	57.63 ± 19.28	61.25 ± 18.70
	t(*p*)	−1.86(0.70)		−1.66(0.10)	
	ES	0.10		0.14	
	%Change	4.57		6.28	
	% (+/trivial/-)	94/0/6		95/0/5	
	QI	Unclear		Unclear	
Fatigue	*M SD*	40.88 ± 23.59	42.88 ± 24.93	45.88 ± 24.44	46.63 ± 24.74
	t(*p*)	−1.87(0.69)		-0.83 (0.41)	
	ES	0.08		0.02	
	%Change	5.78		2.30	
	% (+/trivial/-)	97/0/3		72/0/28	
	QI	Very Likely +ive		Unclear	

Note. T1 = Task 1, T2 = Task 2, T3 = Task 3, T4 = Task 4. NOPR = no pass restriction, PR = pass restriction. ES = effect size, QI = qualitative inference, +ive = positive. *** $p < 0.001$.

4. Discussion

The purpose of this study was to analyze the effects of limiting pass decisions on physical and mental load and fatigue during soccer training tasks through a rule stating that the goal is only valid if a minimum number of players participate in the passes before achieving the goal. Thus, we proposed two training sessions with the same tasks (with or without the constraint) and compared their results. The main findings of the study suggested that RPE and mental fatigue levels were affected by these constraints because higher values were found in these variables using the limitation, especially during the MBPG score system tasks. However, the external physical load reported by players was not affected or decreased by the use of constraints in pass decisions, either in MBPG or MBPG-G.

We expected (Hypotheses (1) that the limitation in pass decisions would increase internal and external physical values. Indeed, internal load results were higher during the limitation tasks. However, contrary to the hypothesis, most of the external physical values were higher or unchanged in no-limitation tasks. Previous research showed synergistic increases/decreases both in internal and external physical load with the use of soccer constraints like the size of the pitch [2,11,15]. However, we cannot consider these constraints as similar to pass constraints decisions. Other previous constraints and tactical behaviors more closely related to this constraint such as player's unbalanced or the limitation in the ball touches can increase the external physical load through the players' distributions, the increase in the speed of the ball or the type of defender marking derived from the tasks and limitations. These constraints showed increases both in internal and external load [15,26]. However, the level of the participants (semi-professionals) or the complexity of the task designed could be the key to the results of the present study, due to a greater number of errors in the pass and less effective time of practice [44]. This could explain the important decreases shown in the MBI analysis for distance/minute.

On another hand, the disagreement between the decreases in external load and the increases in the internal load values could be explained by the mediated effect of mental fatigue. This explanation is justified by the psychobiological model. This model is characterized by increases in internal load (RPE) values without increases in external load [45]. According to this model, the increase in internal physical load (RPE) observed during these situations is mediated by the mental load increases, and according to these authors, the external physical not changed. These statements agree with the results of the present study, which showed unchanged/decreased values for external load and important increases in the internal load values. Another possible explanation is that the decreases in the distances covered with tactical objectives are caused by the effects of mental fatigue on physical performance. This behavior was observed by Coutinho et al. (2018) but, in our opinion, this explanation is improbable in the present study due to (i) the duration of the task and (ii) the team's tactical behavior is more influenced by the objective of the task.

Concerning mental values, we expected (Hypothesis (2) that the limitations in pass decision would increase mental load and fatigue. Specifically, the results confirmed that mental and physical effort, time pressure, and mental fatigue increased in MBPG. Additionally, positive and significant changes in performance satisfaction were obtained for MBPG-G. The increases in mental load values due to the pass decision constraint could be influenced by the extra mental effort that this limitation produces in players because they must increase their attention and cognitive levels to achieve the objectives and conditions of the training tasks. Other previous studies confirmed that the task's entropy can increase with the use of soccer constraints like the scoring system [10] or the task's objective [19]. However, contrary to the results shown by Ponce-Bordon et al. (2020), these constraints have a higher effect in MBPG than in MBPG-G. These results could be explained by the increase in the complexity of the development or the higher level of stress caused by these types of tasks [46]. These statements coincide with the increases in performance satisfaction during MBPG-G.

Concerning mental fatigue, it is difficult to find studies to discuss the results found, because most of the studies published do not use specific soccer strategies. In this sense, Thompson et al. (2020) proved that the use of Stroop tasks before measuring sports performance has increased knowledge about mental fatigue, but mental fatigue accumulation does not occur before matches; the accumulation of mental fatigue occurs during and after soccer matches. The importance of studies that increase the information and practical applications about how coaches can manipulate mental fatigue with specific soccer strategies has been highlighted by these authors. Moreover, the control of these types of fatigue is very important because an important increase in the accumulation of mental fatigue levels can reduce soccer performance [12].

4.1. Study Limitations and Future Research

Probably, the main limitations of the study were the exclusion of the previous training mental fatigue levels and the effective time of practice. In future research, the quantification of prior mental fatigue levels (before the task) could increase the information obtained.

Additionally, the inclusion of the effective time of practice and information about all types of fatigue. Another interesting aspect is the implementation of this intervention at different moments of the season (early, mid, or end-season), because the training load is not the same during the whole season. The different influence of this constraint on the types of tasks may also be considerable.

On the other hand, in future studies it could be interesting to analyze the implementation of this constraint during more training sessions or other types of tasks, different from MBPG and MBPG-G, comparing the types of tasks. Additionally, it would be interesting to compare the fatigue that different tasks induced. Future research should examine the differences between these results and the findings obtained with professional players or even the quantification of the effective practice time.

4.2. Practical Implications

In our opinion, these results add important information for researchers, practitioners, and coaches about the use of this constraint. The use of this limitation in pass decisions is a frequently used strategy during soccer training sessions, and based on the effects reported in this research, coaches can use this specific soccer constraint to manipulate the load according to their objectives.

5. Conclusions

The present study confirmed that the use of pass restrictions during soccer tasks may modify the effort perceptions and mental fatigue reported by players during soccer training sessions. Specifically, these variables increase with the use of these restrictions, with higher effects in MBPG tasks than in MBPG-G. These increases are probably mediated by the effect of mental fatigue on internal physical load, because the values of the external physical load were not modified. The cause of these unchanged values of external values could be the decreases in effective practice time, which could be caused by the complexity of this constraint or the player's level.

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Article

Muscle Damage and Performance after Single and Multiple Simulated Matches in University Elite Female Soccer Players

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Abstract: The present study aimed to compare changes in muscle damage and performance parameters after playing single versus multiple soccer matches to examine fixture congestion effects on performance. Twelve elite female university soccer players performed single, three and six consecutive 90-min bouts of the Loughborough Intermittent Shuttle Test (LIST) with ≥12-weeks between conditions in a pseudo-randomized order. Heart rate, blood lactate, rating of perceived exertion and covering distance in each LIST were examined. Changes in several types of muscle damage (e.g., maximal voluntary isometric torque of the knee extensors: MVC-KE) and performance measures (e.g., Yo-Yo Intermittent Recovery Test level 1: YYIR1) were taken before each LIST, 1 h, and 1–5 d after the last LIST. The total distance covered during the LIST was shorter ($p < 0.05$) in the 2nd–3rd, or 2nd–6th LISTs when compared with the 1st LIST. Changes ($p < 0.05$) in all measures were observed after the LIST, and the greatest changes were observed after the six than after the three LISTs followed by one LIST (e.g., largest changes in MVC-KE: $-26 > -20 > -14\%$; YYIR1: $-31 > -26 > -11\%$). Many of the variables did not recover to the baseline for 5 d after six LISTs. These suggest that fixture congestion induces greater muscle damage and performance decline than a single match.

Keywords: soccer; football; Loughborough Intermittent Shuttle Test; muscle soreness; maximal isometric contraction strength; countermovement jump; Yo-Yo Intermittent Recovery Test level 1

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1. Introduction

Playing a soccer (football) match induces muscle damage that is represented by a combination of delayed onset muscle soreness and prolonged decreases in muscle function [1–4]. Systematic review papers have shown that a soccer match alters muscle damage markers, impairs physical performance such as sprint and jump abilities [5], and exacerbates perceptual responses for at least three days post-match [6]. Andersen et al. [1] showed significant decreases in sprint performance (−3%), countermovement jump (CMJ) height (−4%), peak concentric contraction torque of knee extension (−7%) and flexion (−9%), and increases in serum creatine kinase (CK) activity (+152%) and muscle soreness in Swedish and Norwegian female players after the first friendly international soccer match of the season in the highest division, and CMJ height was still reduced (−3%) at the beginning of the second match performed three days later. Moreover, Hughes et al. [4] found that muscle soreness and increased plasma CK activity lasted for seven days after an official soccer match of youth female players. Additionally, Thomas et al. [3] reported that maximal voluntary isometric contraction (MVC) torque of the knee extensors (MVC-KE) and countermovement jump (CMJ) height decreased, muscle soreness developed and plasma creatine kinase (CK) activity increased for three days after 90 min of a simulated soccer match using the Loughborough Intermittent Shuttle Test (LIST) performed by 15 male semi-professional male soccer players. Considering the time it takes for recovery from an official or a simulated match, it appears that performance in a match is affected by a previous match if the interval between matches is short. However, the magnitude of the effects of multiple matches on muscle damage and performance have not been well documented.

Julian et al. [6] defined "fixture congestion" as a minimum of two successive official soccer matches, and examined the effects of an inter-match recovery period of ≤4 days on adult male players using a semi-automated video system and/or GPS device. They showed that fixture congestion affected variables such as the low- and moderate-intensity distance covered but did not affect the total distance covered, probably due to pacing strategies to maintain high-intensity movements. The authors suggested that with ever increasing numbers of competitive matches scheduled, more research was required using consistent measures of performance with an integration of physical, technical and tactical aspects. Although professional soccer leagues do not require their teams to play official matches over successive days, multiple soccer matches are played with short intervals in some tournaments [7,8]. A common challenge for players competing in these tournaments is that the time available for full recovery between matches is limited, thus physical performance might be reduced in successive matches, and risks of injuries may be increased.

Some studies have demonstrated that residual fatigue accumulated over three to four successive soccer matches and performance is adversely affected in junior and young male players [7–11]. Benítez-Jiménez et al. [8] reported that a significant decrease in CMJ height during three consecutive friendly soccer matches played daily over three days (match 1: −14%; match 2: −19%; match 3: −14%; two days after match 3: −15%), when compared to the baseline level in 22 youth male players. Similarly, Chaves et al. [7] showed a decrease in perceived recovery when the U−19 male players had four competitive matches in four days. Additionally, even if the match frequency was less, Saidi et al. [12] showed significant decreases in the Yo-Yo Intermittent Recovery Test level 1 (YYIR1; −35%), repeated shuttle sprint ability (−3%), and squat jump (−3%) after 10 soccer matches played over six weeks by male soccer players. Carling et al. [13] suggested a need for research to examine the extent to which players' match running profiles were compromised during intensified competition periods. It seems likely that as more matches are performed, the greater impairment of muscle and physical function is induced. However, no previous study has systematically investigated the effects of playing multiple soccer matches with short intervals on muscle damage and fatigue and performance of female players.

Therefore, the aim of the present study was to investigate changes in indirect markers of muscle damage and performance variables after multiple (three and six) simulated soccer matches (90-min LIST) performed by elite female university soccer players in comparison to a single LIST condition. In the present study, the same players performed a LIST or three or six LISTs on consecutive days, and performance in the LIST, several indirect markers of muscle damage, and soccer-specific performance measures were taken before every LIST, one hour, and one to five days after the last LIST. The six LIST conditions were included as a possible worst-case scenario. It was hypothesized that the recovery and changes in muscle damage and performance variables would be slower and greater in the order of six LISTs, three LISTs, and the single LIST.

2. Materials and Methods

2.1. Experimental Approach and Study Design

In order to simulate soccer matches, a 90-min LIST protocol was used to mimic a typical soccer match [3,14,15]. In a pseudo-randomized, counterbalanced design, 12 elite female university soccer players played a single LIST, three LISTs and six LISTs, with more than 12 weeks between conditions (Figure 1A). The LISTs were performed in the same indoor facility in which the environmental temperature was 30–34 °C and relative humidity was 77–85% for all conditions. Six days before the first session, the participants were familiarized with all test procedures. They also performed a maximal oxygen consumption

(VO_{2max}) test three to four days before the first session to calculate the speeds (55% and 95% VO_{2max}) applied during the LIST. To examine the effects of the LISTs on muscle damage and performance, MVC-KE and maximal voluntary isometric contraction torque of knee flexors (MVC-KF), muscle soreness of the knee extensors (SOR-KE) and flexors (SOR-KF), plasma CK activity, CMJ, 30-m dash, 30-m timed hop, balance, agility *t*-test, 6 × 10-m shuttle run and YYIR1 were measured one to two days before the 1st LIST (baseline) and one hour after each LIST, and one to five days after the last LIST (Figure 1B). Changes in the variables were compared among the conditions (single LIST, three LISTs, six LISTs) by two-way repeated measures of analysis of variance (ANOVA).

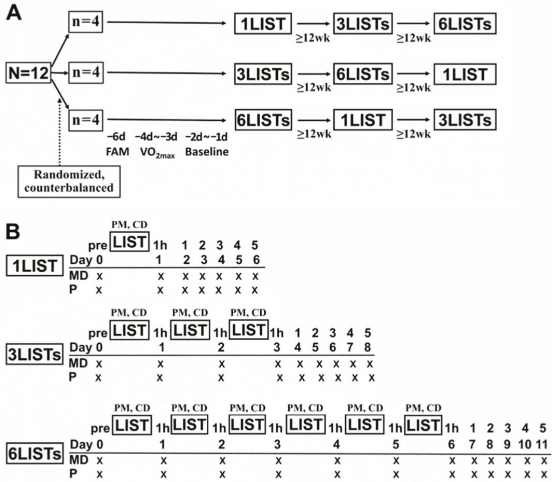

Figure 1. Experimental design and testing procedures of the study. (**A**): Three conditions were based on the number of Loughborough Intermittent Shuttle Tests (LISTs) performed consecutively by 12 participants: one (1LIST), three (3LISTs) and six (6LISTs). The order of the three conditions was semi-counterbalanced among the participants such that 1LIST–3 LISTs–6LISTs (n = 4), 3LISTs–6LISTs–1LIST (n = 4), and 6LISTs–1LIST–3LISTs (n = 4). (**B**): Time course of measurements for 1LIST, 3LISTs and 6LISTs conditions. FAM: familiarization session. $\dot{V}O_{2max}$: maximal oxygen consumption test. PM: physiological markers including heart rate, rating of perceived exertion (RPE) and blood lactate concentration measures during the LIST. CD: total covered distance during the LIST. MD: muscle damage markers including maximal voluntary isometric contraction torque of the knee extensors (KEs) and flexors (KFs), muscle soreness of KEs and KFs, countermovement jump height, and plasma creatine kinase activity. p: performance parameters consisting of 30-m dash, 30-m timed hop, balance, agility *t*-test, 6 × 10-m shuttle run and Yo-Yo Intermittent Recovery Test level 1 tests.

2.2. Participants

The sample size was estimated using the data from our pilot study in which the effects of a single LIST versus three LISTs over three days on maximal voluntary isometric contraction torque of the dominant knee extensors (MVC-KE) were compared in six female soccer players. Based on the effect size of 1 for a difference in MVC-KE change post-match between the two conditions, it was estimated that at least 11 participants were necessary for each condition, with an alpha level of 0.05 and power ($1 - \beta$) of 0.80 [16]. Considering a possible drop-out and an estimation error, 12 players were recruited for the study.

Twelve elite female university soccer players who were selected for the Chinese Taipei Team of the 2018 Asian University Football Tournament provided informed consents to participate in the present study, which had been approved by the Research Ethics Committee of National Taiwan Normal University, Taiwan (Approval #: 201812HM023). The study was conducted in conformity with the policy statement regarding the use of human subjects by the Declaration of Helsinki. None of them had injuries during the period of the data collection and completed the three conditions. They played 17–20 official matches during the experimental period of 40 weeks and had training sessions five days a week (2.5–3 h per session). The present study was performed when the players had not had an official match for more than five days before the 1st LIST, and each condition (single, three and six LISTs) was preceded by at least five days of rest. All of the players had experienced three official matches in a row, and some of them had played an official match every day for five days.

2.3. Maximal Oxygen Uptake Test

The participants performed an incremental continuous run test on a treadmill (Mercury, h/p/cosmos, Nussdorf, Traunstein, Germany) until the point of volitional fatigue to determine maximal oxygen uptake ($\mathrm{VO}_{2\mathrm{max}}$) and maximal heart rate ($\mathrm{HR}_{\mathrm{max}}$). An automatic gas analysis system ($\mathrm{V}_{\mathrm{max}}$29c, SensorMedics, Yorba Linda, CA, USA) was used to measure oxygen consumption. Participants warmed up at a speed of 6.4 km/h on a gradient of 1% for 5 min, and the speed was increased by 1.6 km/h every 3 min while a gradient of 1% was kept [17–20]. From the $\mathrm{VO}_{2\mathrm{max}}$, running speeds corresponding to 55% and 95% $\mathrm{VO}_{2\mathrm{max}}$ were calculated. Thereafter, the participants performed and practiced the running corresponding to 55% and 95% $\mathrm{VO}_{2\mathrm{max}}$ on the treadmill for 5 min for each intensity.

2.4. The Loughborough Intermittent Shuttle Test (LIST)

The LIST for 90 min was performed in a sports hall according to Nicholas et al. [15]. The details of the LIST can be found elsewhere [15], but briefly, the participants were instructed to run between two lines, 20 m apart, at various velocities dictated by an audio signal for two parts: Part A and Part B.

Part A was of a fixed duration and consisted of five 15-min exercise periods separated by 3 min of recovery. The exercise periods consisted of the set pattern of intermittent high-intensity running shown below and were designed to be similar to the activity pattern typically recorded for a soccer match-play.

3 × 20 m at walking pace;
1 × 20 m at maximal running speed;
4 s recovery;
3 × 20 m at a running speed corresponding to 55% of individual $\dot{\mathrm{V}}\mathrm{O}_{2\mathrm{max}}$;
3 × 20 m at a running speed corresponding to 95% of individual $\mathrm{VO}_{2\mathrm{max}}$.

Part B was an open-ended period of intermittent shuttle running, designed to exhaust the participants within approximately 10 min. The participants were required to run at speeds corresponding to 55% and 95% of predicted $\mathrm{VO}_{2\mathrm{max}}$, the speed alternating every 20 m. This pattern of exercise was repeated continuously until the participants were unable to maintain the required speed for two consecutive shuttles at the higher of the two exercise intensities.

2.5. Familiarization Session

In the familiarization session, the participants experienced the measurements of muscle soreness, countermovement jump (CMJ), sub-maximal and maximal voluntary isometric contractions at 90° and 30° of knee flexion for knee extensors and flexors, respectively, on an isokinetic dynamometer (Biodex System S4 Pro; Biodex Medical Systems, Shirley, NY, USA), 30-m dash, 30-m timed hop, balance, agility *t*-test, 6 × 10-m shuttle run and YYIR1, and performed the LIST for 20 min (Figure 1).

2.6. Dependent Variables

Heart rate (HR), rating of perceived exertion (RPE), blood lactate (LA) and distance covered during LIST.

During each LIST, heart rate (HR) was recorded by a Polar HR monitor (Polar M430, Polar Electro Oy, Kempele, Finland); rating of perceived exertion (RPE) was assessed with a 6–20 Borg's scale [17,21]; and covering distance of each participant in each LIST was recorded manually by the investigators. Blood lactate (LA) concentration was measured by a lactate test meter (LactateScout+, h/p/cosmos, Nussdorf-Traunstein, Germany) using a capillary sample obtained from a fingertip of each participant before and 1 min after every 15 min of exercise during Part A, and 1 min after Part B of the LIST [17,22,23]. Changes in HR during each LIST were analyzed by automatic software provided by the Polar company, and all results were averaged during each LIST [3,15]. RPE was assessed immediately after each exercise period as shown in the LIST section below, and the total of six exercise periods during each LIST was averaged as the final result [3,15]. The total six different time points of blood lactate during each LIST were averaged [15].

2.7. Muscle Damage Markers

2.7.1. Maximal Voluntary Isometric Contraction (MVC) Torque

MVC torque of the dominant knee extensors (MVC-KE) and flexors (MVC-KF) were adopted from our previous studies, and the details were described elsewhere [24–27]. The dominant leg was determined as the leg that was preferred for kicking a soccer ball to a target [28], and the measures were performed by the dominant leg. Each participant lay in supine and prone positions for the MVC-KE and MVC-KF measures on the platform of an isokinetic dynamometer (Biodex System S4, Shirley, NY, USA), respectively. The trunk and the dominant leg were strapped to the platform of the dynamometer. MVC-KE and MVC-KF were measured at 90° and 30° of knee flexion (0° = full knee extension), respectively, after gravity correction. Each participant was instructed to generate maximal force for 5 s, and this was repeated three times with 45 s rest between trials, and 5 min was provided between MVC-KE and MVC-KF measures, and the highest value of the three measurements was used for further analysis for each measure.

2.7.2. Countermovement Jump (CMJ)

CMJ was considered to be a marker of muscle damage, according to previous studies [29–31], although CMJ is also used as a performance measure in soccer studies [2,32]. The participant stood erect with a knee angle of 0° (0° = full knee extension) with hands on hips and performed a countermovement until the knee angle reached an approximate 90° angle, followed immediately by a vertical jump as high as possible [33–35]. CMJ was performed on a jumping mat (Smart Jump, Fusion Sport, Queensland, Australia). The jumps were interspersed with a 30-s rest period, and the best jump (in cm) among three trials was used as the test result.

2.7.3. Muscle Soreness

Muscle soreness was quantified by a visual analog scale that had a 100-mm continuous line with "not sore at all" on one end (0 mm) and "very, very sore" on the other end (100 mm). Muscle soreness of the dominant knee extensors and flexors was assessed, separately, when each participant performed a full squat of dominant knee extensors and flexors, respectively [18,19,36].

2.7.4. Plasma CK Activity

Approximately 5 mL of venous blood was withdrawn by a standard venipuncture technique from the cubital fossa region and centrifuged for 10 min to extract plasma, and the plasma samples were stored at −80 °C until analyses. Plasma CK activity was assayed spectrophotometrically by an automated clinical chemistry analyzer (Model 7080, Hitachi, Co. Ltd., Tokyo, Japan) using a commercial test kit (Roche Diagnostics, Indianapolis, Indiana) [18,37].

2.8. Performance Indices

Before the tests, all the participants performed warm-up exercises consisting of jogging, specific mobility exercises and stretching routines, and three 10-m sprints in 10–15 min.

All measures (30-m dash, 30-m timed hop, balance, agility *t*-test, 6 × 10-m shuttle run and YYIR1 tests) were performed indoors, and the order of measures was 30-m dash, balance, 30-m timed hop, agility *t*-test, 6 × 10-m shuttle run and YYIR1 tests with 5–10 min rest between tests. All participants had performed these tests regularly (eight times a year) for one year before the present study in a project by the Sport Administration, Ministry of Education (Taiwan); thus, they were familiar with the tests. However, performing all tests over consecutive days had not been done before the current study.

2.8.1. 30-m Dash

Sprint ability was assessed using telemetric photoelectric cells placed at 0, 10, 20 and 30 m (Smart Speed, Fusion Sport, Queensland, Australia). Each participant stood 0.3 m behind the starting line, started on a verbal signal being time-activated when the player crossed the first pair of photocells, and was instructed to run as fast as possible to complete the 30-m distance [32]. Participants completed two runs interspersed by a 1-min recovery period, and the best time was used for further analysis.

2.8.2. 30-m Timed Hop Test

The 30-m timed hop test was adapted from a previous study [38]. The 30-m timed hop test protocol was the same as that of the 30-m dash, but the difference was that the participants used their dominant leg to hop as fast as possible over a distance of 30 m. Participants completed two tests interspersed by a 2-min recovery period and the best time was used for further analysis.

2.8.3. Balance Test

The present study used a test of eyes closed on unstable surface (ECUS) as a measure of balance ability using the Biodex BioSway Portable Balance System (Model 950–460; Biodex Medical Systems, Shirley, NY, USA). Each participant was instructed to maintain her feet on the platform for 30 s for each test and had a 30-s rest between tests. Based on the study by Collado-Mateo et al. [39], a heel-to-heel distance of 16 cm and an external rotation of 15° were set. The sway index (SI) quantifying sways over the 30 s was calculated as the standard deviation (SD) of the sway angle [39]. Participants completed two tests interspersed by a 30-s recovery period, and the best result (i.e., SI) was used for further analysis.

2.8.4. Agility *t*-Test

An adapted version of the *t*-test by Semenick [40,41] was used. Each participant sprinted forward (9.14 m), shuffled to the left (4.57 m) and to the right (9.14 m), shuffled back to the left (4.57 m), and ran backward to the starting point. The time was measured by the same telemetric photoelectric cells as those for the 30-m dash. Two trials were performed with a 3-min rest between trials, and the better time was used for further analysis.

2.8.5. 6 × 10-m Shuttle Run

The 6 × 10-m shuttle run was carried out using the same telemetric photoelectric cells placed at the start line and 10 m. Each participant stood 0.3 m behind the start line, started on a verbal signal being time-activated when the participant crossed the first pair of photocells, and was instructed to run as fast as possible to complete the 10-m distance and then returned to the starting line for six repetitions. Players completed two runs interspersed by a 5-min recovery period, and the best time was used for further analysis.

2.8.6. Yo-Yo Intermittent Recovery Test Level 1 (YYIR1)

Endurance was assessed through the YYIR1, commonly used to assess endurance performance in soccer players [42]. Keeping to a series of beeps, participants were required to run 20 m shuttles, followed by a 10-s rest interval. The test's running speed increased progressively throughout until the players reached volitional exhaustion or until participants missed two beeps, resulting in the test being terminated. Participants completed one run on each time point, and consistent verbal encouragement was given to participants during the YYIR1. Total running distance, HR and RPE during the YYIR1 were recorded.

2.9. Statistical Analyses

Data were verified by a Shapiro–Wilk test for the normality and a Levene test for the homogeneity of variance assumption. All dependent variables before the single LIST condition, the 1st LIST of the three LIST and six LIST conditions were compared by one-way ANOVA. Changes in HR, RPE, lactate concentration, total distance covered during the LIST were compared among the trials and conditions by two-way repeated measures ANOVA. Changes in each dependent variable before, 1 h after, and 1–5 d after the 1st, 3rd and 6th LIST for the single LIST, three LIST and six LIST conditions, respectively, were compared by two-way repeated measures ANOVA.

The normalized changes in muscle damage and performance measures from the baseline at 1 h and 1–5 d after the 1st LIST for the single, three and six LIST conditions were obtained and were compared by two-way repeated measures ANOVA. When a significant interaction effect was found, a Tukey's post-hoc test was performed, and η^2 was calculated as a measure of effect size, which was considered as ~0.02 = small effect; ~0.13 = medium effect; and >0.26 = large effect [43]. Cohen's *d* effect size (ES) was calculated by the method of Thalheimer and Cook [44] based on the largest changes for the single versus three, three versus six, and single versus six LIST conditions, respectively. ES of 0.2, 0.5, and 0.8 were considered as a small, medium, and large effect, respectively [16]. Pearson Product-Moment Correlation coefficient (r) was used to examine the relationships between the magnitudes of decreases in MVC-KE, MVC-KF or CMJ (% change from the baseline) at 1 d after a single LIST, three LISTs and six LISTs ($n = 36$) and the magnitudes of change in peak muscle soreness of KE and KF as well as peak CK after a single LIST, three LISTs and six LISTs. Similarly, the correlation analyses were performed for the magnitude of the decreases in MVC-KE, MVC-KF or CMJ and the magnitude of changes in the 30-m dash, 30-m timed hop test, balance, agility *t*-test, 6 × 10 m shuttle run and YYIR1 at 1 d after the single LIST, three LISTs and six LISTs ($n = 36$). A significant level was set at $p \leq 0.05$. The data were presented as mean ± SD.

3. Results

3.1. Baseline Measurements

The mean ± SD (range) age, height, body mass, percentage of body fat, and maximal oxygen consumption (VO_{2max}) of the participants were 21.0 ± 1.1 (19–23) y, 159.1 ± 4.6 (152–165) cm, 56.2 ± 6.7 (45–65) kg, 14.4 ± 4.3 (7.3–21.5)%, and 54.1 ± 4.4 (47.9–59.2) mL/kg/min, respectively. No significant differences in the baseline MVC-KE ($p = 0.919$, $\eta^2 = 0.008$), MVC-KF ($p = 0.959$, $\eta^2 = 0.004$), muscle soreness of KE ($p = 1.00$, $\eta^2 = 0.000$) and KF ($p = 1.00$, $\eta^2 = 0.000$), plasma CK activity ($p = 0.562$, $\eta^2 = 0.051$), CMJ ($p = 0.739$, $\eta^2 = 0.027$), 30-m dash ($p = 0.943$, $\eta^2 = 0.005$), 30-m timed hop test ($p = 0.992$, $\eta^2 = 0.001$), balance ($p = 0.909$, $\eta^2 = 0.009$), agility *t*-test ($p = 0.995$, $\eta^2 = 0.001$), 6 × 10-m shuttle run ($p = 0.832$, $\eta^2 = 0.017$), and YYIR1 (average distance: $p = 0.850$, $\eta^2 = 0.015$) were evident among the single LIST, three LIST and six LIST conditions (Figures 3 and 4). Before the 1st LIST, no significant differences among the conditions were found for HR ($p = 0.907$, $\eta^2 = 0.009$), RPE ($p = 0.426$, $\eta^2 = 0.075$), and LA concentration ($p = 0.398$, $\eta^2 = 0.080$).

3.2. HR, RPE, LA and Distance Covered during LIST

No significant differences in the total distance covered ($p = 0.951$, $\eta^2 = 0.005$), HR ($p = 0.632$, $\eta^2 = 0.041$), RPE ($p = 0.637$, $\eta^2 = 0.040$), and post-exercise LA ($p = 0.866$, $\eta^2 = 0.013$) in the 1st LIST were found among the three conditions (Figure 2). Changes in average HR ($p = 0.632$, $\eta^2 = 0.041$), RPE ($p = 0.637$, $\eta^2 = 0.040$) and LA ($p = 0.866$, $\eta^2 = 0.013$) during the 1st LIST were similar among the conditions (Figure 2b–d). The total distances covered during the LISTs were significantly shorter ($p < 0.001$) in the 2nd to 6th LISTs (10,088 ± 493 m–10,330 ± 628 m) for six LISTs ($\eta^2 = 0.418$), and the 2nd (10,277 ± 220 m) and 3rd LISTs (9883 ± 339 m) for three LISTs ($\eta^2 = 0.580$) when compared with the 1st LIST of all conditions (10,844 ± 528 m; Figure 2a).

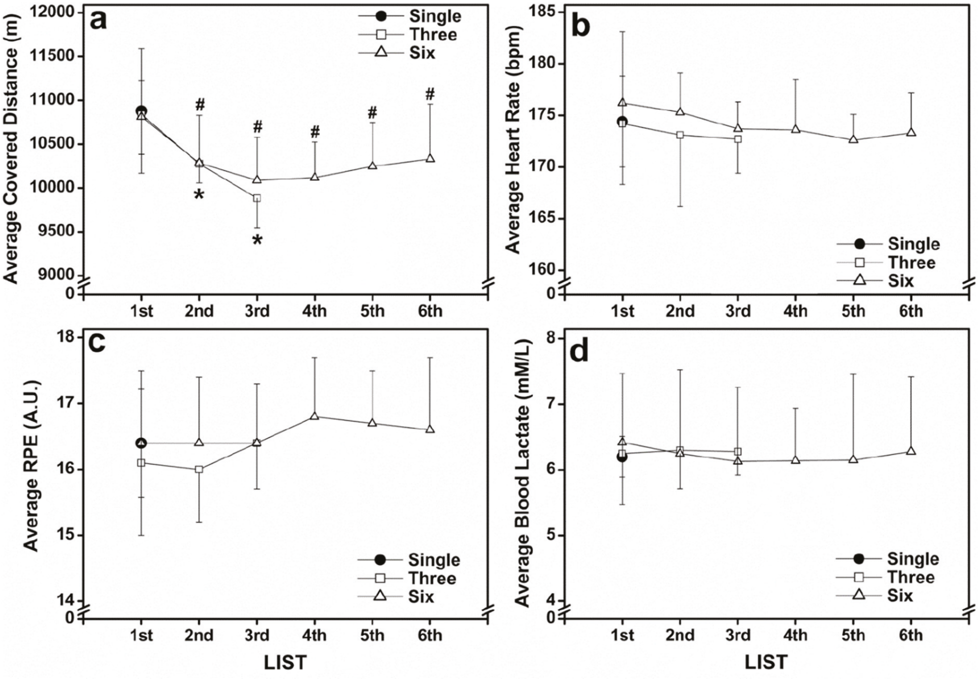

Figure 2. Average changes (mean ± SD) in the total distance covered (**a**), heart rate (**b**), ratings of perceived exertion (RPE, (**c**)), and blood lactate concentration (LA, (**d**)) in the Loughborough Intermittent Shuttle Test (LIST) for one LIST (Single), three LISTs (Three) and six LISTs (Six) conditions. An asterisk (*) indicates a significant difference ($p < 0.05$) between Single and Three conditions; a hash ($^{\#}$) indicates a significant difference ($p < 0.05$) between Single and Six conditions.

The baselines of LA ($p = 0.012$, $\eta^2 = 0.230$; 2.3 ± 0.9–2.9 ± 0.8 mM/L), HR ($p = 0.005$, $\eta^2 = 0.255$; 76.5 ± 6.1–78.3 ± 5.0 bpm), and RPE ($p < 0.001$, $\eta^2 = 0.546$; 8.8 ± 2.0–10.3 ± 2.0) before the 2nd to 5th or 6th LIST of the six LISTs were significantly greater than those before the 1st LIST (LA: 1.9 ± 0.5 mM/L, HR: 72.8 ± 4.2 bpm, RPE: 6.8 ± 0.4). This was also the case for the baselines of LA ($p < 0.001$, $\eta^2 = 0.571$; 2.8 ± 1.0–3.3 ± 1.4 mM/L), HR ($p = 0.009$, $\eta^2 = 0.347$; 75.0 ± 2.8–77.9 ± 7.9 bpm) and RPE ($p < 0.001$, $\eta^2 = 0.811$; 9.4 ± 1.3–10.6 ± 2.2) before the 2nd and 3rd LISTs of the three and six LISTs when compared with the 1st LIST (LA: 1.9 ± 0.5 mM/L, HR: 81.8 ± 3.8 bpm, RPE: 7.3 ± 0.8).

3.3. Changes in Muscle Damage Markers

Figure 3 shows changes in muscle damage parameters before the 1st LIST, 1 h (Day 1) after the single LIST, 1 h after each LIST for the three LISTs (Day 1–3) and six LISTs (Day 1–6), and 1–5 d after the single LIST (Day 2–6), three LISTs (Day 4–8) and six LISTs (Day 7–11). The magnitude of decrease in MVC-KE and MVC-KF at 1 h after the LIST was greater ($p < 0.001$) after six LISTs (KE: $\eta^2 = 0.964$; KF: $\eta^2 = 0.853$) and three LISTs (KE: $\eta^2 = 0.724$; KF: $\eta^2 = 0.633$) than a single LIST, and the decreases were greater ($p < 0.01$) after six LISTs than three LISTs (KE: $\eta^2 = 0.712$; KF: $\eta^2 = 0.625$). The recovery of MVC-KE and MVC-KF was slower ($p < 0.01$) after six LISTs (interaction effect: KE: $\eta^2 = 0.831$; KF: $\eta^2 = 0.722$) and three LISTs (KE: $\eta^2 = 0.552$; KF: $\eta^2 = 0.243$) than a single LIST, and after six LISTs than three LISTs (KE: $\eta^2 = 0.552$; $\eta^2 = 0.287$).

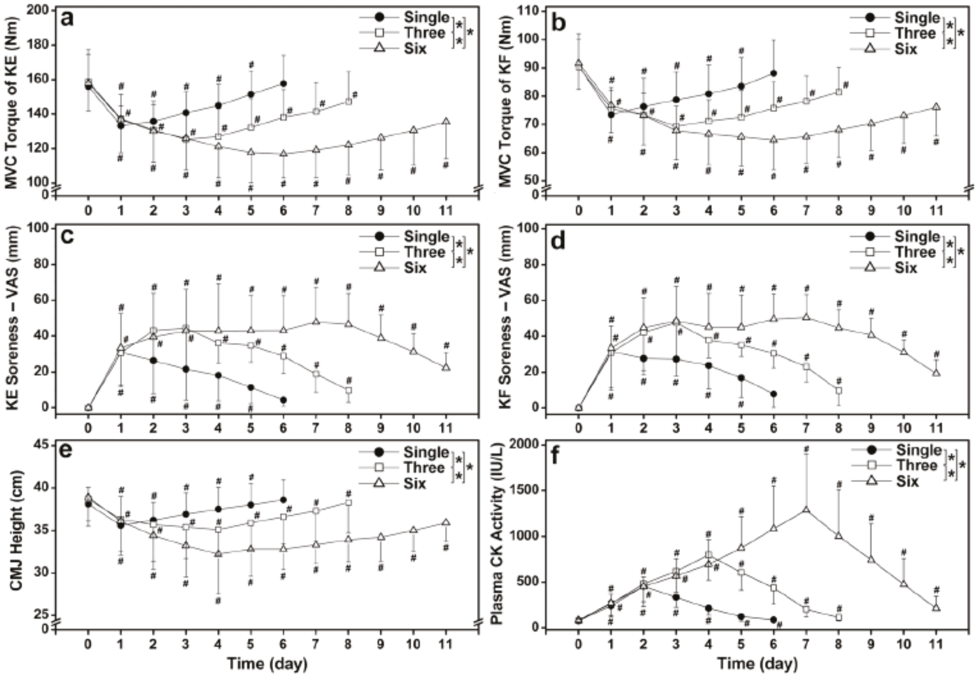

Figure 3. Changes (mean ± SD) in maximal voluntary isometric contraction torque of the knee extensors (MVC-KE, (**a**)) and flexors (MVC-KF, (**b**)), muscle soreness assessed by a 100-mm visual analog scale of the KE (**c**) and KF (**d**), countermovement jump height (CMJ, (**e**)), and plasma creatine kinase (CK) activity (**f**) at baseline (0), 1 h after the Loughborough Intermittent Shuttle Test (LIST) (Day 1), and 1, 2, 3, 4 and 5 d (Day 2–6) after the LIST (Single), before the 1st LIST (0), 1 h after each LIST performed 3 d in a row (Day 1–3) and 1, 2, 3, 4 and 5 d (Day 4–8) after the 3rd LIST (Three), and before the 1st LIST (0), 1 h after each LIST performed 6 d in a row (Day 1–6) and 1, 2, 3, 4 and 5 d (Day 7–11) after the 6th LIST (Six). * indicates a significant ($p < 0.05$) difference between groups based on the interaction effect shown by the ANOVA. # indicates a significant ($p < 0.05$) difference from the baseline value.

The magnitude of decrease in CMJ height was greater after six LISTs ($p = 0.001$, $\eta^2 = 0.641$) than a single LIST, and the decreases were greater after six LISTs than three LISTs ($p < 0.001$, $\eta^2 = 0.699$) without differences between three LISTs and a single LIST ($p = 0.238$, $\eta^2 = 0.124$). The recovery of CMJ height was slower ($p < 0.001$) after six LISTs ($\eta^2 = 0.748$) and three LISTs ($\eta^2 = 0.346$) than a single LIST, and after six LISTs than three LISTs ($p < 0.001$, $\eta^2 = 0.517$).

Muscle soreness of KE and KF after six LISTs (KE: $p < 0.001$, $\eta^2 = 0.400$; KF: $p < 0.001$, $\eta^2 = 0.479$) and three LISTs (KE: $p = 0.022$, $\eta^2 = 0.208$; KF: $p = 0.026$, $\eta^2 = 0.202$) was significantly greater than that after a single LIST, and after six LISTs than three LISTs (KE: $p = 0.012$, $\eta^2 = 0.228$; KF: $p = 0.016$, $\eta^2 = 0.219$). The extent of increases in plasma CK activity after six LISTs ($\eta^2 = 0.738$) and three LISTs ($\eta^2 = 0.745$) was significantly greater ($p < 0.001$) than that after a single LIST, and the increases were greater after six LISTs than three LISTs ($p < 0.001$, $\eta^2 = 0.721$).

3.4. Changes in Performance Indices

As shown in Figure 4, the extent of changes in the 30-m dash (interaction effect; six LISTs: $\eta^2 = 0.735$; three LISTs: $\eta^2 = 0.511$), 30-m timed hop (six LISTs: $\eta^2 = 0.828$; three LISTs: $\eta^2 = 0.382$), balance (six LISTs: $\eta^2 = 0.957$; three LISTs: $\eta^2 = 0.624$), agility *t*-test (six LISTs: $\eta^2 = 0.748$; three LISTs: $\eta^2 = 0.532$), 6 × 10-m shuttle run (six LISTs: $\eta^2 = 0.731$; three

LISTs: $\eta^2 = 0.532$), and YYIR1 (six LISTs: $\eta^2 = 0.696$; three LISTs: $\eta^2 = 0.478$) after six LISTs and three LISTs were significantly greater ($p < 0.001$) than that after single LIST, and the changes were greater ($p < 0.001$) after six LISTs than three LISTs (e.g., 30-m: $\eta^2 = 0.735$; 30-m timed hop: $\eta^2 = 0.553$; balance: $\eta^2 = 0.969$; agility *t*-test: $\eta^2 = 0.517$; 6 × 10-m shuttle run: $\eta^2 = 0.429$; YYIR1: $\eta^2 = 0.445$).

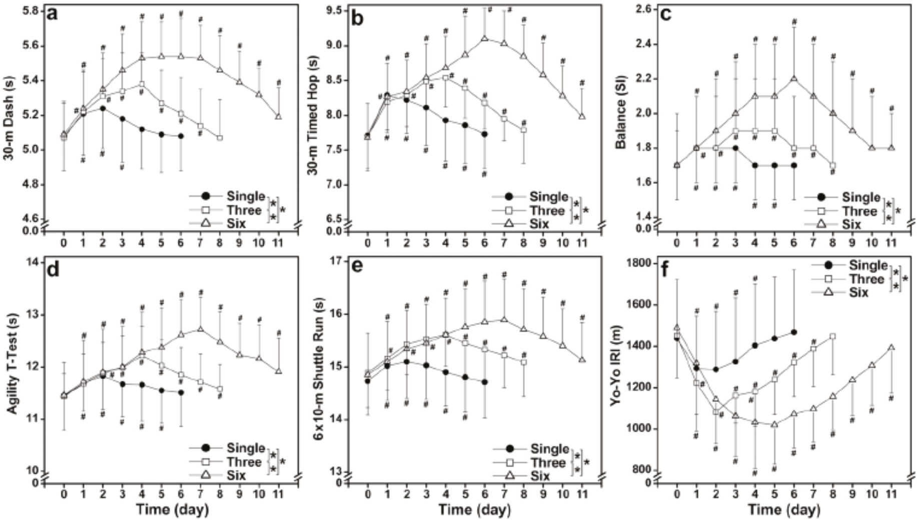

Figure 4. Changes (mean ± SD) in 30-m dash (**a**), 30-m timed hop test (**b**), balance with eyes closed on unstable surface (Balance, (**c**)), agility *t*-test (**d**), 6 × 10-m shuttle run (**e**), and Yo-Yo Intermittent Recovery Test level 1 (Yo-Yo IR1; (**f**)) at baseline (0), 1 h after the Loughborough Intermittent Shuttle Test (LIST) (Day 1), and 1, 2, 3, 4 and 5 d (Day 2–6) after the LIST (Single), before the 1st LIST (0), 1 h after each LIST performed 3 d in a row (Day 1–3) and 1, 2, 3, 4 and 5 d (Day 4–8) after the 3rd LIST (Three), and before the 1st LIST (0), 1 h after each LIST performed 6 d in a row (Day 1–6) and 1, 2, 3, 4 and 5 d (Day 7–11) after the 6th LIST (Six). * indicates a significant ($p < 0.05$) difference between groups based on the interaction effect shown by the ANOVA. # indicates a significant ($p < 0.05$) difference from the baseline value.

Table 1 shows normalized changes in muscle damage markers relating to muscle function (MVC-KE, MVC-KF, CMJ) and all performance measures from the baseline at 1 h and 1–5 d (D1–D5) after the 1st LIST for the single, three and six LIST conditions, and summary of the statistical analysis results. It should be noted that the 2nd and 3rd LISTs were performed in the three LIST condition on D2 and D3, and the 2nd to 5th LISTs were performed on D2–D5 for the six LIST condition. A significant condition x time interaction effect was found for all variables, and performing additional LISTs made all variables worse. No indication of recovery was found for the six LIST condition in the time frame. It should be noted that the magnitude of decrease in performance varied among the variables, and relatively larger changes were observed for MVC-KE and MVC-KF torque and YYIR1.

Table 1. Comparison among the single, three, and six Loughborough Intermittent Shuttle Test (LIST) conditions for changes (mean ± SD) in maximal voluntary isometric contraction torque of the knee extensors (MVC-KE) and flexors (MVC-KF), countermovement jump height (CMJ), 30-m dash (30-mD), 30-m timed hop (30-mTH), balance, agility *t*-test (*t*-test), 6 × 10-m shuttle run (SR) and Yo-Yo Intermittent Recovery level 1 (YYIR1) from baseline at 1 h (H1) and 1–5 d after the 1st LIST (D1–D5).

Measure	Condition	H1	D1	D2	D3	D4	D5	ANOVA Results, Eta Square (η^2)	ES
MVC-KE (%)	Single	−14.2 ± 4.4	**−15.0 ± 5.9**	−11.0 ± 5.7	−7.6 ± 5.3	−2.9 ± 4.0	1.3 ± 2.0	**C:** F = 73.72, $p < 0.001$, $\eta^2 = 0.870$	1.982
	Three	−13.3 ± 3.4	−20.3 ± 3.6 *	**−25.4 ± 4.5 ***	−25.3 ± 6.6 *	−21.0 ± 9.0 *	−15.9 ± 9.7 *	**T:** F = 17.28, $p < 0.001$, $\eta^2 = 0.611$	1.700
	Six	−16.7 ± 4.7	−25.2 ± 7.4 *	−30.0 ± 8.8 *#	−34.1 ± 9.8 *#	**−35.3 ± 6.9 *#**	−33.7 ± 8.9 *#	**C** × **T:** F = 30.80, $p < 0.001$, $\eta^2 = 0.737$	3.162
MVC-KF (%)	Single	−19.0 ± 3.5	**−19.7 ± 4.3**	−15.7 ± 5.1	−12.8 ± 5.2	−9.0 ± 4.0	−3.3 ± 2.6	**C:** F = 23.57, $p < 0.001$, $\eta^2 = 0.682$	1.844
	Three	−16.4 ± 2.8	−22.6 ± 3.8 *	**−28.7 ± 5.4 ***	−27.7 ± 4.7 *	−24.9 ± 11.1 *	−21.1 ± 14.1 *	**T:** F = 14.78, $p < 0.001$, $\eta^2 = 0.573$	1.235
	Six	−16.2 ± 6.4	−24.9 ± 10.3	−33.7 ± 12.9 *	−38.5 ± 16.5 *#	−41.0 ± 17.3 *#	**−43.2 ± 15.7 *#**	**C** × **T:** F = 46.31, $p < 0.001$, $\eta^2 = 0.808$	2.042
CMJ (%)	Single	**−6.6 ± 6.7**	−5.7 ± 2.9	−4.0 ± 2.7	−2.1 ± 2.7	−0.8 ± 2.2	0.9 ± 1.5	**C:** F = 7.52, $p = 0.003$, $\eta^2 = 0.406$	0.744
	Three	−6.5 ± 5.4	−8.9 ± 7.0	−9.7 ± 4.8 *	**−10.4 ± 2.7 ***	−8.1 ± 4.3 *	−6.1 ± 4.5 *	**T:** F = 5.75, $p < 0.001$, $\eta^2 = 0.343$	4.370
	Six	−7.0 ± 9.3	−13.5 ± 15.4 *	−18.0 ± 18.0 *#	**−22.2 ± 25.0 *#**	−22.0 ± 24.5 *#	−19.6 ± 11.7 *#	**C** × **T:** F = 7.99, $p < 0.001$, $\eta^2 = 0.421$	3.054
30-mD (%)	Single	2.5 ± 2.3	**3.1 ± 2.0**	1.9 ± 2.1	0.7 ± 1.4	0.2 ± 1.3	0.0 ± 0.7	**C:** F = 31.02, $p < 0.001$, $\eta^2 = 0.738$	1.786
	Three	3.1 ± 1.9	4.8 ± 1.9 *	5.1 ± 2.2 *	**5.9 ± 1.4 ***	3.8 ± 1.3 *	2.8 ± 1.4 *	**T:** F = 13.94, $p < 0.001$, $\eta^2 = 0.559$	1.039
	Six	2.9 ± 3.3	4.9 ± 3.5	6.9 ± 3.7 *	7.9 ± 3.0 *#	**8.2 ± 2.8 *#**	8.2 ± 3.1 *#	**C** × **T:** F = 15.83, $p < 0.001$, $\eta^2 = 0.590$	2.225
30-mTH (%)	Single	**7.7 ± 5.0**	6.1 ± 3.4	4.9 ± 3.9	2.7 ± 4.7	1.8 ± 4.6	0.3 ± 3.5	**C:** F = 21.12, $p < 0.001$, $\eta^2 = 0.657$	0.563
	Three	6.7 ± 4.6	7.4 ± 3.2 *	9.7 ± 3.5 *	**10.0 ± 2.9 ***	8.2 ± 3.6 *	5.9 ± 2.8 *	**T:** F = 3.44, $p < 0.001$, $\eta^2 = 0.238$	2.215
	Six	7.7 ±1.6	8.0 ± 1.9 *	10.3 ± 1.3 *	11.7 ± 1.7 *#	13.7 ± 3.0 *#	**16.1 ± 2.6 *#**	**C** × **T:** F = 45.20, $p < 0.001$, $\eta^2 = 0.804$	2.108
Balance (%)	Single	6.1 ± 2.4	**6.7 ± 1.3**	5.7 ± 1.8	4.1 ± 2.3	2.6 ± 2.1	0.7 ± 1.3	**C:** F = 118.08, $p < 0.0$, $\eta^2 = 0.915$	4.095
	Three	6.6 ± 2.9	10.2 ± 3.2 *	**14.1 ± 2.2 ***	13.2 ± 2.4 *	10.2 ± 3.3 *	7.1 ± 2.7 *	**T:** F = 135.44, $p < 0.001$, $\eta^2 = 0.925$	2.710
	Six	6.7 ± 4.3	10.6 ± 3.2 *#	15.9 ± 3.9 *#	20.1 ± 3.7 *#	20.6 ± 3.2 *#	**21.7 ± 3.3 *#**	**C** × **T:** F = 84.13, $p < 0.001$, $\eta^2 = 0.884$	5.981
t-test (%)	Single	2.2 ± 1.5	**3.3 ± 1.2**	1.9 ± 1.0	1.8 ± 1.5	0.9 ± 0.8	0.6 ± 0.8	**C:** F = 15.15, $p < 0.001$, $\eta^2 = 0.579$	1.995
	Three	2.1 ± 2.2	3.7 ± 2.5	4.6 ± 2.3 *	**6.4 ± 1.9 ***	4.8 ± 2.0 *	4.8 ± 2.4 *	**T:** F = 16.89, $p < 0.001$, $\eta^2 = 0.606$	1.719
	Six	2.2 ± 3.1	3.7 ± 4.3	4.3 ± 3.1 *	6.7 ± 2.9 *	7.4 ± 2.3 *#	**9.3 ± 1.5 *#**	**C** × **T:** F = 18.576, $p < 0.001$, $\eta^2 = 0.628$	4.631
SR (%)	Single	2.0 ± 0.9	**2.5 ± 0.8**	2.0 ± 1.0	1.1 ± 0.9	0.5 ± 0.7	−0.1 ± 0.6	**C:** F = 23.67, $p < 0.001$, $\eta^2 = 0.683$	2.319
	Three	1.8 ± 1.7	3.6 ± 1.2 *	4.2 ± 2.0 *	**4.6 ± 1.0 ***	3.6 ± 1.6 *	2.9 ± 1.4 *	**T:** F = 16.34, $p < 0.001$, $\eta^2 = 0.598$	1.186
	Six	1.7 ± 2.0	3.3 ± 3.0	3.9 ± 2.1 *	5.0 ± 2.1 *	5.9 ± 1.6 *#	**6.4 ± 1.9 *#**	**C** × **T:** F = 24.60, $p < 0.001$, $\eta^2 = 0.691$	2.675
YYIR1 (%)	Single	−9.9 ± 2.6	**−11.9 ± 3.7**	−9.5 ± 5.7	−3.0 ± 4.4	−0.4 ± 4.7	1.8 ± 4.6	**C:** F = 37.01, $p < 0.001$, $\eta^2 = 0.771$	1.419
	Three	−15.9 ± 12.0	**−33.1 ± 20.8 ***	−27.5 ± 11.0 *	−23.5 ± 6.8 *	−18.1 ± 6.2 *	−10.5 ± 6.8 *	**T:** F = 14.84, $p < 0.001$, $\eta^2 = 0.574$	0.758
	Six	−11.7 ± 6.6	−26.7 ±10.5 *	−38.3 ± 17.0 *#	−45.1 ± 19.7 *#	**−47.6 ± 17.3 *#**	−41.4 ± 9.0 *#	**C** × **T:** F = 21.62, $p < 0.001$, $\eta^2 = 0.663$	2.854

In the second to last column, the two-way ANOVA results (C: condition effect, T: time effect, C × T: condition x time interaction effect; F- and *p*-values) and eta square (η^2) are shown. In the last column, Cohen's *d* effect size (ES), based on the largest changes (indicated in bold), is shown for the Single versus Three, Three versus Six, and Single versus Six conditions, respectively. *: significantly different from the Single condition, #: significantly different from the Three condition.

3.5. Correlations between Changes in Muscle Damage and Performance Markers

Significant ($p < 0.001$) correlations were evident between the magnitude of decrease in MVC-KE torque at 1 d after a single LIST, three LISTs and six LISTs; CMJ height at 1 d after a single LIST, three LISTs and six LISTs (r = 0.907); peak muscle soreness of KE (r = −0.606) and KF (r = −0.762) as well as peak CK activity (r = −0.875). Significant ($p < 0.001$) correlations were also evident between MVC-KF torque and CMJ height (r = 0.880), peak muscle soreness of KE (r = −0.653) and KF (r = −0.873) and peak CK activity (r = −0.849). Peak CK activity was also correlated ($p < 0.001$) with peak soreness of KE (r = 0.708) and KF (r = 0.838).

The magnitude of changes in the measures at 1 d after the last LIST (average of single LIST, three LIST and six LIST conditions) varied ($p < 0.005$) among MVC-KE (−19 ± 7%), MVC-KF (−22 ± 7%), CMJ (−10 ± 5%), balance (16 ± 8%), 30-m dash (6 ± 3%), 30-m timed hop (12 ± 6%), agility *t*-test (7 ± 4%), 6 × 10-m shuttle run (5 ± 2%) and YYIR1 (−18 ± 8%). As shown in Figure 4, the normalized changes in MVC-KE torque at 1 d after a single LIST, three LISTs and six LISTs ($n = 36$) were correlated ($p < 0.001$) with the changes in 30-m dash (r = −0.762), 30-m timed hop (r = −0.793), balance (r = −0.793), agility *t*-test (r = −0.821), 6 × 10-m shuttle run (r = −0.822), and YYIR1 (r = 0.806) at 1 d after a single LIST, three LISTs and six LISTs. This was also the case for the normalized changes in MVC-KF and 30-m dash (r = −0.854), 30-m timed hop (r = −0.795), balance (r = −0.799), agility *t*-test (r = −0.831), 6 × 10-m shuttle run (r = −0.882) and YYIR1 (r = 0.891). The normalized changes in CMJ at 1 d after a single LIST, three LISTs and six LISTs ($n = 36$) were also correlated ($p < 0.001$) with the changes in 30-m dash (r = −0.770), 30-m timed hop (r = −0.803), balance (r = −0.836), agility *t*-test (r = −0.851), 6 × 10-m shuttle run (r = −0.889), and YYIR1 (r = 0.886) at 1 d after a single LIST, three LISTs and six LISTs (Figure 5).

4. Discussion

The results of the present study revealed that the distance covered in the 2nd–6th LISTs was shorter than that in the single or 1st LIST (Figure 2), and the multiple LISTs induced greater changes in muscle damage and performance markers than the single LIST (Figures 3 and 4, Table 1). Additionally, the magnitude of the changes in muscle damage markers significantly correlated with the magnitude of the changes in performance parameters (Figure 5). These results support the hypothesis and suggest that playing multiple soccer matches on consecutive days accumulates fatigue and muscle damage, impairing the performance of well-trained female soccer players.

The level of the female players used in the present study was considered to be high, since their physiological characteristics (e.g., VO_{2max}: 54.1 ± 4.4 mL/kg/min, MVC-KE torque: 158 ± 18 Nm, CMJ height: 38.6 ± 2.7 cm, YYIR1: 1460 ± 244 m) were similar to those of North European elite female players reported in the previous studies [1,45]. Previous studies also used the LIST to simulate a 90-min soccer match-play and reported that the total distance covered in the 90-min LIST was similar to that of official 90-min soccer matches by male (10,000–12,000 m) [15,46] or female players at the local Premier Division standard or higher, with three National representatives in New Zealand (10,800 m) [47]. In the present study, the total distance covered in the 1st LIST from the three conditions was 9240–11,620 m (average: 10,844 ± 528 m), which was also similar to the level of elite female players.

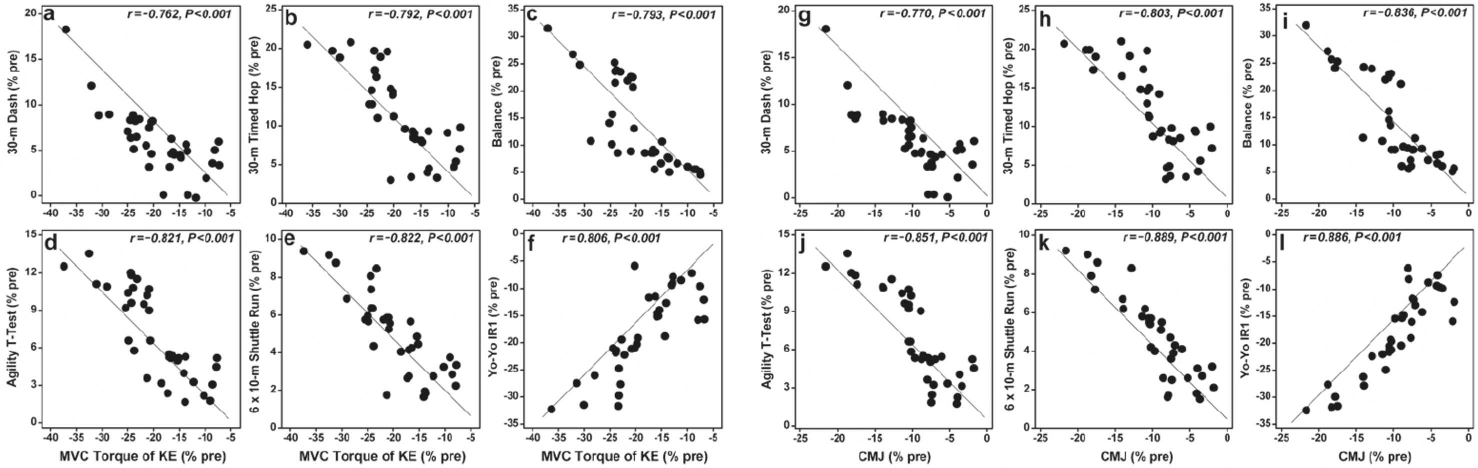

Figure 5. Correlations between the magnitude of normalized changes (% pre) in maximal voluntary isometric contraction torque of knee extensors (MVC-KE) or countermovement jump (CMJ) at 1 d after one Loughborough Intermittent Shuttle Test (LIST) and the normalized changes in 30-m dash (MVC-KE: (**a**), CMJ: (**g**)), 30-m timed hop test (MVC-KE: (**b**), CMJ: (**h**)), balance with eyes closed under unstable surface (MVC-KE: (**c**), CMJ: (**i**)), agility *t*-test (MVC-KE: (**d**), CMJ: (**j**)), 6 × 10-m shuttle run (MVC-KE: (**e**), CMJ: (**k**)) and Yo-Yo Intermittent Recovery Test level 1 (MVC-KE: (**f**), CMJ: (**l**)) at 1 d after LIST with one, three, and six LIST groups combined ($n = 36$). For each figure, r value based on Pearson correlation coefficient and its significance, and a regression line are included.

As shown in Figure 2a, the distance covered in a LIST was 5–10% shorter in the 2nd and 3rd, or 2nd–6th LISTs than in the 1st LIST. This was in line with the findings of a previous study [9] reporting that the covered distance during the 3rd (8331 ± 370 m, −8.5%) and 4th matches (8227 ± 339 m, −9.6%) of junior male players was significantly shorter than that in the 1st match (9102 ± 620 m) in a 4-d (one match per day) soccer tournament. These results suggest that players do not fully recover from a previous match and their performance is reduced when the subsequent match is held on the next day. It should be noted that not only the LIST but also many other performance measures were performed every day in the three and six LIST conditions. Thus, these measures might have affected the LIST performance and recovery, although all participants were familiar with the tests. It has been reported that plasma CK and lactate dehydrogenase activities increase after a YYIR1 [48,49]; however, no previous studies have examined the effects of the other tests on muscle damage and performance measures. The effects of the multiple performance measures on LIST performance should be investigated in a future study.

Significant changes in muscle damage and performance markers were observed after the single LIST, and none of the measures returned to the baseline levels until 4–5 d post-LIST (Figures 3 and 4, Table 1). Previous studies also showed that 3–7 d were required for muscle damage and performance measures to return to the baseline values after an official match [4,50–52], a friendly match [1] or a simulated match [3] performed by well-trained players. Silva et al. [5] showed in their review paper that hamstring force production capacity (ES = −0.7), physical performance such as CMJ (ES = −0.4 to −0.6), *t*-test (ES = −0.4 to 0.5), and linear sprint time (ES = 0.4 to 0.6), CK activity in the blood (ES = 0.4), well-being (fatigue: ES = 0.3–0.9; sleep: ES = 0.2–0.3; stress: ES = 0.2–0.3) and muscle soreness (ES = 0.6–1.3) remained substantially impaired at 3 d after an official soccer match. When compared to simulation protocols, a match format (11 versus 11 players) induced greater increases in CK activity in the blood (ES = 1.8 versus 0.7), IL−6 (ES = 2.6 versus 1.1), monocytes (ES = 1.71 versus 0.95) and neutrophil counts (ES = 2.06 versus 1.04) and muscle soreness (ES = 1.5 versus 0.7). The authors concluded that a period of 3 d post-match-play would not be long enough to completely restore homeostatic balance, and the recovery period post-soccer match was not a "one size fits all" situation [5]. To the best of our knowledge, only one study investigated female players. Hughes et al. [4] found that muscle soreness and increased plasma CK activity lasted for 7 d after an official soccer match of elite female youth players. Regarding male players, Thomas et al. [3] reported that decreased MVC-KE torque and CMJ height, and increased muscle soreness and plasma CK activity were still evident at 3 d after a 90-min LIST performed by 15 semi-professional soccer players. They also reported 2% reduction in voluntary activation, and 5% decrease in quadriceps potentiated twitch force at 2 d post-LIST. In the present study, the time course of changes in muscle damage and performance parameters varied, but most of the parameters did not return to the baseline values at 4 d after a single LIST (Figures 3 and 4, Table 1). It seems reasonable to assume that the responses of the female players to the single LIST shown in the present study were comparable to those of an official soccer match. It is possible that the time course of recovery is influenced by the severity of a match; characteristics of the players such as age, fitness level, gender, and experience; and other factors such as environmental temperature and humidity [2,6]. However, it seems unlikely that even elite female players can fully recover within 3 d after an official match.

Silva et al. [5] stated that match congestion in elite soccer induces residual fatigue and underperformance due to insufficient recovery time. Using time–motion analyses, a couple of studies reported that running performance represented by distances covered was unaffected by match congestion [6,13]. Carling et al. [13] recommended analyses of movement variables including accelerations, decelerations and turns that were more metabolically taxing. Thus, the total distance covered may not be the best indicator of performance. To the best of our knowledge, the present study was the first to examine the effects of three and six LISTs played on consecutive days on muscle damage and performance parameters, and show that multiple matches performed every day negatively affect performance in the LIST, increase muscle damage, and impair performance test results of female soccer players. The changes in muscle damage and performance markers after three LISTs and six LISTs were greater than those after a single LIST (Table 1), and most of the measures did not return to the baseline values even at 5 d after the last LIST (Figures 3 and 4). When the multiple LISTs were performed, it appeared that muscle damage was accumulated and performance got worse (Table 1). As shown in Figure 4, the extent of decreases in performance measures following the last LIST of three LISTs was significantly greater than that after a single LIST, and that following six LISTs was significantly greater than that after three LISTs. It seems that the more multiple soccer matches are performed, the greater the magnitude of muscle damage. However, it should be noted that the magnitude of muscle damage after six LISTs was not six times greater than that after a single LIST. For example, the magnitude of maximal decrease in MVC-KE torque at 1 d after a single LIST, three LISTs and six LISTs was 13%, 20% and 25%, respectively, and the magnitude of decrease in YYIR1 at 1 d after a single LIST, three LISTs and six LISTs was 11%, 19%, and 26%, respectively. It is important to note that the recovery rate of the variables after the last LIST was not largely different among the single LIST, three LISTs and six LISTs. This suggests that the magnitude of muscle damage was attenuated over multiple LISTs due to the repeated bout effect, and the recovery ability was not impaired by multiple LISTs for the well-trained players.

Although it is rare or unlikely that professional soccer players are involved in several official matches in a row, it is possible that players have three [8] or four matches [7,9,10] in a row, in school soccer competitions. The players in the present study had experienced three official matches over three days, and some had played five matches over five days. Although playing six matches in six days is rare in an official soccer tournament, Moreira et al. [11] reported that a congested match schedule such as seven matches played in seven days decreased testosterone concentration in elite Brazilian youth male players and negatively affected their mucosal immunity and impaired the capacity to perform certain technical actions such as tackles, interceptions, and passes. Since the present study used elite female university soccer players, it is not known how higher levels of players, including male professional players, would respond to multiple matches in fixture congestion periods. However, it seems likely that if teams are required to play matches on consecutive days, the time for recovery of players between matches is limited, their physical performance in a subsequent match could be impaired, and fatigue and injury risks would increase [8,11].

In the present study, 1 h after three LISTs, the 30-m dash (−5%), 30-m timed hop (−11%), balance (−16%), agility *t*-test (−5%), 6 × 10-m shuttle run (−4%), and YYIR1 (−19%) all decreased. The magnitude of the decrease in some of the variables appeared to be greater in the present study when compared with that of the previous study [12]. It should be noted that YYIR1 showed the largest decrease (average: −35%) among the performance parameters in the study of Saidi et al. [12]. As shown in Figure 2, the total distance covered in the 2nd to 3rd LISTs in the three LIST condition was 5–9% shorter when compared with the 1st LIST of the three LIST condition, but this was much smaller than the decrease in YYIR1 (Figure 4, Table 1). It should be noted that YYIR1 consists of repeated accelerations, decelerations and changes of direction, which require eccentric contractions. In the present study, no eccentric contraction strength measures were included. It may be that decreases in eccentric contraction strength affected YY1R1 greater than the LIST. This would suggest that the YYIR1 test may be a sensitive marker of soccer performance.

As shown in Figure 5, significant correlations were found between the normalized changes in MVC-KE torque and all performance measures, and this was also the case for the normalized changes in MVC-KF torque. Thus, it seems likely that the decreases in the performance measures were associated with the decreases in KE and KF muscle strength. It is important to note that the normalized changes in CMJ height also significantly correlated with the changes in all performance measures, and the r values were not largely different from those of MVC-KE torque (Figure 5). This may suggest that CMJ height can be used to assess muscle damage and its effects on physical performance in a field, when MVC torque measures are not possible.

The mechanisms underpinning the greater extent of muscle damage and impaired performance measures following multiple LISTs were not investigated in the present study. As discussed above, a single soccer match leads to acute fatigue and muscle damage characterized by a prolonged decline in maximal muscle strength and muscle soreness, which could require at least three days to fully recover (Figure 3, Table 1). Thus, if the next soccer match is performed within three days, it seems likely that players have less fitness when compared with the first match [7,9,10], thus the second match requires more effort than the first match because of the reduced muscle function. This could lead to additional fatigue and muscle damage, thus impairing the performance of the players further [6]. It seems possible that repeatedly performing eccentric actions such as changes in direction, stopping, and decelerations with weaker muscles induces more mechanical stimuli especially to lower limb muscles during a subsequent soccer match [53,54]. It is also possible that recovery of muscle glycogen, dehydration, and mental fatigue would be incomplete, if the recovery time is not long enough [2,6]. This may also exacerbate muscle damage and retard recovery. Thus, strategies for minimizing cumulative fatigue and improving recovery from muscle damage are necessary. Since eccentric muscle actions of leg muscles are performed frequently in a soccer match-play [2,55], and muscle damage is induced by unaccustomed eccentric contractions [53,56], it seems possible that regular eccentric resistance training will attenuate muscle damage [57]. Performing eccentric resistance exercise training may reduce muscle damage and attenuate performance decrement in multiple matches over days in a soccer tournament. However, this hypothesis is need to be explored further.

There are several limitations in the present study. Firstly, the participants of the study were female university soccer players, thus the results of the study may not reflect male, youth and professional players. Secondly, the changes in ovarian hormone status of these female players during the study were not recorded, and the possible effects of the hormones on the outcome measures were not controlled. Thirdly, the LIST does not include kicking a ball, tackles, maximal jumps, changes of directions, and direct contacts with opposing players, and the LIST was performed on the wooden floor of an indoor sport hall in the present study. Thus, this may be different from actual matches played on a grass pitch. Fourthly, previous studies showed that aerobic performance measurements such as YYIR1 affected the recovery of other tests such as short-sprint tests (e.g., 30-m dash) after a soccer match [2,58]. In the present study, no measurements were taken immediately after the LIST and between one and 24 h after the LIST, but many measurements (e.g., 6 × 10-m shuttle running, YYIR1) were taken daily together with the LIST, which may have affected the recovery from the LIST. In the present study, a control group with players experiencing muscle damage and performance measures without performing any LIST was not included. Thus, the effects of measurements on the variables are not known. Fifthly, all participants performed single, three and six LISTs at least 12-week intervals using a semi-counterbalance fashion, but this could potentially result in the repeated bout effect [56]. Although the order of the three conditions was pseudo-randomized among the participants and the time between the conditions was more than 12 weeks, it may be that the players who had the six LIST condition first ($n = 4$) might have had more difficulty than those who had a single LIST ($n = 4$) or three LIST condition ($n = 4$) first. Sixthly, the present study did not assess the effects of muscle damage on skill performance, which is assumed to be affected and influence a game performance. Furthermore, previous studies [59,60] reported that a hot and humid environment impaired the performance of soccer players. In the present study, the LIST was performed in an indoor facility without air-conditioning with the environmental temperature being 30–34 °C and relative humidity being 77–85%. However, it should be noted that the participants of the present study were used to the environment, since they trained and played matches in similar conditions year round in Taiwan. Lastly, the present study was rather descriptive, and a mechanistic approach to investigate the factors affecting muscle damage and performance was absent.

Future studies are warranted to consider these limitations and examine inflammatory responses (e.g., cytokines), changes in central (e.g., transcranial magnetic stimulation) and peripheral (e.g., surface electromyography) neuromuscular parameters, and glycogen and other substances in muscles.

5. Conclusions

In conclusion, multiple LISTs resulted in greater muscle damage and impaired performance than a single LIST, and the extent of muscle damage was associated with the extent of decline in performance measures. The findings of the present study suggest that playing multiple soccer matches can impair the performance of elite female players; thus strategies to minimize muscle damage and enhance recovery are important for the players to perform better in a tournament.

Author Contributions: The study was designed by T.-Y.C. and T.C.C., and discussed with K.N. T.-Y.C. and T.C.C. performed data collection and analyses. All of the authors (T.-Y.C., K.N., T.C.C.) discussed and interpreted the data, contributed to drafting and revising the manuscript, and approved the final version of the manuscript. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Institutional Review Board (or Ethics Committee) of the Research Ethics Committee of National Taiwan Normal University (Approval #: 2018HM023 on 9 April 2019).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data of the current study are available from the corresponding author on reasonable request.

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Conflicts of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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MDPI

Article

Match Day-1 Reactive Strength Index and In-Game Peak Speed in Collegiate Division I Basketball

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Abstract: Basketball is a game of repeated jumps and sprints. The objective of this study was to examine whether repeated jump assessments the day prior to competition (MD-1) could discriminate between fast and slow in-game performances the following day. Seven NCAA Division I Basketball athletes (4 guards and 3 forwards; 20 ± 1.2 years, 1.95 ± 0.09 m, and 94 ± 15 kg) performed a repeated-hop test on a force platform before and after each practice MD-1 to assess Reactive Strength Index (RSI) and Jump Height (JH). Peak speed was recorded during games via spatial tracking cameras. A median split analysis classified performance into FAST and SLOW relative to individual in-game peak speed. Paired *T*-tests were performed to assess post- to pre-practices differences. An independent sample *T*-test was used to assess the differences between FAST and SLOW performances. Cohen's d effect sizes (ES) were calculated to determine the magnitude of the differences. Statistical significance was set for $p \leq 0.05$. Post-practice RSI and JH were significantly higher than pre-training values prior to the FAST but not the SLOW in-game performances. A significant difference was found for MD-1 RSI when comparing FAST and SLOW conditions ($p = 0.01$; ES = 0.62). No significant between-group differences were obtained in JH ($p = 0.07$; ES = 0.45). These findings could have implications on the facilitation of reactive strength qualities in conjunction with match-play. Practitioners should evaluate the placement of stimuli to potentiate athlete readiness for competition.

Keywords: neuromuscular; repeated jump; max speed

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1. Introduction

Basketball is a court-based team sport that requires contributions from various physical parameters and bio-motor abilities [1]. These broad arrays of skills are principal components of in-game performance [2]. Particularly, basketball requires large expressions of speed and power qualities for match-play success. The technical and tactical aspects of the game put a high demand on the neuromuscular system relative to the sporting activity [3]. Therefore, the process of monitoring changes in these qualities for each individual player becomes paramount during the season (in view of the various stressors encountered by the players) [4–6], as it allows for evaluating longitudinal fluctuations over time [7] and provides insight on speed- and power-related performances.

Within basketball, standardized and repeatable jumping assessments are amongst the most popular to assess neuromuscular function [8–12]. The ability to produce substantial amounts of force onto the ground to vertically displace the center of mass is an important skill contextually within the game, since basketball athletes execute around 45 jumps per game [3]. Thus, it is logical that practitioners collect and analyze jump data throughout the competitive season [13] to allow for a more in-depth neuromuscular function assessment [14–16]. This is particularly important since jump height (JH) alone does not always indicate athlete readiness as individuals may change movement strategies to achieve similar outputs [17]. In this context, the assessment of variables other than height in various jump tasks could be a suitable approach to monitor fatigue and readiness in the in-season period [18].

Previous research has examined jumping ability in basketball, with most studies utilizing the countermovement jump (CMJ) to assess neuromuscular function [18–22]. However, basketball mainly requires rapid stretch-shortening cycle (SSC) actions as well as the activation of H-reflex responses [23] that are not always reflected within the CMJ. To overcome this issue, repeated jumping and hopping tasks can be used, as they permit evaluating the ability to produce high vertical ground reaction forces in short ground contact times. In fact, the reactive strength index (RSI) (i.e., ratio of JH/contact time) has been previously used to measure both performance and fatigue within athletes [8,22].

Along with jumping, running speed is also an important characteristic in basketball [24]. Although the sport is played in a 28 by 15-m court, the ability to reach high top speeds and rates of acceleration can be extremely advantageous within the context of the game [1]. Whether it is via jumping- or running-based actions, athletes that can produce large amounts of force is a short amount of time are more likely to be in optimal positions on the court to garner competitive advantages (e.g., grab a rebound or intercept a pass) [25]. Conversely, if an athlete is producing less force and having longer ground contact times relative to their normative datapoint, this may be a potential sign of fatigue [26,27]. It is for this reason that examining the effects that fluctuations in reactive strength qualities have on the mechanical demands of in-game performance can provide informative decision-making on readiness to compete and recovery needs.

To the best of the authors' knowledge, no previous research has investigated whether a repeated-hop test performed the day before basketball competition can provide meaningful information regarding match-play mechanical demands. Therefore, the main purpose of this study was to investigate if fluctuations in reactive strength qualities could be used as an indicator to discriminate between faster and slower physical in-game performance the following day. This research may help coaches and sports scientists to make more informed decisions on both training and recovery.

2. Materials and Methods

A prospective comparative study was conducted. Neuromuscular performance was assessed on the training day before competition (i.e., Match-day-1 [MD-1]) via a repeated-hop test. Match-play data was recorded during all 17 matches at the team's home arena. All data was collected between the months of November 2017 and February 2018 by the strength and conditioning staff as routine for the daily assessment of fatigue and player loads.

To evaluate neuromuscular performance (i.e., RSI and JH) on MD-1 for all 17 games, a repeated-hop test [28] was performed. The test was performed both pre-practice and post-practice to account for any of the acute effects imposed by the training session the day before the competition. A standardized warm-up of squats, lunges, and free arm swing CMJ preceded the assessment. Three repeated-hops were performed on a triaxial force platform (9260 AA-Kistler, Kistler Group, Winterhur, Switzerland) with the athletes' hands on their hips. Players were instructed to jump as high and as fast as possible while spending minimal time on the plate without resetting between jumps. All tests were completed 15-min prior to, and after practice. The tests were disregarded if the athlete did not complete the standardized warm-up or did not fall within the 15-min windows. Likewise, data was not considered if the player did not test both pre- and post-practice. All jumps were recorded via a data acquisition system (DAQ System Type 5691 A- Kistler, Kistler Group, Winterhur, Switzerland). Each trial was exported to a TXT file and analyzed with the ForceDecks Software (Vald Performance, Brisbane, Australia) [29]. For each athlete, the difference between post- and pre-practice values were calculated (i.e., delta [Δ]). A positive or a negative integer would indicate an increase or decrease in neuromuscular performance, respectively. The mean of the 3 jumps RSI (calculated by dividing JH/contact time) in $m{\cdot}s^{-1}$, and JH, in cm, were considered for analysis.

Match-play activity profiles were tracked for each of the 17 home games throughout the 2017–2018 season via spatial tracking cameras (Sport VU®, Stats Perform, Chicago, IL, USA). This six-camera system was set up in the home gymnasium during competitions to track distance and speed of each athlete. The activity profile data was collected via Stats Sports VU software and exported to a customized spreadsheet (Microsoft Excel 2016, Microsoft Corporation, Redmond, WA, USA). The primary performance metric examined was peak speed ($km{\cdot}h^{-1}$), given that it is an intensity-related variable that can provide a good gauge of neuromuscular readiness. A median split relative to individual's peak speed was used to determine fast versus slow in-game performances. All 7 players competed in every home match.

Data is presented as means and standard deviation. Data normality was tested using the Shapiro-Wilk test ($n < 30$). For every player, in-game performances ($n = 17$) were divided using a median split analysis into two groups (i.e., FAST: above the individual's median value, and SLOW: below the player's median) according to the peak speed achieved by each athlete during competition. Paired *T*-tests were performed to assess post- to pre-practices differences. An independent Sample *T*-test was used to assess the differences between FAST and SLOW performances. Cohen's d effect sizes (ES) [30] were calculated to determine the magnitude of the differences and classified as: trivial (<0.2), small (>0.2–0.6), moderate (>0.6–1.2), large (>1.2–2.0), and very large (>2.0–4.0). Statistical significance was set for $p \leq 0.05$.

3. Results

Table 1 shows the descriptive data and the comparison between FAST and SLOW performances. Post-practice RSI and JH were significantly higher than pre-training values prior to the FAST but not the SLOW in-game performances. Moreover, when considering the ergogenic response from before to after training (i.e., Δ), a significant difference was found for MD-1 RSI when comparing FAST and SLOW conditions ($p = 0.01$; ES = 0.62). No significant between-group differences were obtained in JH ($p = 0.07$; ES = 0.45).

Table 1. Repeated-hop descriptive data from Match-Day -1 and comparison between FAST and SLOW in-game performances.

	In-Game Performance			
	FAST	**SLOW**	***p***	**ES (95% CI)**
Jump Height (cm)				
Pre-Practice	19.1 ± 5.7	20.9 ± 4.0	0.16	−0.37 (−0.9–0.16)
Post-Practice	23.5 ± 8.7 **	22.1 ± 4.5	0.45	0.20 (−0.32–0.73)
Δ	4.4 ± 8.1	1.2 ± 4.7	0.07	0.49 (−0.05–1.03)
RSI ($m{\cdot}s^{-1}$)				
Pre-Practice	42.6 ± 20.1	45.1 ± 16.1	0.54	−0.13 (−0.66–0.39)
Post-Practice	57.5 ± 27.2 **	47.1 ± 17.4	0.16	0.45 (−0.09–0.98)
Δ	16.4 ± 27.1	2.0 ± 18.3	0.01	0.62 (0.06–1.17)

** Significant increase with respect to pre-practice ($p \leq 0.01$). **Δ**: delta, change from pre- to post-practice; CI: confidence interval; ES: effect size; RSI: reactive strength index.

4. Discussion

The aim of the present study was to examine MD-1 pre- to post-practice differences (i.e., Δ) in repeated jump outputs and determine whether potentiation or degradation of neuromuscular performance in training could discriminate between faster and slower in-game physical performance. The main findings indicated that large gains in RSI (from before to after training) were observed the day prior to competitions in which higher peak speed values were reached during match-play. These preliminary results are novel and suggest that testing athletes' repeated jump ability both prior to and after practice MD-1 (to account for any potential acute onset of fatigue or potentiation) can provide meaningful information regarding neuromuscular readiness to compete. This study is also unique in that it evaluated elite level basketball players throughout the entire competitive season.

Of note, vertical jump has been previously found to be highly related to running speed [24] and a predictor of repeated-sprint ability in elite basketball players [25]. However, the present study is the first to identify what seemed to be a positive influence of gains in RSI MD-1 in peak speed of subsequent basketball competition. This finding could be extremely useful to practitioners considering that neuromuscular performance usually fluctuates during a typical in-season week [26]. Knowing that speed is a primary component in basketball [1,3], coaches can, therefore, optimize training strategies with the aim of maximizing reactive strength qualities prior to competition. This may, in turn, translate into superior neuromuscular status of the athletes that can place them at an optimal position for in-game success.

Remarkably, Δ JH MD-1 was not able to discriminate between FAST and SLOW in-game performances. Gathercole et al. [11] reported that neuromuscular function alternations 24 h after a fatiguing protocol were not detected when using JH alone (i.e., in both CMJ and drop jump tasks) and suggested that complementary variables such as Flight Time:Contact Time ratio should be assessed. Likewise, it appears that in the repeated-hop test herein, Δ RSI was more sensible than JH to determine neuromuscular readiness the following day. Based on the previous, it appears that an athlete's ability to express high-force outputs in reduced contact times may better discriminate between FAST and SLOW games when compared to how high he can jump in a repeated-hop task. From a practical perspective, coaches are recommended to utilize the RSI metric obtained from a high rate of frequency test to assess their players on MD-1.

The limitations of the present study should be addressed. Firstly, the small sample size limits the generalization of the current findings to other athletic populations. Nevertheless, since 17 games were analyzed here, the preliminary results obtained open a new perspective and should be investigated more in-depth. Secondly, it is important to keep in mind that peak speed is only one of many in-game physical parameters (e.g., accelerations, decelerations, or jumps); hence, further research should consider a more complete set of metrics to provide a clearer picture regarding match-play performance. Finally, variables other than RSI alone may influence subsequent in-game physical performance (e.g., MD-1 training load, recovery protocols, priming strategies). Thus, the reader should interpret the present results cautiously.

In summary, MD-1 sessions that resulted in greater post-practice increases in RSI were observed prior to faster in-game performances when examining peak speed in elite collegiate basketball players. However, larger JH gains were not able to discriminate between faster and slower performances. These finding could impact stimuli provided to athletes prior to competition. Exposures to menu items that promote maximal high force outputs applied in reduced contact times may be most appropriate close to competition.

5. Conclusions

Athletes with greater gains (i.e., Δ) in RSI from pre- to post-practice were found to achieve greater peak speeds in match-play the following day. Conversely, no differences were found between FAST or SLOW performances when JH was the variable analyzed. It is for this reason that professionals should closely examine acute adaptations to MD-1 as it may influence player selection or training strategies that place their athletes in the best position to succeed on the court. Having a critical thought process in regard to the sequencing of menu items is vital in the appreciation of the heterochronicity and different time courses of adaptive processes for varying stimuli. Specifically, actions that foster reactive strength and short ground contacts should be placed as close to the competition as possible within a training week. Further research on these topics is needed to gain a more robust insight into how to best create an environment for optimal neuromuscular outputs around match-play. The proper application of stimulus relative to match-play could have a direct impact on the optimization of neuromuscular status for in-game performance.

Author Contributions: For this present study A.J.P. was responsible for data collection and writing. T.T.F. was responsible for data curation, formal analysis, and editing. J.C.-G. and P.E.A. were responsible for methodologies, editing, and supervision. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The University Institutional Review Board (IRB #17-04-632) approved this study in accordance with the Helsinki Declaration and researchers were provided de-identified data to analyze. As student-athletes for the university's basketball program, each player provided individual consent for study participation as part of their team requirements.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available within the article.

Conflicts of Interest: The authors declare no conflict of interest.

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Article

Data Mining to Select Relevant Variables Influencing External and Internal Workload of Elite Blind 5-a-Side Soccer

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Abstract: (1) Background: Data mining has turned essential when exploring a large amount of information in performance analysis in sports. This study aimed to select the most relevant variables influencing the external and internal load in top-elite 5-a-side soccer (Sa5) using a data mining model considering some contextual indicators as match result, body mass index (BMI), scoring rate and age. (2) Methods: A total of 50 top-elite visually impaired soccer players (age 30.86 ± 11.2 years, weight 77.64 ± 9.78 kg, height 178.48 ± 7.9 cm) were monitored using magnetic, angular and rate gyroscope (MARG) sensors during an international Sa5 congested fixture tournament.; (3) Results: Fifteen external and internal load variables were extracted from a total of 49 time-related and peak variables derived from the MARG sensors using a principal component analysis as the most used data mining technique. The principal component analysis (PCA) model explained 80% of total variance using seven principal components. In contrast, the first principal component of the match was defined by jumps, take off by 24.8% of the total variance. Blind players usually performed a higher number of accelerations per min when losing a match. Scoring players execute higher $\text{Distance}_{\text{Explosive}}$ and $\text{Distance}_{21\text{–}24\ \text{km/h}}$. And the younger players presented higher HR_{AVG} and Acc_{Max}. (4) Conclusions: The influence of some contextual variables on external and internal load during top elite Sa5 official matches should be addressed by coaches, athletes, and medical staff. The PCA seems to be a useful statistical technique to select those relevant variables representing the team's external and internal load. Besides, as a data reduction method, PCA allows administrating individualized training loads considering those relevant variables defining team load behavior.

Keywords: soccer; performance analysis; heart rate; technology; inertial measurement units

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1. Introduction

Soccer 5-a-side (Sa5) is an adapted Paralympic sport for people with blindness [1]. The game has different modifications compared to soccer for persons without a disability. The game is played in a 40 × 20 m field with barriers on the sides and a ball that sounds when moving [2]. To be orienteered, players receive auditory references during the game by three sighted components; their coach, their goalkeeper, and the "caller", who stands behind the opponent's goal [3].

The Sa5 game requires some crucial adaptations of the sport technic and tactic because it is played in a total absence of visual references, which differentiates it from other soccer modalities. These unique characteristics are presented in scientific literature, with diverse approaches [4], highlighting performance analysis in sports, focusing on the main technical aspects [5,6], and defining performance indicators that explain the success in this sporting context [7–11].

In recent years, research on performance analysis in sports for people with disabilities has used new technological devices to quantify athletes' external load. This load is usually linked with other internal load indicators (e.g., heart rate) to have a global perspective of the physical and physiological game demands [12–14]. The use of the so-called electronic performance and tracking systems (EPTS) has increased due to its portability and availability of many variables. These devices integrate multiple sensors (e.g., accelerometers, gyroscopes, magnetometers, global position systems and tracking technology) [15], allowing to record data related to the workload profile. These variables bring information about the magnitude and frequency of accelerometric-based (e.g., impacts, jumps, steps, landings, changes of direction) and speed-based indicators (e.g., distance, mean speed). Due to the sensor's capacity, up to 250 variables are registered at a sampling frequency of 100 to 1000 Hz. This is why this information is defined as big data [16,17]. To identify, cluster, and select the most relevant variables in a specific team and task, it is necessary to implement a data mining technique [18]. The reduction in the data sets size allows to objectively identify the variables to assess the interaction between the external and internal load with other contextual factors that may influence performance.

One of these data mining methods is known as Principal Component Analysis (PCA). This is the most used technique to reduce data into a small series of variables (5–15 variables), explaining up to 70% of the data set variance. Although some studies have applied this statistical method to select and cluster anthropometric, biomechanical, physical, and physiological variables of team top elite sports, this procedure has never been used in the performance analysis of adapted sports for people with disabilities [19].

Considering that some contextual and situational factors may influence game's physical and physiological performance, as other studies have revealed, it is hypothesized that due to the particular characteristics of the Sa5 game, the magnitude of some external and internal load variables could be influenced by contextual variables as match result, age, goal scorer and anthropometric variables. We hypothesized that both internal and external load variables may be affected by match result, age, goal scorer and some anthropometric variables, based on previous results of similar studies. Consequently, this study aimed to explore the potential differences in the Sa5 internal and external load variables selected by PCA considering three variables: a. match result, b. body mass index (BMI), c. scoring rate and d. age.

2. Materials and Methods

2.1. Study Design

A cross-sectional and observational protocol approached the problem of the study. The external and internal load variables were assessed during a Sa5 International Tournament. This congested tournament was held on a single weekend, and the teams were representatives of European national teams. A total of four matches were played per each team under similar circumstances and in the same venue. The Sa5 International Tournament was held in the city of Seville (Spain) in May 2019 (temperature = 21.2 ± 3.7 °C, relative humidity = 65.2 ± 5.3%), in which the teams of Spain, Italy, the Czech Republic, and an Andalusian team participated.

2.2. Participants

Data were collected from 50 blinded male players (age 30.86 ± 11.2 years, weight 77.64 ± 9.78 kg, height 178.48 ± 7.9 cm). The players were members of top elite national European teams. There were no reports of neuromuscular injuries that could compromise physical or physiological performance. The players who participated >85% of the matches' effective time were included in the analysis.

Before data collection, all participants signed an informed consent document, which contained all the investigation details. The protocol followed the Helsinki Declaration guidelines for biomedical research. The study was reviewed and approved by the Institutional Review Board (University of Extremadura, Reg. Code 67/2017). Besides, the teams' staff and tournament managers gave their consent for participation in this research.

2.3. Instruments and Procedures

Before the matches, each player was equipped with a heart rate monitor (GARMIN^{TM}, Lenexa, KS, USA) to record internal load variables. Magnetic, angular rate, and gravity (MARG) sensors (WIMU^{TM}, RealTrack Systems, Almería, Spain) were fixed using an adapted anatomically harness at the height of T2–T4 vertebrae between scapulae. The devices were calibrated considering previously published guidelines [20]. The MARG sensors integrate data of four three-axis microelectromechanical system accelerometers, gyroscope, and magnetometer to assess external load-related variables. After registration, the data was processed using special software (SPRO^{TM}, RealTrack Systems, Almería, Spain) immediately after each match. Moreover, the MARG sensor incorporate GPS and UWB systems to register all speed and distance based variables. The sampling was made using a 5 Hz sampling frequency for the GPS system and 100 Hz for accelerometric-based variables [21]. All players were used to wear the MARG sensors during soccer matches.

2.4. Variables

While the MARG sensors provide up to 200 variables, considering there could be differences in the time played in each match, only peak and time-related variables were initially selected (n = 44). This criterion is used to homogenize the average demands of each match [22–24]. These variables were introduced in a correlation matrix to select the uncorrelated representative variables; those with an $r > 0.7$ were discarded [25]. Before an Exploratory Factor Analysis called Principal Component Analysis (PCA), this procedure was performed, and previous similar studies' statistical protocol was followed [19,22]. Variables with variance = 0 were excluded from the analysis.

The 15 selected variables after the correlation matrix were scaled and centered (Z-scores). Suitability of PCA was confirmed by Kaiser-Meyer-Olkin (KMO = 0.71), and Barleth's Sphericity test was significant ($p < 0.01$) [26,27]. Eigenvalues >1 were considered for the extraction of principal components (PC) [27]. A VariMax-orthogonal rotation method was performed to identify high correlations of components and guarantee that each principal component offered different information. A threshold of 0.6 in each PC loading was retained for interpretation, extracting the highest factor loading when a cross-loading was found between PCs. PCA procedure followed standard quality criteria, meeting 21 out of 21 of the quality items [19]. Moreover, the report of the PCA model results followed previous guidelines for team sport performance analysis [28].

The contextual variables considered during this tournament were match result (losers vs. winners), BMI (lower vs. higher based on the BMI mean), scoring rate (those scorers at least once during a match vs. non-scorers), and age (younger vs. older players based on the age mean).

2.5. Statistical Analysis

Data were expressed in mean and standard deviation with respective upper and lower limits for descriptive purposes. Independent *t*-tests were performed to explore differences by match result (loser vs. winner), BMI (lower vs. higher), scoring rate (scorer vs. non-scorer) and age (younger vs. older). The magnitude of *t*-test differences was interpreted using Cohen's d (d) as follows: 0–0.2 trivial; 0.2–0.5 low; 0.5–0.8 moderate and >0.8 high [29]. Statistical differences were considered if $p < 0.05$. Data exploratory analysis was performed using the Statistical Package for the Social Sciences (SPSS, IBM, SPSS Statistics, v.22.0 Chicago, IL, USA).

3. Results

Table 1 shows absolute descriptive data of the 15 selected variables of the whole match. A total of seven PCs were extracted after performing PCA. The whole model explains 80.5% of the total variance. PC cumulative variance of each PC is shown in Table 1.

Table 1. External workload and locomotion variables extracted from principal components analysis in soccer 5-a-side playing.

	M ± DS	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**	**PC7**
Eigenvalue		4.2	2.9	1.8	1.6	1.1	1.1	1
% Variance	Whole Match	24.8	1.3	10.3	9.3	6.5	6.4	5.9
% Cumulative Variance		24.8	42.1	52.4	61.7	68.2	74.6	80.5
Jumps (n/min)	0.08 ± 0.08 (0.01; 0.5)	0.99						
TakeOff$_{0–3\ \text{g}}$ (n/min)	0.07 ± 0.05 (0; 0.25)	0.86						
TakeOff$_{3–5\ \text{g}}$ (n/min)	0.01 ± 0.04 (0; 0.25)	0.85						
Acc (n/min)	42.41 ± 4.54 (33.88; 54.46)		−0.81					
HR$_{\text{AVG}}$ (bpm)	138.53 ± 19.86 (87; 171)		0.84					
Distance$_{\text{Explosive}}$ (m/min)	2.72 ± 2.03 (0; 8.42)			0.7				
Distance$_{21–24\ \text{km/h}}$ (m/min)	0.02 ± 0.11 (0; 0.69)			0.71				
Dec$_{5–4\ \text{m/s}}$ (n/min)	0.01 ± 0.02 (0; 0.09)			0.67				
Impacts$_{5–8\ \text{g}}$ (n/min)	1.74 ± 1.67 (0; 6.85)			0.61				
Acc$_{4–5\ \text{m/s}}$ (n/min)	0 ± 0.01 (0; 0.03)				0.83			
Dec$_{6–5\ \text{m/s}}$ (n/min)	0 ± 0.01 (0; 0.03)				0.87			
Acc$_{\text{Max}}$ (m/s)	3.33 ± 0.99 (33.88, 54.46)					0.81		
Acc$_{6–10\ \text{m/s}}$ (n/min)	0 ± 0 (0; 0.02)					0.96		
Acc$_{5–6\ \text{m/s}}$ (n/min)	0 ± 0 (0; 0.02)						0.95	
TakeOff$_{5–8\ \text{g}}$ (n/min)	0 ± 0.01 (0; 0.03)							0.93

The results suggested differences by match result in only one external load variable. There were differences by match results in Acc per minute, and the losers make higher accelerations during the matches compared to the winners (see Table 2). This change was qualified as low based on effect size.

Table 2. External workload and locomotion variables in soccer 5-a-side playing by match result.

Variable	**Winner (n = 23)**	**Loser (n = 27)**	**t (*p* Value)**	**Cohen's *d***
Jumps (n/min)	0.09 ± 0.05 (0.02; 0.22)	0.08 ± 0.09 (0.01; 0.5)	0.37 (0.71)	0.05
TakeOff$_{0–3\ \text{g}}$ (n/min)	0.08 ± 0.05 (0.02; 0.22)	0.07 ± 0.05 (0; 0.25)	1.02 (0.31)	0.14
TakeOff$_{3–5\ \text{g}}$ (n/min)	0.01 ± 0.02 (0; 0.08)	0.01 ± 0.05 (0; 0.25)	−0.64 (0.53)	0.09
Acc (n/min)	40.73 ± 3.91 (33.88; 51.14)	43.8 ± 4.61 (38.26; 54.46)	−2.55 (0.01) *	0.4
HR$_{\text{AVG}}$ (bpm)	142.7 ± 3.91 (93;170)	134.85 ± 20.55 (87; 171)	1.39 (0.17)	0.2
Distance$_{\text{Explosive}}$ (m/min)	2.64 ± 2.37 (0.07; 8.42)	2.79 ± 1.72 (0; 5.96)	−0.26 (0.8)	0.04
Distance$_{21–24\ \text{km/h}}$ (m/min)	0.05 ± 0.16 (0; 0.69)	0 ± 0 (0; 0)	1.52 (0.14)	0.21
Dec$_{5–4\ \text{m/s}}$ (n/min)	0.01 ± 0.02 (0; 0.09)	0.01 ± 0.01 (0; 0.04)	0.39 (0.18)	0.06
Impacts$_{5–8\ \text{g}}$ (n/min)	0.01 ± 0.02 (0; 0.08)	0.02 ± 0.04 (0; 0.17)	0.04 (0.97)	0.01
Acc$_{4–5\ \text{m/s}}$ (n/min)	0 ± 0.01 (0; 0.03)	0 ± 0.01 (0; 0.03)	0.27 (0.79)	0.04

Table 2. *Cont.*

Variable	Winner (n = 23)	Loser (n = 27)	t (*p* Value)	Cohen's *d*
Dec$_{6\text{–}5\ \mathrm{m/s}}$ (n/min)	0 ± 0.01 (0; 0.02)	0 ± 0.01 (0; 0.03)	−0.9 (0.37)	0.13
Acc$_{\mathrm{Max}}$ (m/s)	3.2 ± 0.92 (1.43; 5.4)	3.44 ± 1.06 (1.07; 7.43)	−0.87 (0.39)	012
Acc$_{6\text{–}10\ \mathrm{m/s}}$ (n/min)	0 ± 0.01 (0; 0.02)	0 ± 0.01 (0; 0.02)	−0.92 (0.36)	0.13
Acc$_{5\text{–}6\ \mathrm{m/s}}$ (n/min)	0 ± 0.01 (0; 0.02)	0 ± 0.01 (0; 0.02)	1.09 (0.28)	0.15
TakeOff$_{5\text{–}8\ \mathrm{g}}$ (n/min)	0 ± 0.01 (0; 0.03)	0 ± 0.01 (0; 0.01)	1.21 (0.23)	0.17

* Significant differences with low effect size.

Additionally, there were no differences in external or internal workload demands considering BMI (see Table 3). No differences were found between those players categorized in low or high BMI. Besides, effect sizes showed trivial changes by group.

Table 3. External workload and locomotion variables in soccer 5-a-side playing by BMI.

Variable	Lower BMI (n = 34)	Higher BMI (n = 16)	t (*p* Value)	Cohen's *d*
Jumps (n/min)	0.08 ± 0.05 (0.02; 0.22)	0.09 ± 0.11 (0.01; 0.5)	−0.56 (0.58)	0.08
TakeOff$_{0\text{–}3\ \mathrm{g}}$ (n/min)	0.07 ± 0.04 (0.02; 0.22)	0.07 ± 0.06 (0; 0.25)	0.04 (0.97)	0.01
TakeOff$_{3\text{–}5\ \mathrm{g}}$ (n/min)	0.01 ± 0.02 (0; 0.08)	0.02 ± 0.06 (0; 0.25)	−1.19 (0.24)	0.17
Acc (n/min)	41.71 ± 4.73 (33.88; 54)	43.9 ± 3.82 (39.46; 54.46)	−1.19 (0.24)	0.17
HR$_{\mathrm{AVG}}$ (bpm)	140.52 ± 19.15 (87; 170)	134.44 ± 21.3 (91; 171)	−1.75 (0.09)	0.25
Distance$_{\mathrm{Explosive}}$ (m/min)	2.9 ± 2.13 (0; 8.42)	2.33 ± 1.79 (0.24; 5.96)	0.97 (0.34)	0.14
Distance$_{21\text{–}24\ \mathrm{km/h}}$ (m/min)	0.03 ± 0.13 (0; 0.69)	0 ± 0 (0; 0)	0.93 (0.36)	0.13
Dec$_{5\text{–}4\ \mathrm{m/s}}$ (n/min)	0.01 ± 0.02 (0; 0.09)	0.01 ± 0.01 (0; 0.04)	0.95 (0.35)	0.14
Impacts$_{5\text{–}8\ \mathrm{g}}$ (n/min)	1.68 ± 1.6 (0; 5.9)	1.85 ± 1.87 (0.1; 6.85)	0.97 (0.34)	0.14
Acc$_{4\text{–}5\ \mathrm{m/s}}$ (n/min)	0.01 ± 0.01 (0; 0.03)	0 ± 0.01 (0; 0.02)	1.02 (0.32)	0.14
Dec$_{6\text{–}5\ \mathrm{m/s}}$ (n/min)	0.01 ± 0.01 (0; 0.03)	0 ± 0 (0; 0.01)	1.18 (0.24)	0.14
Acc$_{\mathrm{Max}}$ (m/s)	3.26 ± 0.89 (1.07; 5.4)	3.47 ± 1.2 (2.28; 7.43)	−0.69 (0.5)	0.1
Acc$_{6\text{–}10\ \mathrm{m/s}}$ (n/min)	0 ± 0.01 (0; 0.02)	0 ± 0.01 (0; 0.02)	−1 (0.33)	0.14
Acc$_{5\text{–}6\ \mathrm{m/s}}$ (n/min)	0 ± 0 (0; 0.02)	0 ± 0.01 (0; 0.02)	−1.48 (0.15)	0.21
TakeOff$_{5\text{–}8\ \mathrm{g}}$ (n/min)	0 ± 0.01 (0; 0.03)	0 ± 0 (0; 0.01)	0.64 (0.53)	0.09

There were found differences in distance variables extracted from the PCA model. Those players who scored at least once during the matches showed higher Distance$_{\mathrm{Explosive}}$ and Distance$_{21\text{–}24\ \mathrm{km/h}}$ than non-scorers (see Table 4). These variables showed low changes between groups based on the effect size.

Table 4. External workload and locomotion variables in soccer 5-a-side playing by goal scorer.

Variable	Non Scorer (n = 32)	Scorer (n = 13)	t (*p* Value)	Cohen's *d*
Jumps (n/min)	0.09 ± 0.09 (0.02; 0.5)	0.07 ± 0.04 (0.01; 0.17)	0.54 (0.59)	0.08
TakeOff$_{0\text{–}3\text{ g}}$ (n/min)	0.07 ± 0.05 (0.02; 0.25)	0.07 ± 0.04 (0; 0.14)	0.18 (0.86)	0.03
TakeOff$_{3\text{–}5\text{ g}}$ (n/min)	0.01 ± 0.05 (0; 0.25)	0 ± 0.01 (0; 0.04)	0.82 (0.42)	0.1
Acc (n/min)	42.68 ± 4.44 (33.88; 54.04)	41.64 ± 4.9 (34.58; 54.46)	0.71 (0.48)	0.1
HR$_{\text{AVG}}$ (bpm)	138.56 ± 20.32 (87; 171)	138.46 ± 19.32 (91; 168)	0.01 (0.99)	0
Distance$_{\text{Explosive}}$ (m/min)	2.36 ± 1.58 (0; 5.02)	3.74 ± 2.79 (0.24; 8.42)	−2.18 (0.03) *	0.31
Distance$_{21\text{–}24\text{ km/h}}$ (m/min)	0 ± 0.01 (0; 0.02)	0.08 ± 0.21 (0; 0.69)	−2.44 (0.02) *	0.34
Dec$_{5\text{–}4\text{ m/s}}$ (n/min)	0.01 ± 0.01 (0;0.04)	0.02 ± 0.03 (0; 0.09)	−1.34 (0.19)	0.19
Impacts$_{5\text{–}8\text{ g}}$ (n/min)	1.53 ± 1.54 (0; 6.85)	2.33 ± 1.94 (0.1; 5.9)	−1.51 (0.14)	0.21
Acc$_{4\text{–}5\text{ m/s}}$ (n/min)	0 ± 0.01 (0; 0.03)	0.01 ± 0.01 (0; 0.03)	−0.45 (0.65)	0.06
Dec$_{6\text{–}5\text{ m/s}}$ (n/min)	0 ± 0.01 (0; 0.03)	0 ± 0.01 (0; 0.02)	−0.07 (0.95)	0
Acc$_{\text{Max}}$ (m/s)	3.34 ± 1.1 (1.07; 7.43)	3.3 ± 0.64 (2.28; 4.29)	0.14 (0.89)	0.02
Acc$_{6\text{–}10\text{ m/s}}$ (n/min)	0 ± 0 (0; 0.02)	0 ± 0 (0; 0)	0.59 (0.56)	0.08
Acc$_{5\text{–}6\text{ m/s}}$ (n/min)	0 ± 0 (0; 0.02)	0 ± 0 (0; 0)	0.59 (0.56)	0.08
TakeOff$_{5\text{–}8\text{ g}}$ (n/min)	0 ± 0.01 (0; 0.03)	0 ± 0.01 (0; 0.02)	0.32 (0.71)	0.05

* Significant differences with low effect size.

There were found differences by age in HR$_{\text{AVG}}$ and Acc$_{\text{Max}}$ as internal and external load variables, respectively. Younger players performed higher HR$_{\text{AVG}}$ and Acc$_{\text{Max}}$ compared to the older ones. Effects sizes of these changes were classified as low (see Table 5).

Table 5. External workload and locomotion variables in soccer 5-a-side playing by age.

Variable	Younger (n = 22)	Older (n = 28)	t (*p* Value)	Cohen's *d*
Jumps (n/min)	0.07 ± 0.03 (0.03; 0.13)	0.1 ± 0.1 (0.01; 0.5)	−1.06 (0.29)	0.15
TakeOff$_{0\text{–}3\text{ g}}$ (n/min)	0.07 ± 0.03 (0.03; 0.11)	0.08 ± 0.06 (0; 0.25)	−0.54 (0.59)	0.08
TakeOff$_{3\text{–}5\text{ g}}$ (n/min)	0 ± 0.01 (0; 0.02)	0.02 ± 0.05 (0; 0.25)	−1.26 (0.22)	0.18
Acc (n/min)	41.17 ± 4.47 (33.88; 54.04)	43.38 ± 4.43 (37.87; 54.46)	−1.74 (0.09)	025
HR$_{\text{AVG}}$ (bpm)	147.17 ± 4.47 (33.88; 54.04)	131.04 ± 20.79 (87; 168)	3.19 (0.003) *	0.45
Distance$_{\text{Explosive}}$ (m/min)	3.13 ± 1.49 (0.55; 6.44)	2.4 ± 2.34 (0; 8.42)	1.29 (0.2)	0.18
Distance$_{21\text{–}24\text{ km/h}}$ (m/min)	0.03 ± 1.49 (0.55; 6.44)	0.01 ± 0.07 (0; 0.35)	0.58 (0.56)	0.08
Dec$_{5\text{–}4\text{ m/s}}$ (n/min)	0.01 ± 0.01 (0; 0.04)	0.01 ± 0.02 (0; 0.09)	0.07 (0.94)	0.01
Impacts$_{5\text{–}8\text{ g}}$ (n/min)	1.7 ± 1.31 (0.14; 4.06)	1.77 ± 1.93 (0; 6.85)	−0.15 (0.88)	0.15

Table 5. *Cont.*

Variable	Younger (n = 22)	Older (n = 28)	t (p Value)	Cohen's d
$Acc_{4–5\ m/s}$ (n/min)	0.01 ± 0.01 (0.14; 4.06)	0 ± 0.01 (0; 0.03)	1.04 (0.3)	0.14
$Dec_{6–5\ m/s}$ (n/min)	0 ± 0.01 (0; 0.03)	0 ± 0 (0; 0.02)	1.4 (0.17)	0.2
Acc_{Max} (m/s)	3.73 ± 1.06 (2.52; 7.43)	3.02 ± 0.82 (1.07; 4.29)	2.68 (0.01) *	0.4
$Acc_{6–10\ m/s}$ (n/min)	0 ± 0 (0; 0.02)	0 ± 0 (0; 0)	1.13 (0.26)	0.16
$Acc_{5–6\ m/s}$ (n/min)	0 ± 0 (0; 0.02)	0 ± 0 (0; 0)	1.13 (0.26)	0.16
$TakeOff_{5–8\ g}$ (n/min)	0 ± 0 (0; 0)	0 ± 0.01 (0; 0.03)	−1 (0.32)	0.14

* Significant differences with low effect size.

4. Discussion

The purpose of this study was to explore the potential differences in the Sa5 internal and external load variables selected by PCA considering three variables as match result, body mass index (BMI), scoring rate and player's age. The results suggested that players usually performed a higher number of accelerations per min when losing a match. There were no differences in external workload variables by player's BMI. Those Sa5 players that scored during a match execute higher $Distance_{Explosive}$ and $Distance_{21–24\ km/h}$. And younger players presented higher HR_{AVG} and Acc_{Max}.

In actual soccer-playing, high-intensity actions (e.g., sprints, high-speed running, jumps, etc.) are considered the most relevant external load performance indicators in team sports. Moreover, these variables seem to be crucial during congested fixture conditions, and it is essential to understand how these external and internal load variables could be affected by some contextual factors [22]. Addressing these potential load differences could be fundamental when planning and monitoring both training and official matches.

In this research, 80.5% of the total variance was explained by the PCA model using seven PCs. The 15 variables extracted from the model were heart rate, accelerations, decelerations, high-intensity speed, impacts, jumps, and take-offs. The present PCA results are in line with analyses previously performed in team sports3/17/2021 10:34:00 PM were external and internal load variables derived from MARGS and inertial measurement units in team sports were selected through PCAs [19]. After the variables extraction, the results suggested some impact on external and internal loads by match outcome, scoring rate, and age.

It has been found that match outcome is significantly related to performance in some external and internal load variables in soccer. In this study, it was found that losers teams performed more accelerations per minute than the winners. In this sense, it has been also reported that total distance increases when losing even when distance performed between 0–6 km/h decreased [30]. These results suggest that high-intensity actions as accelerations could increase to improve the final score as the losing team is trying to look after new goal opportunities [30]. Although, there is a lack of agreement in soccer research since the link between the higher external and internal is not clearly understood; considering that other match contextual factors as opponent level, team strategies, or match status could also influence load and it is difficult to isolate the individual effect of these contextual variables [30–32]. The external and internal load demands could also increase and decrease during the match whether the team is winning, drawing, or losing [30].

While in soccer, BMI seems to be a crucial parameter that determines muscle power, fatigue index, and strength [33,34]; in Sa5, BMI does not influence external or internal load demands. BMI is a relevant indicator of performance that allows differentiation between players level and defines in-field actions as speed [35]. In Sa5, the developed speed during matches is lower than in regular similar soccer modalities [36]; it could be why BMI is not that determinant in the blinded player's load. Speed could not be as critical as the change of direction, acceleration, or other external load variables as stated in recent studies [37,38]. Despite this evidence, more studies should be developed to explore the above more in-depth.

While the practice of any sport predisposes individuals to suffer injuries, particularly in Sa5 soccer, there are up to 80% of injuries of traumatic etiology [39]. Despite there are some rules that protect blinded players from an injury (e.g., the "go" rule), the inherent danger of hitting other players remains latent. As with other anthropometric variables, BMI should be monitored and controlled to enhance performance and prepare the body to resist those impacts.

In this study, those who scored at least once presented higher $\text{Distance}_{\text{Explosive}}$ and $\text{Distance}_{21\text{–}24\ \text{km/h}}$. This may suggest the requirement to train the ability to perform high-intensity actions in these players. Considering that the actions usually started in the pre-offensive zone of the field had more probabilities of finish in goal in Sa5 [7], the attention should be focus on those players that due to tactical or positional characteristics play in this zone.

This result is also in line with other studies that suggest that most soccer goals are preceded by at least one high-intensity action performed by the assisting or scoring player [40]. Straight sprints, jumps, rotations and change of directions were the most common actions executed prior a goal situation. Moreover, decisive passes are preceded by these kind of high intensity actions enabling the attackers to locate in an optimal position to score [40].

In the present study, younger players presented higher HR_{AVG} and Acc_{Max} when compare to the older ones. In this respect, older players are usually present some physio-psychological factors as higher experience, higher self-confidence, better game reading and self-efficacy, allowing to dose their effort throughout the match [41] requiring less physical demands. Conversely, there are contrast evidence if the younger players present better physical performance in professional soccer compare to their older peers [42]. Besides it is clearly known that the rate of maturation impacts the physical performance characteristics of the players. Still, it usually depends on the relative age effect and no in broader age ranges as in professionals [42]. In this sense, national team coaches should consider these differences when identifying and selecting representative players.

5. Limitations

While the results of this study have provided information regarding how contextual factors as age, scoring abilities and match result could affect external and internal load demands, these research outcomes must be seen in the light of some limitations. One of the limitations in this study concerns the sample studied, the locomotion demands presented in this research must be applied to top-elite blinded soccer players and could serve as a reference to other inferior divisions. Due to the authors did not influence the natural dynamic of the competitions or the tournament schedule, the sample between the compared groups were distributed unequally. Besides, despite the matches were performed under the same conditions for all players (e.g., same venue, same turf, same referees) some other situational factors that could affect the game demands were not controlled (e.g., temperature). Finally, due to the lack of evidence in Sa5, some other soccer modalities were studied as reference.

6. Conclusions

This study represents the first effort to report external and internal load demands of Sa5 elite soccer, selecting, using an objective statistical criterion, those representative variables with great influence in physical performance. It was found that players usually performed higher number of accelerations per min when losing a match possible due to the need to increase their efforts to score. Those Sa5 players that scored during a match execute higher $\text{Distance}_{\text{Explosive}}$ and $\text{Distance}_{21\text{–}24\ \text{km/h.}}$ Considering the goals are usually anteceded by high-intensity actions (e.g., jumps, sprints), those Sa5 players that scored during a match execute higher $\text{Distance}_{\text{Explosive}}$ and $\text{Distance}_{21\text{–}24\ \text{km/h.}}$ Due to some technical and tactical Sa5 conditions that differentiate the more experienced players from the younger ones, the younger players presented higher HR_{AVG} and Acc_{Max}.

7. Practical Applications

Coaches, athletes and medical staff should address the influence of some contextual variables on external and internal load during top elite Sa5 official matches. The comprehension of the potential differences by match outcome, players age and scoring rate could redirect the designing of conditioning training programs, match strategies, tactical decisions and recovery protocols, especially during congested fixture tournaments.

Coaches should acknowledge the match partial results to adequate tactical tasks, that may improve the team demands optimizing general performance. The coaches should also consider age differences between players to equilibrate the team demands to avoid fatigue effect and potential performance decrease. Besides, those players demanded to score should undergo particular high-intensity training tasks, considering that in soccer goals are usually preceded by peak accelerations, decelerations, high-intensity running and sprints.

Finally, PCA seems to be a useful statistical technique to objectively select those relevant variables that represent teams external and internal load. Data mining techniques may be applied to MARG sensors derived data to improve the data management and technical report to the coaching and medical staff. This data reduction method allows administrating individualized training loads considering those relevant variables defining team load behavior.

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Article

Comparison of Running Distance Variables and Body Load in Competitions Based on Their Results: A Full-Season Study of Professional Soccer Players

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Abstract: The aims of this study were to compare the external workload in win, draw and defeat matches and to compare first and second halves in the Iranian Premier League. Observations on individual match performance measures were undertaken on thirteen outfield players (age, 28.6 ± 2.7 years; height, 182.1 ± 8.6 cm; body mass, 75.3 ± 8.2 kg; BMI, 22.6 ± 0.7 kg/m^2) competing in the Iranian Premier League. High-speed activities selected for analysis included total duration of matches, total distance, average speed, high-speed running distance, sprint distance, maximal speed and GPS-derived body load data. In general, there were higher workloads in win matches when compared with draw or defeat for all variables; higher workloads in the first halves of win and draw matches; higher total distance, high-speed running distance and body load in the second half in defeat matches. Specifically, lower average speed was found in matches with a win than with draw or defeat ($p < 0.05$). Sprint distance was higher in the first half of win than defeat matches and high-speed running distance was lower in draw than defeat matches (all, $p < 0.05$). In addition, first half presented higher values for all variables, regardless of the match result. Specifically, high-speed running distance was higher in the first half of matches with a win ($p = 0.08$) and total distance was higher in the first half of matches with a draw ($p = 0.012$). In conclusion, match result influences the external workload demands and must be considered in subsequent training sessions and matches.

Keywords: association football; performance; load monitoring; high-speed running; match; match result

1. Introduction

Quantification of training/match load represents an important procedure for adjusting training stimuli provided to players for the demands of the match [1,2]. The load quantification not only provide the researcher with clearer statistics, but also help coaches and sports scientists to gather more comprehensive performance data. Interest has grown in this area of study over the last decades as it enables sports scientists to identify the current demands placed on players in competition and apply data to training and testing protocols [3].

Previous studies have shown that internal and external load may vary throughout a season in different team sports [4–10]. Specifically, regarding variations in external imposed workloads, it has been shown that matches induce significant biochemical and neuromuscular responses related to fatigue [11] because of the high intensity actions demanded [12,13].

As such, matches are expected to have a significant effect on athletes' weekly workloads. Studies have examined external workload imposed by official matches in an array of leagues around the world and despite a plethora of research, there are no criterion measure to distinguish physical performance in elite soccer matches has been identified but the total distance covered and particularly the large amount of high-speed running distance (HSRD) [14] and also the demands required by the accelerations and decelerations [15] seem to be useful metrics. For instance, the amount of HSRD accounts for approximately 8% of the total distance covered during match-play [16] and may be used as a valid measure of physical performance during soccer match-play. HSRD allows differentiating between different standards of play [17] and tactical role of players [18]. This measure is related to the overall success of the team [16,18]. Like all measures of sports performance, HSRD in soccer match-play are not stable properties but are subject to variation between successive matches [10,17].

Recently derived variables, such as the new player load or the new body load were proposed to investigate changes of direction along all the axes and can provide useful information for comprehending the external workload of training sessions and matches [12]. Recently, Nobari et al. [7] used body load (BL) in professional soccer players during a full-season and found that starter players present regularly higher values when compared to non-starters. The same authors stated that this variable is higher in matches. The use of BL along with distance variables will help to determine relevant information for coaches and their staff to better understand external workload imposed by matches.

In addition, changes in the physical condition of the player [9,19] and contextual conditions [10] will lead to workload variations across the competitive season. Contextual factors such tactical formation, quality of opposition, and match stoppages may influence overall workloads during matches [8]. In light of the variability presented, where factors such as fitness are unlikely to change, it is important for practitioners to monitor the imposed demands on their own group of players. As a consequence of the variation that is likely to be mediated through both the inherent demands of the game and the individual's ability to regulate their own activity, the variability in HSRD in soccer is likely to be relatively large [10]. When considering match scenarios, there are considerable inter-week variation in terms of determinant external load measures caused by the own dynamics of the match and its contextual factors [20]. The gained insights from a load profile which can and should be the foundation of team management will help coaches and staff to better adjust workload and periodization through the different phases of the season.

Despite the aforementioned research and, to the author's knowledge, only one study has explored the potential relationship of match result (win, draw, defeat) on the external workload produced by professional soccer players [21], but without including running distance variables. Moreover, win matches produce higher external workload variables when compared with draw or defeat result [21] and produce relevant ramifications for subsequent training and competition. Notwithstanding, the accumulated fatigue during matches (differences between the first and the second half) produces a decreasing performance in total distance covered, HSRD or sprints [18,22]. A greater understanding of how this situational match result might be affecting external workload could help coaches and practitioners to make more informed decisions when prescribing subsequent training load. In addition, it could help to identify if there are certain matches results in the season when players might need additional support to cope with the demands (e.g., losing to a bottom-table team).

Therefore, we expect to contribute to the literature by providing some reference values with regard to running distance and body load variables in won, defeated and drawn matches. Thus, the aims of this study were to compare the running distances variables and BL in win, draw and defeat matches in the Iranian Premier League (IPL). A comparison between first and second halves was also analysed for this study.

2. Materials and Methods

2.1. Experimental Approach to the Problem

This study includes a professional team that participated in the highest level of professional football, the IPL (Persian Gulf Premier League and knockout tournament in this country). In this league, each team is allowed to use the Global Positioning System (GPS) to record the physical fitness statistics of its players. We analyse 33 matches where 16 wins, 14 draws and three defeats occurred. During each match, players were monitored by a GPS (Model: SPI High-Performance Unit HPU, GPSPORTS Systems Pty Ltd., Canberra, Australia) and the study variables were collected daily during the full-season (i.e., all training and matches). The two aims of this study were to describe and compare total duration of training session, total distance (TD), average speed (AvS), HSRD, total sprint distance (TSD), maximal speed (MS) and BL data collected in different match results and between first and second halves.

2.2. Participants

Thirteen professional soccer players (age, 28.6 ± 2.7 years; height, 182.1 ± 8.6 cm; body mass, 75.3 ± 8.2 kg; BMI, 22.6 ± 0.7 kg/m^2, and total training and match time, 8935.2 ± 1214.7 min) participated in this study. All players of this team had at least a history of playing in the national youth team of Iran, or the highest level of the country’s soccer league from the youth category (over 10 years). The inclusion criterion required that players must participate in at least three training sessions each week. Also, player had to participate in three consecutive full matches. The exclusion criteria included: (i) players with prolonged injury or a lack of participation in training for at least two consecutive weeks (two players were removed based on this criterion); (ii) goal keepers were excluded from the study due to differences in training activities and workload in training and matches. The experimental approach and study design were presented to the players after which written consent was obtained from all players. The study followed the ethical guidelines of Helsinki Declaration for the study in Humans and was approved by the Ethics Committee of the University of Isfahan (IR.UI.REC.1399.064).

2.3. Monitoring External Load

GPS Receiver Specifications

During the season, all workouts and match sessions were monitored using model SPI HPU GPS-based tracking systems for professional athletes, which offer 15 Hz position GPS and data source BL used a triaxial accelerometer. According to a previous study, this device has a high validity and reliability [23]. There were no reported adverse weather conditions to affect data collection.

Data collection. Prior to the start of the match, belts were placed on the players’ shoulder and chest. After each cool down session at the end of the training, the belts were collected from the players. All belts were checked by the team’s GPS manager and then entered into the dock system to download the information, which was then stored on the computer with the Team AMS software. The data from each session was automatically deleted from the belt memory after download. Prior to the next session, the belts were placed in an electric charge station. The SPI IQ Absolutes were adjusted for GPS default zone throughout the season. Also, the personal characteristics (such as height and weight) of each player were entered in the software and each player registered a belt in his own name for use until the end of the season. The following variables were then selected: total duration of training session, TD, AvS, HSRD (18–23 km·h^{-1}), TSD (>23 km·h^{-1}), maximal speed (MS) and GPS-derived BL data.

2.4. Statistical Analysis

Data were analysed using the SPSS for Windows statistical software package version 22.0 (SPSS Inc., Chicago, IL, USA). Initially descriptive statistics were used to describe and characterize the sample. Shapiro-Wilk and Mauchly's tests were used to verify the assumption normality and sphericity, respectively. Repeated measures ANOVA was used with Bonferroni post hoc, once variables obtained normal distribution (Shapiro-Wilk > 0.05) and it was used ANOVA Friedman and Mann-Whitney tests for the variables that not obtained normal, to compare different match results. Also, paired sample t-test was used to compare data from first half with second half according to the final result of the match. Results were significant with $p \leq 0.05$. The effect-size (ES) statistic was calculated to determine the magnitude of effects by standardizing the coefficients according to the appropriate between subject's standard deviation and was assessed using the following criteria: <0.2 = trivial, 0.2 to 0.6 = small effect, 0.6 to 1.2 = moderate effect, 1.2 to 2.0 = large effect and >2.0 = very large [24].

3. Results

Descriptive results and comparisons between wins, draws and defeats results of the variables studied are presented in Table 1.

Regarding total match differences based on results, there were significant differences between win and draw for match duration (ES = 0.36 [−0.43, 1.12]), between win and defeat (ES = 2.30 [1.25, 3.20]) and between draw and defeat for AvS (ES = 2.19 [1.16, 3.08]). In the 1st half, there were significant differences between win and draw for match duration (ES = 7.0 [4.45, 8.96]) and between win and defeat for sprint distance (ES = 1.15 [2.40, 5.38]). In the 2nd half, there were significant differences between win and defeat for HSRD (ES = 0.86 [0.09, 1.15]).

Descriptive results and comparisons between 1st and 2nd halves of the variables studied are presented in Table 2.

Table 1. Comparison of full match-day, first half and second half data between wins, draws and defeat per squad average, mean (SD) and CI, 95%.

Full-Match	**Win (CI, 95%)**	**Draw (CI, 95%)**	**Defeat (CI, 95%)**	**CI, 95% (Win vs. Draw)**	**CI, 95% (Win vs. Defeat)**	**CI, 95% (Draw vs. Defeat)**
Duration (min), n = 13	88.8 ± 11.9 * (81.6–95.9)	84.2 ± 13.7 (75.9–92.5)	82.1 ± 27.4 (65.5–98.6)	0.15 to 8.98	−12.94 to 26.32	−14.71 to 18.98
TD (m), n = 13	9369.9 ± 1641.1 (8378.2–10,361.6)	9263.4 ± 1350.8 (8477.1–10,109.6)	8673.6 ± 2828.8 (6964.1–10,383.0)	−698.03 to 851.08	−1474.13 to 2866.84	−1074.36 to 2314.02
AvS (m/min), n = 13	106.0 ± 14.8 ** (97.1–114.9)	111.2 ± 11.2 *** (104.4–117.9)	188.8 ± 48.8 (159.4–218.4)	−11.63 to 1.26	−119.04 to −46.74	−113.96 to −41.45
HSRD (m), n = 13	247.9 ± 100.4 (187.2–308.6)	228.0 ± 93.2 (171.6–284.3)	225.1 ± 95.7 (167.3–282.9)	−17.39 to 57.30	−57.44 to 103.04	−63.49 to 69.18
TSD (m), n = 12	35.9 ± 19.2 (23.7–48.1)	30.2 ± 15.8 20.1–40.2)	22.7 ± 15.6 (14.0–31.3)	−7.08 to 18.58	−4.80 to 31.30	−3.53 to 18.54
MS (km·h^{-1}), n = 13	28.2 ± 2.2 (26.9–29.6)	28.8 ± 1.3 (28.0–29.6)	29.3 ± 1.5 (28.4–30.2)	−1.74 to 0.57	−2.66 to 0.51	−1.25 to 0.27
BL (au), n = 13	168.6 ± 38.6 (145.3–192.0)	161.8 ± 36.3 (139.8–183.8)	143.2 ± 58.8 (107.6–178.7)	−3.19 to 16.85	−17.81 to 68.73	−23.75 to 61.01
1st half	Win (CI, 95%)	Draw (CI, 95%)	Defeat (CI, 95%)	CI, 95% (win vs. draw)	CI, 95% (win vs. defeat)	CI, 95% (draw vs. defeat)
Duration (min), n = 10	47.2 ± 0.2 ** (46.7–47.7)	46.3 ± 1.2 (43.5–49.1)	48.6 ± 0.2 (48.1–49.0)	−2.58 to 4.40	−2.34 to −0.40	−5.76 to 1.20
TD (m), n = 10	5215.8 ± 156.1 (4862.7–5569.0)	5116.8 ± 108.9 (4870.5–5363.1)	5203.2 ± 151.0 (4861.7–5544.7)	−135.34 to 351.36	−137.53 to 162.70	−256.39 to 83.54
AvS (m/min), n = 10	110.5 ± 10.8 (102.8–118.3)	111.4 ± 13.5 (101.7–121.1)	107.1 ± 9.4 (100.4–113.8)	−8.31 to 6.59	−0.33 to 7.20	−3.95 to 12.54
HSRD (m), n = 10	126.6 ± 56.6 (86.1–167.1)	123.6 ± 51.9 (86.5–160.7)	124.6 ± 61.7 (80.5–168.7)	−15.67 to 21.68	−25.98 to 30.05	−30.70 to 28.77
TSD (m), n = 9	22.0 ± 11.1 ** (13.5–30.6)	15.7 ± 7.1 (10.2–21.6)	10.3 ± 9.2 (3.2–17.4)	−0.88 to 13.59	3.07 to 20.39	−3.45 to 14.19
MS (km·h^{-1}), n = 10	28.9 ± 1.9 (27.5–30.3)	29.1 ± 1.4 (28.2–30.1)	29.1 ± 1.9 (27.7–30.5)	−1.88 to 1.36	−2.04 to 1.52	−1.12 to 1.12
BL (au), n = 10	88.4± 32.5 (65.2–111.7)	80.8 ± 24.4 (63.3–98.3)	82.1 ± 28.3 (61.8102.3)	−3.31 to 18.51	−1.51 to 14.20	−11.67 to 9.16
2nd half	Win (CI, 95%)	Draw (CI, 95%)	Defeat (CI, 95%)	CI, 95% (win vs. draw)	CI, 95% (win vs. defeat)	CI, 95% (draw vs. defeat)
Duration (min), n = 13	43.7 ± 7.6 (39.0–48.3)	39.8 ± 8.0 (35.0–44.7)	44.7 ± 10.1 (28.6–50.9)	−1.79 to 9.43	−11.07 to 8.95	−12.26 to 2.50
TD (m), n = 13	4340.6 ± 1207.3 (3611.0–5070.2)	4390.5 ± 741.4 (3942.5–4838.6)	4671.1 ± 883.3 (4137.3–5204.8)	−909.30 to 809.37	−1578.99 to 917.98	−898.63 to 337.54
AvS (m/min), n = 13	100.3 ± 23.3 (86.3–114.4)	111.6 ± 13.2 (103.6–119.6)	106.5 ± 14.1 (98.0–115.0)	−25.19 to 2.62	−21.84 to 9.48	−5.39 to 15.59
HSRD (m), n = 10	108.7 ± 46.0 (80.9–136.5)	102.4 ± 37.7 *** (79.6–125.2)	129.3 ± 23.3 (112.2–146.4)	−14.83 to 27.35	−52.08 to 10.81	−48.23 to −5.56
TSD (m), n = 11	16.9 ± 9.5 (10.5–23.3)	15.8 ± 10.6 (8.7–23.0)	15.6 ± 10.3 (8.7–22.5)	−8.95 to 10.99	−14.47 to 17.07	−13.20 to 13.76
MS (km·h^{-1}), n = 13	28.5 ± 1.6 (27.5–29.4)	28.7 ± 1.3 (27.9–29.4)	29.6± 1.7 (28.6–30.6)	−1.25 to 0.83	−2.85 to 0.60	−2.09 to 0.26
BL (au), n = 13	76.3 ± 19.3 (64.6–88.0)	76.1 ± 15.2 (66.9–85.3)	80.0 ± 27.4 (63.5–96.6)	−14.48 to 14.93	−25.45 to 18.02	−18.42 to 10.53

au = arbitrary units; m = meters; TD = total distance; HSRD = high-speed running distance; TSD = total sprint distance; BL = body load; AvS = average speed; MS = Maximal speed; CI = confidence interval.
* significant differences between win vs. draw, $p < 0.05$. ** significant differences between win vs. defeat, $p < 0.05$. *** significant differences between draw vs. defeat, $p < 0.05$.

Table 2. Comparison of first half and second half data for wins, draws and defeat per squad average, Mean (SD).

Variables	1st Half (CI, 95%)	2nd Half (CI, 95%)	*p*	CI, 95%
Win				
Duration (min), n = 13	45.1−7.9 (40.3–49.9)	43.7 ± 7.6 (39.0–48.3)	0.613	−4.64 to 7.54
TD (m), n = 13	5029.3 ± 954.0 (4452.9–5605.8)	4340.6 ± 1207.3 (3611.0–5070.2)	0.108	−174.83 to 1552.39
HSRD (m), n = 13	139.3 ± 59.4 (103.4–175.2)	108.7 ± 46.0 (80.9–136.5)	0.008 *	9.62 to 51.59
TSD (m), n = 13	18.2 ± 11.8 (11.0–25.3)	16.1 ± 8.9 (10.7–21.5)	0.380	−2.84 to 6.93
MS (km·h^{-1}), n = 13	28.0 ± 4.4 (25.4–30.6)	28.5 ± 1.6 (27.4–29.4)	0.726	−3.41 to 2.44
BL (au), n = 13	92.3 ± 31.6 (73.2–111.4)	76.3 ± 19.3 (64.6–88.0)	0.129	−5.41 to 37.40
AvS (m/min), n = 13	111.8 ± 9.7 (105.9–117.7)	100.3 ± 23.3 (86.3–114.4)	0.063	−0.72 to 23.66
Draw				
Duration (min), n = 13	44.4 ± 6.5 (40.4–48.3)	39.8 ± 8.0 (35.0–44.7)	0.008 *	1.40 to 7.64
TD (m), n = 13	4902.9 ± 748.7 (4450.4–5355.3)	4390.5 ± 741.4 (3942.5–4838.6)	0.012 *	132.05 to 892.61
HSRD (m), n = 13	125.6 ± 63.2 (87.4–163.8)	102.4 ± 37.7 (79.6–125.2)	0.096	−4.80 to 51.13
TSD (m), n = 11	16.2 ± 7.6 (11.1–21.3)	15.8 ± 10.6 (8.7–23.0)	0.915	−6.80 to 7.50
MS (km·h^{-1}), n = 13	28.9 ± 1.7 (27.9–29.9)	28.7 ± 1.6 (27.9–29.4)	0.499	−0.56 to 1.08
BL (au), n = 13	85.7 ± 23.9 (71.3–100.2)	76.1 ± 15.2 (66.9–85.3)	0.063	−0.61 to 19.86
AvS (m/min), n = 13	110.9 ± 12.0 (103.7–118.2)	111.6 ± 13.2 (103.6–119.6)	0.833	−7.58 to 6.22
Defeat				
Duration (min), n = 10	48.6 ± 0.6 (48.1–49.0)	47.1 ± 7.4 (41.8–52.4)	0.537	−3.73 to 6.69
TD (m), n = 10	5203.2 ± 477.4 (4861.7–5544.7)	4864.4 ± 481.4 (4520.0–5208.7)	0.054	−7.95 to 685.71
HSRD (m), n = 10	124.6 ± 61.7 (80.5–168.7)	130.6 ± 31.9 (107.8–153.5)	0.664	−36.68 to 24.53
TSD (m), n = 9	10.3 ± 9.2 (3.2–17.4)	11.8 ± 7.5 (6.1–17.6)	0.587	−7.79 to 4.72
MS (km·h^{-1}), n = 10	29.1 ± 1.9 (27.7–30.5)	29.9 ± 1.8 (28.6–31.1)	0.307	−2.33 to 0.82
BL (au), n = 10	82.1 ± 28.3 (61.8–102.3)	77.9 ± 26.7 (58.8.97.0)	0.099	−0.96 to 9.27
AvS (m/min), n = 10	107.1 ± 9.4 (100.4–113.8)	105.2 ± 15.3 (94.2–116.1)	0.592	−5.96 to 9.84

au = arbitrary units; m=meters; TD = total distance; HSRD = high-speed running distance; TSD = total sprint distance; BL = body load; AvS = average speed; MS = Maximal speed. * denotes difference from 2nd half. all $p < 0.05$.

Regarding matches with a win there were significant differences between first half and second halves for HSRD (ES = 0.56 [−0.23, 1.34]).

Regarding matches with a draw there were significant differences between first and second halves for match duration (ES = 0.61 [−0.18, 1,40]), TD (ES = 0.67 [−0.12, 1.46]), MS (ES = 0.12 [−0.65, 0.89]).

Regarding matches with defeat there were no significant differences. Descriptive results and comparisons between wins, draws and defeats for TD, AvS, HSRD, sprint distance and BL are also presented in Figure 1 for better clarity.

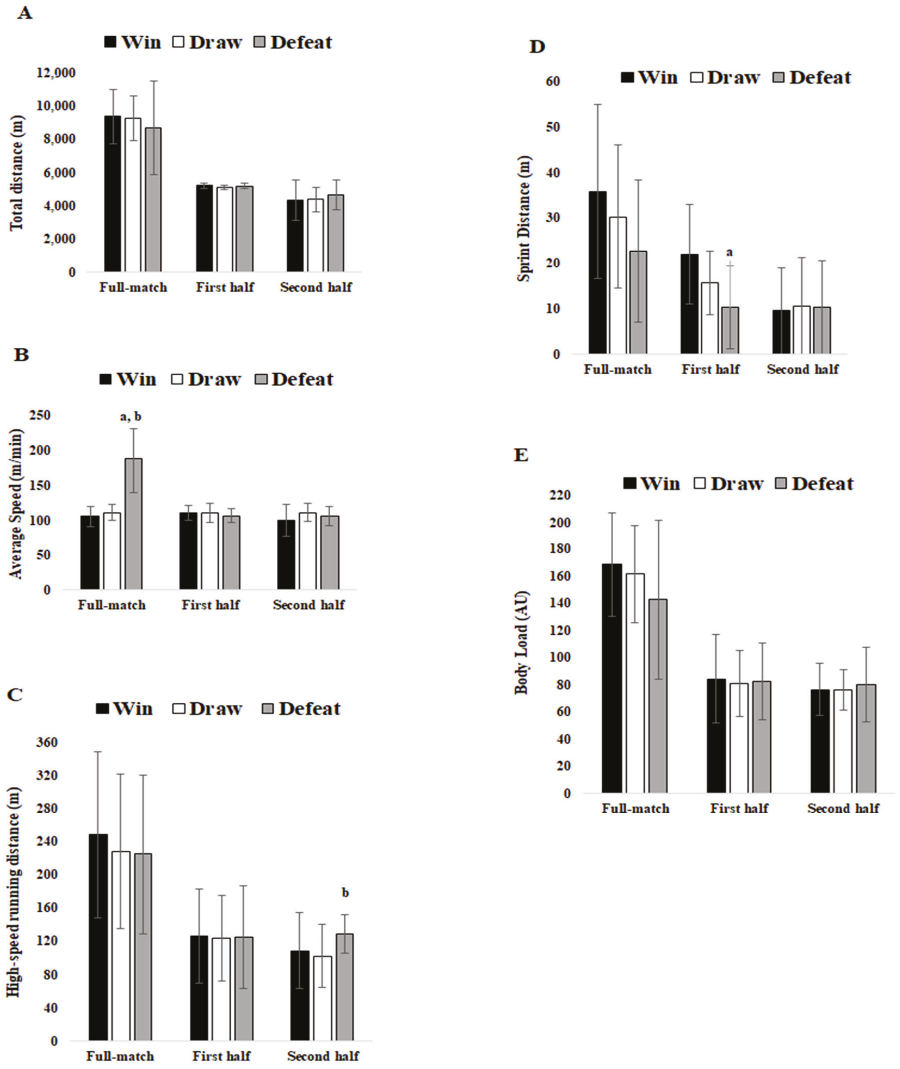

Figure 1. Comparisons between full, first and second halves for match results for (**A**) Total distance. (**B**) Average Speed. (**C**) High-speed Running Distance. (**D**) Sprint Distance. (**E**) Body Load. a denotes significant differences between win vs. defeat; a denotes difference between defeat vs. win; b denotes significant difference between defeat vs. draw. All ($p < 0.05$).

4. Discussion

The aim of this study was to compare running distance variables and BL between matches with different results (win, draw and defeat) and also between first and second halves of matches. The main findings of the present study reflected that: (1) a win match outcome impacted significantly the duration thus in a win result the match duration is longer than in draws or defeat, and (2) with regard to the match outcome, higher AvS was covered in matches were a defeat occurred than those with win or draw results.

The findings of the present study showed that the mean full-match duration in official matches is dependent on match outcome. We found that there were higher values in win than draw or defeat matches (win > draw > defeat). For instance, it was found that higher full duration in won matches is associated with higher total distance, HSRD, sprint distance and BL.

In the present study the results for TD covered during an official game are not dependent on match outcome. These findings are not corroborated by Smpokos et al. [25] who claim that a team cover significantly longer distance in won matches than in draw and lost matches ($p < 0.001$). According to the authors this could be explained by the observation that the team may regulate the physical efforts according to the specific demands of individual matches and periods of the game. The TD covered in the present study is, however, in the total playing time and in both halves of the game lower than those reported by previous studies [16,25–29]. In the present team studied, a plausible justification that can give grounds for similar TD regardless of the match results could be associated to the tactical system and strategy applied by coaches, even with more duration in won matches.

Furthermore, when analysing match result, the results are similar to those reported by the study of elite German soccer players during the 2014–2015 from Andrzejewski et al. [30] that reported similar values for all position between different results with the exception of the forwards. This finding was also reported before by Lago et al. [31] in Spanish Premier League (SPL) players during the 2005–2006 season and more recently by Moalla et al. [28] in Stars League during 2013–2015. The present study cannot provide such finding once only thirteen players were included in the analysis and therefore, no comparison between player positions were conducted.

When addressing to the halves of the game, some studies [32,33] have reported that a longer TD is covered during the first half of the match compared to the second half. In the present study there was a tendency on higher values in the first half with no statistically differences between halves of won and defeated matches. However, in matches with a draw, there was significant differences ($p < 0.05$). In opposition, Andrzejewski et al. [29] reported a slightly higher total distance covered in second half than the first half. Furthermore, the same study showed the same load patter regarding sprint distance. When analysing match results, the findings of the present study are similar to other study that found higher TD, HSRD and sprint distance when team was winning [28].

Previous studies have generally reported evidence of time-dependent reductions in the HSRD covered by players over the course of elite match play, from the first to second halves [34,35]. In fact, our study corroborated those findings in win and draw matches but not for defeat matches where higher values were found in the second half. In opposition, other studies showed that soccer players' work rate was higher when losing than winning a match [28,36–38]. This can be attributed to the more offensive style of play when a team is in need of a goal than when they are not, and the players may, therefore, have a higher work rate when they are pursuing a goal [39]. It seems that when the team is losing, there are a tendency to players try to reach their maximal activity in order to win or draw the match [28,30]. Finally, it was found that values from the present study fall short when compared with Moalla et al. [28] study that observed more than 600 m of HSRD and 230 m of sprint distance or compared with Andrzejewski et al. [30] study that found more than 2000 m of HSRD, regardless of match result.

The MS running in the present study was similar to the 28 $\text{km}\cdot\text{h}^{-1}$ reached by other study conducted in FA Premier League [33], lower than 31 $\text{km}\cdot\text{h}^{-1}$ conducted in SPL by Rey et al. [40], and lower than 31.9 $\text{km}\cdot\text{h}^{-1}$ conducted with Europa League soccer player by Andrzejewski, et al. [29]. However, it is important to notice that different GPS were used what could influence results. Even so, IPL players still need to improve to achieve the numbers presented by Europa League players.

Andrzejewski, et al. [29] observed around 21 ± 3 m as the mean sprint distance covered regardless of the match result. However, the present study showed a much higher value specially in matches with a win or draw result. Only defeat matches presented similar values. These results could be attributed to the evolution of the game and the specificity of the IPL which not fully studied at this point. Also, it is important to acknowledge that

Andrzejewski, et al. [29] analysed 147 soccer players and did not analyse the differences between match result.

Regarding BL and to the best of the authors' knowledge, no studies were conducted with the same variable. However, since BL is similar to player load, we observed that the pattern of the present study showed higher values in the first half which is in line with Reche-Soto et al. [21] study. The same study also found higher values for win matches than other results. Body load is obtained by calculating the sum of the accelerations in the three-movement axis, although some differences regarding this calculation are noticeable in the literature [41]. Despite accelerations were not analysed in this study, we speculate higher values in the first half.

Some limitations should be addressed. Despite the study has a strong inclusion criterion in order to include a player for analysis, only thirteen players from a single team were included which is not large enough to make full generalizations. Another limitation of the present study is the unequal number of analysed matches with win (16), draw (14) and defeat (3) results that compromises the statistical power. Nevertheless, the present represent the actual training and competition environment from athletes.

Furthermore, there are other situational variables that could add some information regarding workload imposed by matches, such as location or quality of the opponents.

5. Conclusions

The study found higher workloads in win matches when compared with draw or defeat for all variables. In addition, it was found higher workloads in the first halves of win and draw matches, but in defeat matches, higher total distance, HSRD and BL was found in the second halves. The present results must be considered in subsequent training sessions and matches and will help to better periodization training load through the full-season.

For instance, in order to win or draw matches, it was found that TD covered should reach around 9263.4 ± 1350.8 to 9369.9 ± 1641.1 m; while BL should reach 168.6 ± 38.6 to 161.8 ± 36.3 au. In order to win matches HSRD and TDS should reach 247.9 ± 100.4 m and 35.9 ± 19.2 m, respectively, while AvS should be close to the 100 m/min. With the reported values, coaches and staff can prepare training sessions to achieve those values in some training sessions to simulate the demands obtained in won matches. Also, they can emphasize higher workloads in the first half of training sessions to achieve a better match result.

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Article

Greater Power but Not Strength Gains Using Flywheel Versus Equivolumed Traditional Strength Training in Junior Basketball Players

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Abstract: The main aim of the present study was to compare the effects of flywheel strength training and traditional strength training on fitness attributes. Thirty-six well trained junior basketball players (n = 36; 17.58 ± 0.50 years) were recruited and randomly allocated into: Flywheel group (FST; n = 12), traditional strength training group (TST; n = 12) and control group (CON; n = 12). All groups attended 5 basketball practices and one official match a week during the study period. Experimental groups additionally participated in the eight-week, 1–2 d/w equivolume intervention conducted using a flywheel device (inertia = 0.075 $\text{kg}\cdot\text{m}^{-2}$) for FST or free weights (80%1 RM) for TST. Pre-to post changes in lower limb isometric strength (ISOMET), 5 and 20 m sprint time (SPR5m and SPR20m), countermovement jump height (CMJ) and change of direction ability (*t*-test) were assessed with analyses of variance (3 × 2 ANOVA). Significant group-by-time interaction was found for ISOMET (F = 6.40; $p = 0.000$), cmJ (F = 7.45; $p = 0.001$), SPR5m (F = 7.45; $p = 0.010$) and T test (F = 10.46; $p = 0.000$). The results showed a significantly higher improvement in cmJ ($p = 0.006$; 11.7% vs. 6.8%), SPR5m ($p = 0.001$; 10.3% vs. 5.9%) and *t*-test ($p = 0.045$; 2.4% vs. 1.5%) for FST compared to the TST group. Simultaneously, th FST group had higher improvement in ISOMET ($p = 0.014$; 18.7% vs. 2.9%), cmJ ($p = 0.000$; 11.7% vs. 0.3%), SPR5m ($p = 0.000$; 10.3% vs. 3.4%) and *t*-test ($p = 0.000$; 2.4% vs. 0.6%) compared to the CON group. Players from the TST group showed better results in cmJ ($p = 0.006$; 6.8% vs. 0.3%) and *t*-test ($p = 0.018$; 1.5% vs. 0.6%) compared to players from the CON group. No significant group-by-time interaction was found for sprint 20 m (F = 2.52; $p = 0.088$). Eight weeks of flywheel training (1–2 sessions per week) performed at maximum concentric intensity induces superior improvements in cmJ, 5 m sprint time and change of direction ability than equivolumed traditional weight training in well trained junior basketball players. Accordingly, coaches and trainers could be advised to use flywheel training for developing power related performance attributes in young basketball players.

Keywords: isoinertial training; strength training; vertical jump; change of direction ability

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1. Introduction

It has been acknowledged in the scientific literature that strength training produces several morphological and neural adaptive changes in the human body, including increases in muscle's cross-sectional area, muscle fiber pennation angles and musculotendinous stiffness as well as motor unit recruitment, rate coding (firing frequency), synchronous motor unit activity and neuromuscular inhibition [1]. These types of adaptations enable an increase in strength and power—both of them have been extensively proven to be related to sport performance across a continuum of sports events [2]. Consequently, strength training has become a cornerstone of strength and conditioning programs for athletes [3]. In addition, optimizing the load and time spent in strength training may be one of the most important considerations for strength and conditioning coaches (especially in team sports), where success is multifaceted and with a broad spectrum of physical, physiological, technical and tactical abilities that need to be targeted regularly in the training process and integrated periodization [4]. Consequently, in both sport science and everyday practice there is a need for elucidating and incorporating effective but also time sparing strength training methods [5]. In this vein, many different strength training methods have been presented in the past, including the use of free weights, kettlebells, elastic bands and resistance training machines [6]. These different traditional strength training methods, including both eccentric and concentric muscle actions, are prescribed based on concentric force parameters with propensity to underload the lengthening phase of movement as muscle produces more force during eccentric phase of movement [7]. There is a growing body of research asserting that strength training programs which adequately load the lengthening phase of movement, called eccentric training, might induce superior neuromuscular adaptations (faster cortical activity, inversed motoneuron activity pattern, improved muscle-tendon unit morphology and structure) compared with traditional strength training. In addition, there is increasing evidence in recent scientific literature implying that eccentric strength training is a potent stimulus for boosting physical performance [8,9], with flywheel iso-inertial resistance training especially highlighted recently for its efficiency in both performance and clinical settings [10] as well as specificity [11].

Concisely, flywheel training is a relatively new training method consisting of participants accelerating a flywheel during concentric phase of movement with kinetic energy returned during the eccentric phase of movement, thus requiring significant eccentric muscle action (eccentric overload) to slow the flywheel. This presents an alternative means of providing external load in resistance exercises which can be achieved by flywheel resistance [12]. Flywheel training enables overload in the eccentric phase, by resisting the eccentric force later in the eccentric range of motion [13]. Considering performance outcomes in the athletic population, eight to eleven weeks of flywheel training with one/two sessions a week has been found effective to enhance countermovement jump height (CMJ), change of direction ability and linear sprint in young and adult soccer players [14–18]. Furthermore, literature found six and seven weeks of flywheel training (two-three and one session per week, respectively) to be a robust tool to significantly enhance cmJ, squat jump, 20 m sprint, change of direction (*t*-test) and maximal strength [19] as well as maximal strength (Half squat 1 RM) and 20 m sprint [20] in professional handball players. Interestingly, the effects of flywheel training on performance outcomes in basketball are scarce. To the best of the authors knowledge, only one study [21] reported significant improvements in countermovement jump and squat power after implementing one session a week of flywheel training (four sets of eight repetitions of the squat, 24 weeks) in a sample of 26 regional level adult basketball players (males and females). Change of direction, muscular strength, vertical jumping ability and repetitive short-distance sprints are all important fitness attributes required for the physical demands of a basketball game [22]. In addition, the relevance of performing explosive and fast movements, such as sprints, jumps and change of direction has increased in modern basketball [22]. Finally, lower body strength has been extensively reported to be related to lower body power performance [23]. Therefore, it is of interest for both sport scientists and basketball practitioners to elucidate the effects of innovative training methods for power and strength development in basketball.

Although strength and conditioning coaches use various methods to develop neuromuscular factors in youth basketball players [24], no studies to date, as far as we know, have investigated the effects of flywheel training on strength and power attributes in young basketball players. It should be recognized that the continuation of habitual team sport practice during puberty was proven to induce substantial improvements in lower body strength per se, without additional resistance training performed [25]. Consequently, the inclusion of the control group with regular basketball practice would improve clarity of whether performance adaptations are consequence of strength training or specific sport training linked to the possible growth and muscular development. This was not the case with previous similar investigations conducted on young soccer players [14,15]. Furthermore, to the best of our knowledge, there are no studies with relatively old (U-18), highly trained and resistance training-experienced adolescents that have compared the effects of continuing with specific sport practice or including flywheel or traditional strength training to regular basketball practice. Recently, meta-analysis exploring the flywheel training performance effects revealed that most interventions caried out on 5 to 10 weeks training period [13]. Further, in vertical inertial flywheel training, similar to our research design [14,19,26], differences in strength and power performance in 6- and 8-week training period were found. As a result of this analysis, an eight-week training period is consistent with previous research.

Taking all aforementioned, the main aim of this study was to compare the in-season effects of eight week of equivolumed flywheel vs. traditional strength training on lower body strength, countermovement jump, *t*-test and 5 and 20 m sprint performance in well-trained young basketball players. We hypothesized that flywheel training will produce superior effect in all observed fitness attributes.

2. Materials and Methods

2.1. Participants

Thirty-six well trained junior male basketball players volunteered to participate in the study and were randomly assigned to 3 groups: the first experimental group (FST; n = 12; age = 17.58 ± 0.52 years; height = 190.54 ± 4.98 cm; body mass = 75.53 ± 5.43 kg; training experience = 6.17 ± 1.19 years) which performed strength training on a flywheel training device ((D11 full, Desmotec, Biella, Italy), the second experimental group (TST; n = 12; age = 17.52 ± 0.58 years; height = 190.58 ± 6.56 cm, body mass = 78.78 ± 8.01 kg; training experience = 6.92 ± 2.88 years) which performed traditional free weights strength training and the control group (CON; n = 12; age = 17.56 ± 0.54 years; body mass = 192.81 ± 3.99 cm; weight = 80.00 ± 8.76 kg; training experience = 6.58 ± 1.38 years) which maintained regular basketball practice.

All players where regional level, from Novi Sad (Serbia) and played for the teams contesting in the junior league of Vojvodina province during the season in which the investigation took place. All players had basketball training experience of a minimum of 4 years, without lower limb injury or illness 4 months prior to the study. During the program, all participants had 5 basketball trainings (90 min per training) and one game a week. In addition, participants were all familiar with resistance training regularly exploited throughout the season, but without previous experience with flywheel device. The requirements and obligations during the study were explained to all participants, as well as the purpose of the research. Each participant could withdraw from the research at any time. No players reported injuries throughout the study duration and no one withdraw from the research. The study fits the Declaration of Helsinki (2008), actualization in Fortaleza 2013 [27], for medical research involving human participants.

The study protocol was reviewed and approved by the ethics committee of the University of Novi Sad, Serbia. (Ref. No. 44-01-02/2019-3). All participants voluntarily accepted to enroll in the study and signed an informed consent, while parents or legal representatives signed for underage subjects.

2.2. Study Design

The experimental program was organized during the second part of the competition period, in March and April 2019. Initial testing was organized seven days prior to the first practice session, and after testing players from the FST and TST groups attempt two sets with six–eight repetitions on an isoinertial device (FST group) and with weights (TST group) in order to familiarize with the training protocol. Three days before starting the program, both experimental groups had a second familiarization training with exercises on an isoinertial device and with free weights. Supervised strength training for the experimental groups was conducted during the morning hours in the lab facility at a Faculty of sport and physical education, University of Novi Sad, supplied with all necessary equipment (flywheel, bars, plates, elastic bands …). All participants were supervised by PhD students with extensive strength training experience to help ensure high quality training sessions. The sessions were performed on every Tuesday, Wednesday and Thursday, in groups of no more than 6 players and monitored by at least two PhD students at all times. Three to six days after the intervention period final testing was conducted, identical with initial one considering time of testing, order and protocols of testing procedures and examiners. All participants were strongly advised to avoid any strenuous activity 24 h before testing. The control group did not receive any additional training apart from regular basketball trainings and weekend-games during the intervention. During the week, but not on the same day as the experimental program, one basketball training session, was supplemented with bodyweight strength training for all groups. This training was regularly implemented throughout the season, at the beginning of the training, lasting 25 to 30 min. The participants were not allowed to take stimulants, or any other substances for improving performance during the study.

2.3. Measurements

Anthropometric measurements were taken by an International Society for Advancement in Kinanthropometry (ISAK) level three anthropometrist, following the standard procedures prior to initial testing [28]. The height and body mass technical error of measurement (TEM) was less than 0.02%, and were measured with an SECA (Seca GmbH, Hambrug, Germany) measuring rod, (precision of 1 mm; range: 130–210 cm) and an SECA model scale (precision of 0.1 kg; range: 2–130 kg).

Prior to initial testing, data on training experience and anthropometric measures of standing height and body weight were taken for each subject. The lower extremity isometric strength test (ISOMET) was performed with peak force measured on an isoinertial device (D11 full, Desmotec, Biella, Italy). The participant was connected to the device by a strap with one end tied to the device and the other to a waistcoat worn by the participant. The strap was tightened not to allow the respondent to move up. The Desmotec device has two contact panels that are connected to a computer equipped with the software (D.Soft, Desmotec, Biella, Italy). The participant stands in a semi-squat position, flexion at 100 degrees angle, and his hands are placed on his hips. At the sign, the subject exerts pressure on the plates for 10 s, maximum voluntary isometric contraction. The contact panels measure the force that the participant produces and which is read on the computer. The test was done twice, with a rest period of 2 min, and the better result, expressed in kilograms, was recorded. Good test-retest reliability ($\alpha = 0.889$) was found for this parameter.

Countermovement jump test—CMJ—was conducted according to Bosco protocol [29] on a contact platform Just Jump, Probotics, USA. During the cmJ, all participants were instructed to start with upright posture and their hands on their hips. After swift downward phase to semi squat position, participants jump up in the air maximally keeping hands on their hips and landing in an upright position with their knees extended. Three attempts were allowed, with 45 s of passive recovery between trials. The best jump performance was registered and used for further analysis. cmJ is characterized by a very low variability between tests (coefficient of variation of 3.0%) [30], with excellent test-retest reliability ($\alpha = 0.918$) found in our study.

Subjects performed a 20 m sprint test, with 5 m split time and times were recorded using light gates (Microgate—Witty, Italy). Two submaximal efforts were included at the end of specific warm up, followed two 20 m sprint trials, with two minutes of passive recovery between trials. After a specific warm-up, including the 2 submaximal efforts (around 90% of max speed), two trials were completed. The subject started from the crouched position with the front foot positioned 0.3 m behind the first timing gate, where players started voluntarily and accelerate maximally to the finish line. During the test, the participants were verbally encouraged to run with maximum effort. The better results were used for further statistical analysis (SPR5 m and SPR20 m). The 20 m sprint test has demonstrated high level of reliability in our study (α = 0.901 and α = 0.914 for 5 m and 20 m sprint, respectively), which is similar to previous study findings [31].

Agility *t*-test was conducted according to Semenick [32]. The participants starts with front foot positioned 0.3 m before the light gate. The test includes forward running, shuffling sideways and in the end backwards running. The trial was not counted if the player crossed one foot over the other while shuffling or failed to touch the base of the cones. Times were recorded using light gates (Microgate—Witty, Italy), placed at the start/end position. Two trials were completed with 2 min of passive recovery, and better result was taken for analysis [33]. Good test-retest reliability (α = 0.875) was found for this parameter.

2.4. Training Interventions

Two sessions were conducted to familiarize participants with the training method in order to optimize training adaptations. Two experimental groups (FST and TST) attended 8 weeks of individually supervised strength training, 1–2 training sessions per week, with 12 training sessions in total. The number of training sessions and sets increased progressively throughout the program (Table 1), with at least 48 h rest between sessions. The experimental groups (FST and TST) had the same number of training sessions, sets and repetitions per set during the experimental treatment for each training session (equivolumed training protocols). Moderate inertial load (0.075 kg m^2) was chosen for half squat and Romanian deadlift for FST group based on findings by Sabido et al. [34] reporting that these loads maximized eccentric overload. All other exercises except Rotational pallof press for both FST and TST participants were conducted with 85% of 1 RM.

Each training session consisted of 5 drills, with the only difference in the two exercises: while the FST group practiced Romanian deadlift (RDL) and half squats (HS) on the isoinertial device, the TST group practiced half squats (HS) and Romanian deadlift (RDL) with free weights. Two minutes of passive recovery was allowed between exercises and sets. For flywheel exercises each set begins with two submaximal attempts that are not counted in the total number of repetitions, and then the subject continues to exercise with maximum voluntary attempts the required number of repetitions. For half squat exercise, the subject begins with concentric phase caried out from about 90-degree knee angle to near full extension and then continues, without stopping, the phase of eccentric contraction. Participants were briefed to perform the concentric phase with maximum effort, while applying maximal force after the first third of the lengthening phase in order to stop the flywheel at about 90 of knee flexion, thus achieving eccentric overload [21]. It has been recognized that special eccentric strategies are required to apply breaking force over the entire range of motion at certain joint angles to achieve the desired eccentric overload [35]. Romanian deadlift was standing upright holding the Kbar in front and with shoulders width apart.

For Romanian deadlift, the participants stands on an isoinertial device, placing a Kbar in front of the body, connected to the device by a strap. In the initial position the participant is bent at the hips, the back is straight, the arms are outstretched and the bar is below the knee (knee almost fully extended). The exercise begins by raising the body with maximal voluntary contraction (concentric phase) to an upright position when the strap is stretched to the maximum. It is immediately continued by winding the tape and the participants enters the braking phase in order to stop in the initial position (eccentric phase), after which the next repetition follows without a pause. The bar moves close to the body during exercise.

Table 1. Training program for flywheel (FST) and traditional strength training (TST) groups.

FST	TST
Week 1–2	Week 1–2
Number of training sessions: 1 One-arm dumbbell row (2 × 8) Rotational pallof press 2 × (2 × 12–15) Biceps curls + upright row complex (2 × 8) Half squat on isoinertial device (2 × 8) Romanian Deadlift (RDL) on isoinertial device (2 × 8)	Number of training sessions: 1 One-arm dumbbell row (2 × 8) Rotational pallof press 2 × (2 × 12–15) Biceps curls + upright row complex (2 × 8) Half squat with free weights (2 × 8) Romanian deadlift (RDL) with free weights (2 × 8)
Week 3–4	Week 3–4
Number of training sessions: 1 One-arm dumbbell row (3 × 8) Rotational pallof press 2× (3 × 12–15) Biceps curls + upright row complex (3 × 8) Half squat on isoinertial device (3 × 8) Romanian Deadlift (RDL) on isoinertial device (3 × 8)	Number of training sessions: 1 One-arm dumbbell row (3 × 8) Rotational pallof press 2 × (3 × 12–15) Biceps curls + upright row complex (3 × 8) Half squat with free weights (3 × 8) Romanian deadlift (RDL) with free weights (3 × 8)
Week 5–6	Week 5–6
Number of training sessions: 2 One-arm dumbbell row (3 × 8) Rotational pallof press 2 × (3 × 12–15) Biceps curls + upright row complex (3 × 8) Half squat on isoinertial device (3 × 8) Romanian Deadlift (RDL) on isoinertial device (3 × 8)	Number of training sessions: 2 One-arm dumbbell row (3 × 8) Rotational pallof press 2 × (3 × 12–15) Biceps curls + upright row complex (3 × 8) Half squat with free weights (3 × 8) Romanian deadlift (RDL) with free weights (3 × 8)
Week 7–8	Week 7–8
Number of training sessions: 2 One-arm dumbbell row (4 × 8) Rotational pallof press 2 × (4 × 12–15) Biceps curls + upright row complex (4 × 8) Half squat on isoinertial device (4 × 8) Romanian Deadlift (RDL) on isoinertial device (4 × 8)	Number of training sessions: 2 One-arm dumbbell row (4 × 8) Rotational pallof press 2 × (4 × 12–15) Biceps curls + upright row complex (4 × 8) Half squat with free weights (4 × 8) Romanian deadlift (RDL) with free weights (4 × 8)

2.5. Statistical Analysis

Data are presented as mean ± standard deviation (SD). Normality of distribution was examined using the Shapiro–Wilk test. Levene's test for the assessment of homoscedasticity was applied. At pre-test, between-group comparisons were analyzed by univariate analysis of variance (ANOVA) with the factor group (FST, TST and CON), and between-group comparisons under the influence of experimental treatment were analyzed by a two-way ANOVA (3 × 2). Statistical significance was set a priori at $p \leq 0.05$. Post-hoc test (Least Significant Difference test—LSD) following ANOVA was used to determine the significance of factors interaction. Cohen's *d* as the measure of the effect size of the mean difference was calculated by subtracting the means and dividing the result by the pooled standard deviation. A Cohen's d of ≤0.20 = trivial, 0.20–0.60 = small, 0.61–1.20 = moderate, 1.21–2.0 = large and ≥2.01 = very large, as suggested by Hopkins et al. [36]. Data were processed using the SPSS statistical software package, version 20 (Chicago, IL, USA).

3. Results

No significant between-group differences were detected in pretest for any variable analyzed. In addition, no meaningful group-by-time interaction was found for sprint 20 m (F = 2.52; $p = 0.088$) (Table 2).

Table 2. Between-group differences in selected variables with % of improvement and Cohen's effect size (d).

	FST				TST				CON				
	IN	**FIN**	**%**	**d**	**IN**	**FIN**	**%**	**d**	**IN**	**FIN**	**%**	**d**	***p***
ISOMET	92.33 ± 10.57	109.83 ± 7.81	18.7	1.883	90.25 ± 10.35	105.25 ± 9.36	16.6	1.520	92.42 ± 4.08	94.33 ± 3.28	2.9	0.516	0.000 ‡
CMJ	52.36 ± 3.33	59.29 ± 2.97	11.7	2.196	51.45 ± 3.61	55.22 ± 3.07	6.8	1.125	50.77 ± 2.53	50.92 ± 2.56	0.3	0.059	0.001 †,‡,Δ
SPR5m	1.16 ± 0.04	1.04 ± 0.02	10.3	3.795	1.18 ± 0.07	1.11 ± 0.05	5.9	1.151	1.18 ± 0.03	1.14 ± 0.06	3.4	0.843	0.010 †,‡
SPR20m	3.20 ± 0.11	3.07 ± 0.09	4.1	1.294	3.24 ± 0.10	3.13 ± 0.11	3.4	1.046	3.21 ± 0.051	3.19 ± 0.56	0.6	0.05	0.088
t-test	10.07 ± 0.10	9.83 ± 0.07	2.4	2.781	10.04 ± 0.09	9.90 ± 0.08	1.4	1.644	10.12 ± 0.07	10.06 ± 0.06	0.6	0.92	0.000 †,‡,Δ

ISOMET—isometric strength test; cmJ—countermovement jump test; SPR5m—20 m sprint test; SPR20m—5 m sprint test; *t* test—agility *t*-test; IN—initial tests result ± standard deviation; FIN—final test result ± standard deviation; %—percentage of improvement; *p*—level of statistical significance; †—statistically significant difference between FST and TST group; ‡—statistically significant difference between FST and CON group; Δ—statistically significant difference between TST and CON group.

Significant group-by-time interaction was found for ISOMET (F = 6.40, $p = 0.000$), while post hoc analysis revealed differences between FST and CON groups ($p = 0.014$). Comparing the results of the initial and final measurements, FST group had an improvement of 18.7%, (large effect size) the TST group achieved an improvement of 16.6% (large effect size), while the CON groups result was improved by 2.9% (small effect size). Significant group-by-time interaction was found for cmJ (F = 7.45; $p = 0.001$), with post hoc analysis revealing differences between FST and TST group ($p = 0.006$), but also FST and CON ($p = 0.000$) as well as CST and CON ($p = 0.006$). The experimental groups, FST and TST achieved progress of 11.7% (very large effect size) and 6.8% (large effect size), respectively. The CON group had an improvement of 0.3% (trivial effect size). The group-by-time interaction for the 5 m sprint variable (SPR5m) showed a significant difference between groups (F = 7.45; $p = 0.010$). Post hoc analysis showed that there were significant differences between the FST and TST groups ($p = 0.001$) and between FST and CON groups ($p = 0.000$), while there was no significant difference between the TST and CON ($p = 0.333$). Considering the percentage of improvements, 10.3% (very large effect size), 5.9% (moderate effect size) and 3.4% (moderate effect size) were reported for the FST, TST and CON groups, respectively. For the *t*-test, an analysis of the group-by-time interaction showed statistically significant differences (F = 10.46; $p = 0.000$) between groups. Post hoc analysis showed a significant difference ($p = 0.000$) between the FST and CON groups as well as between TST and CON groups ($p = 0.018$). Furthermore, a statistically significant difference was also found between the FST and TST groups ($p = 0.045$). When expressed as a percentage, the reported improvements were 2.4% (very large effect size) for the FST group, 1.4% (large effect size) for the TST group and 0.6% for the CON group (moderate effect size).

4. Discussion

It has been proposed that flywheel training is an efficient method for enhancing a myriad of fitness attributes in team sport athletes [13]. However, studies exploring the effectiveness of flywheel training with basketball athletes is lacking. Therefore, the aim of the present investigation was to compare the in-season effects of equivolumed flywheel vs. traditional strength training on lower body strength, countermovement jump, change of directions ability and sprint performance in well-trained young basketball players. The results of this research indicate that there were no differences in strength improvements for two experimental protocols while flywheel training was proved to be superior for developing agility, vertical jump and 5 m sprint time. Flywheel group displayed significantly higher improvements in strength, vertical jump, 5 m sprint time and change of direction ability compared to control group. Players from traditional strength training group showed better results in vertical jump and change of direction ability compared to players from control group. Interestingly, adding one/two sessions a week of flywheel training appears to be an appropriate strategy for enhancing lower body strength during competitive period in young basketball players while adding equivolumed traditional strength training seems less effective. Finally, neither training modality was proved effective for enhancing 20 m sprint performance.

Although this type of practice is very popular in the last decades [13], scanty studies have compared the effects of flywheel and traditional weight training on performance in athletic population [17,19,37], and generally presented data similar to our study findings. In a six week study by Maroto-izguierdo et al. [19], 15 flywheel training sessions (4 × 7 maximal intensity half squats done with 0.145 kg·m^2 moment inertia) produced superior improvements ($p < 0.05$–0.001) compared to traditional weight training (4 × 7 leg presses with load corresponding to 7 repetitions maximum (7 RM) for each set) for vertical jump (9.8% vs. 3.4%), change of direction ability (−7% vs. −4.4%) but also 20 m sprint time (−10% vs. −5.1%) in professional handball players. In addition, no significant differences between strength training modalities were observed for maximum strength improvement (12.2% and 7.9% for flywheel and traditional weight training, respectively). The outcomes of the 8 week Corratela et al. [17] study demonstrated that flywheel strength training performed once per week with up to 6 sets of 8 repetitions of squats produced superior improvements to equivolumed traditional weight training (80% of 1 RM) for change of direction ability (−7% vs. −2%, respectively) and 20 + 20 m sprints (−4% vs. −1%, respectively) but not for jumping (squat jump and countermovement jump) and sprinting abilities (10 m sprint and 30 m sprint) in professional soccer players. Furthermore, lower body strength increased significantly and similarly in both groups. Finally, effects of flywheel and traditional strength training on 10-m sprint, cmJ and lower body strength (1 RM squat) were examined on 38 active male football players by Sagelv et al. [37]. During six weeks of intervention (2 sessions per week), both flywheel and traditional strength training progressively increased squat exercise from 3 sets with 6 repetitions (week one) to 4 sets with 4 repetitions (week six). Flywheel group performed exercise with individually adjusted inertia enabling high power outputs (>4 watts·kg^{-1}) while traditional strength training comprised of 4 sets with 4 repetitions (85% of 1 RM) was performed with maximum intended velocity. In addition, an equivolumed Nordic hamstring exercise was included for both groups with three sets of 4–10 repetitions to counteract expected strength gains in quadriceps muscle. Both groups significantly improved cmJ (9% and 8% for flywheel and traditional strength group, respectively) and identically decreased 10 m sprint time (2%) without between group differences for either variable. Interestingly, traditional strength training was proved superior to flywheel training in improving lower body strength (46% vs. 19%, respectively), with the noteworthy observation that traditional weight training was conducted with high loads (85%) and maximal intended velocity which is likely the primary reason for observed improvements [38]. Collectively, the aforementioned study corroborates our study findings that flywheel training induces superior power-related performance but not strength outcomes to traditional weight training modalities in the athletic population.

In addition, these studies suggest that flywheel training is potent tool for strength and power related performance attribute improvements in the well-trained population, which is broadly supported with several other studies. Indeed, a recent meta-analysis reported flywheel-training induced strength improvements, but also no difference in strength increase after flywheel vs. traditional weight training [39]. Askling et al. [16] and deHoyo et al. [14] after 10 weeks of flywheel training (16 and 17 sessions, respectively) in elite soccer players (seniors and juniors, respectively) reported significant strength ($p \leq 0.05$; 19% and 15% for eccentric and concentric strength, respectively) and 30 m sprint time ($p \leq 0.05$; 2.4%) improvements as well as vertical jump (7.6%) and sprint time (20 m sprint, 1.5%; and 10 m flying sprint, 3.3%) improvements, respectively. In addition, six weeks of flywheel training, performed twice a week, has been shown to induce statistically higher improvements in squat jump and drop jump performance as well as change of direction ability compared to volume-matched plyometric training in well-trained junior soccer players [18]. On the contrary, implementing one flywheel training session per week for 7 weeks was found ineffective for lower body strength (1 RM in the half squat), 20 m sprint time, and cmJ improvements in professional handball players [20], suggesting that more than one flywheel training per week, with up to 4 sets

(7 reps), is needed for substantial power-related performance improvements in the athletic population [1]. Indeed, Corattela et al. [17] reported significant improvements in change of direction ability and vertical jump performance (SJ and cmJ) after 6 weeks of flywheel strength training performed just once per week but with higher number of sets and reps (6 and 8, respectively). Collectively, these data support efficacy of flywheel training for improving broad range of strength and power -related performance attributes in well trained population, with noteworthy caution considering threshold load that needs to be met in order to obtain significant improvements. Clearly, additional investigations about the topic are warranted.

It is interesting to note that we found no significant effects of flywheel nor traditional strength training on 20 m sprint performance in our participants. Somewhat in line with our findings, no change in 20 m sprint time was reported after horizontal flywheel training in physically active men [40]. It has been previously reported that low-velocity strength training may not be effective in improving sprinting ability in adolescents, especially well-trained athletes [41]. However, two-to-three flywheel sessions per week has been proven to increase the sprinting ability in handball players [19]. In addition, sprint time (10 and 20 m) significantly improved following 9 weeks of strength training in youth soccer players [42]. We can speculate that our study results are on one side consequence of the training status of our participant (well trained), as it has been shown that trained adolescents displayed hindered improvements in sprint outcomes with strength training compared to untrained one [43]. On the other hand, training and testing specificity could be also responsible as upward force-vector application during training likely play an important determinant in inducing specific functional adaptations [27]. In addition, 20 m sprint is rarely seen in a basketball game and practice and consequently sprint tests over shorter distances (5–10 m) might be more specific with acceleration and deceleration, rather than speed, as a far stronger predictor of basketball performance [44,45].

Although beyond the scope of this study, mechanisms that enables reported improvements in strength and power related performance outcomes should be concisely hypothesized. Flywheel training enables maximal force output throughout the entire concentric part of movement, but also short periods of overload in the eccentric phase of movement [13]. As exercise intensity has been acknowledged as a major determinant for strength training induced adaptations [46,47]. It can be speculated that this flywheel specific loading pattern (concentrically maximally loaded-eccentrically overloaded) is most likely responsible for superior effects for power-related performance outcomes in our study. Furthermore, eccentric overload induced specific neuromuscular adaptations such as dampened motor recruitment [48] with preferential recruitment of high threshold motor unit and higher cortical activity [49]. Finally, it has been reported that increase in eccentric phase force output leads to increase in following concentric phase force output [50–52]. Collectively, this physiological distinctiveness supports our study findings and the beneficial use of flywheel training to optimize strength and power adaptations in young basketball athletes.

Several limitations of the study should be highlighted. We did not monitor load of regular basketball practice done by all participants with their respective coaches, which could somewhat blur the picture of obtained strength training effects. In addition, this study engaged male trained basketball players, without preceding experience in the flywheel training. Accordingly, the results may not translate to flywheel-experienced athletes. Finally, our study lasted for 8 weeks only, while comparative investigations with traditional strength modalities of longer durations are needed.

5. Conclusions

In summary, eight weeks of flywheel training with 1–2 sessions per week, including up to 4 sets of 8 repetitions of the half squat and Romanian deadlift exercises performed with maximum concentric intensity produces superior enhancement in vertical jump, 5 m sprint time and change of direction ability to equivolumed traditional strength training in well-trained young basketball players. In addition, both strength training modalities were equally effective in maximal strength gains. Therefore, low-volume/high-intensity flywheel strength training seems to be an efficient tool to induce strength and power-related adaptations in well-trained young basketball players.

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Article

Accelerometry-Workload Indices Concerning Different Levels of Participation during Congested Fixture Periods in Professional Soccer: A Pilot Study Conducted over a Full Season

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Abstract: The aim of this study was to analyze the variations of acute load (AL), acute: chronic workload ratio (ACWR), training monotony (TM), and training strain (TS) of accelerometry-based GPS measures in players who started in three matches (S3M), two matches (S2M), and one match (S1M) during congested weeks. Nineteen elite professional male players from a Portuguese team (age: 26.5 ± 4.3 years) were monitored daily using global positioning systems (GPSs) over a full season (45 weeks). Accelerometry-derived measures of high metabolic load distance (HMLD), high accelerations (HA), and high decelerations (HD) were collected during each training session and match. Seven congested weeks were classified throughout the season, and the participation of each player in matches played during these weeks was codified. The workload indices of AL (classified as ACWR, TM, and TS) were calculated weekly for each player. The AL of HMLD was significantly greater for S2M than S1M (difference = 42%; $p = 0.002$; d = 0.977) and for S3M than S1M (difference = 44%; $p = 0.001$; d = 1.231). Similarly, the AL of HA was significantly greater for S2M than S1M (difference = 25%; $p = 0.023$; d = 0.735). The TM of HD was significantly greater for S2M than S3M (difference = 25%; $p = 0.002$; d = 0.774). Accelerometry-based measures were dependent on congested fixtures. S2M had the greatest TS values, while S3M had the greatest TM.

Keywords: association football; performance; GPS; external load; load monitoring; sports science

1. Introduction

The individualization of the training process requires, among other things, systematic monitoring of the load that occurs during sessions and competitions [1]. This kind of monitoring can be of paramount importance, especially considering that in team sports, the heterogeneity of the impact of exercises in players can be high [2], and there can be a discrepancy between coaches' perceptions about the load imposed and the real impact imposed on players [3]. Thus, proper training load monitoring can help coaches to better adjust their training plans to the players and speed up the process of regulating stimuli to improve the recovery mechanisms of players [4].

Aspects of training load monitoring are commonly organized into two dimensions [5]: (i) external load, which is associated with the physical demands imposed on players and the mechanical work performed by players during the exercise; and (ii) internal load, which is related to the psychobiological effects of external load on the players. These two types of load are different in terms of the information available to sports scientists, even though they interact with each other and are related [6]. Internal load is commonly measured using heart rate monitors or rate of perceived exertion scales, while external load is quantified using devices such as global positioning systems (GPSs), accelerometers, and inertial measurement units [7].

Specific indicators of external load that are commonly measured using GPSs include: (i) distances covered at different speed thresholds; (ii) events associated with changes in speed, namely, accelerations/decelerations or changes in direction; and (iii) events related to the use of accelerometers or inertial measurement units (e.g., player load, impacts, or stride variables) [8]. The first two types of indicators (distances and changes in speed) can be highly variable in terms of tactical issues, while indicators of the third type tend to depend on the dynamics of the game [8]. Additionally, accelerometry-based measures can provide a great level of sensitivity and accuracy, considering the capacity of these sensors to collect data at a higher acquisition frequency than GPSs [7].

The quantification of acute load during training sessions and matches is important. However, a proper understanding of accumulated load can be crucial to identifying patterns in the training process and guaranteeing the correct progression and management of the load imposed across weeks [9]. In particular, the relationship between weekly load and chronic load (referred to as "acute: chronic workload ratio", or ACWR) has been used to determine the progression and variation of load across weeks and to identify possible exposures to spikes in load [10]. Fundamentally, ACWR is a measure that can control the progression of load and quickly determine possible drastic and unplanned decreases and increases that may interfere with recovery/readiness and performance or affect injury risk [11,12]. Other indices such as training monotony and training strain can also be useful for monitoring load variations within a week and exposure to consistent high-doses, for example [13]. In particular, training monotony can provide information about the within-week variability of the load, while training strain indicates the overall impact of training on players [13]. These indices have also been used to determine possible relationships between bad overreaching, overtraining, and injury risk [14].

The variations of load can be planned by the coach or influenced by the competitive calendar. In fact, in team sports like soccer, seasons have become more congested, involving more periods of matches with few days of recovery in between [15]. Thus, scientific interest in congested fixture periods has increased in recent years, mainly considering the impact of congested periods on players' performance [16], recovery processes [17], and injury risk [18]. Some of the possible risks of exposing players to congested fixture periods are reduced muscle stiffness [19], increased physiological stress and muscle damage [17], and greater strength deficits [20].

Extensive information regarding the acute impact of congested fixture periods has been provided in the last decade. Despite this, there is a lack of evidence about the influence of such periods on ACWR, training monotony, and strain. It is expected that these indices vary significantly in congested periods. Furthermore, it is possible that the heterogeneity of the indices between players increases. Differences in terms of workload indices between different levels of participation in matches could also be present—specifically between players who are starters (who begin the game) in three matches, two matches, or just one match in the same week. These possibilities must be described to improve our understanding of the impact of congested fixture periods on workload indices variations between players.

On the basis of the reasons stated above, and in an attempt to better characterize the impact of congested fixture periods on accelerometry-based indices regarding different levels of participation in matches, this study aimed to analyze variations of acute load, ACWR, training monotony, and the training strain of accelerometry-based GPS measures in starters of three matches (S3M), two matches (S2M), and one match (S1M) in professional soccer during congested weeks.

2. Materials and Methods

2.1. Experimental Approach to the Problem

This study used a cohort design. Throughout an entire 45-week season (3 July 2018 to 9 May 2019), the external loads of 19 professional soccer players were monitored daily, during both training sessions and matches. Weeks were classified as regular (one match per week) or congested (two matches or more within seven days). Considering the main purpose of this study (to compare workload indices between starters and non-starters in congested weeks), Table 1 presents the characteristics of the congested weeks included in the analysis. Considering the influence of matches on workload indices, the classification of players during congested weeks met the following criteria: (i) starters in three matches (S3M) who participated in three matches in the same week (for at least 45 min in each match); (ii) starters in two matches (S2M) who participated in two matches in the same week (playing for at least 45 min in each match); and (iii) starters in one match (S1M) who participated in a single match in a week (for at least 45 min of the game).

The external loads of players were monitored daily using an 18-Hz GPS. The following accelerometry-derived measures were collected: (i) high metabolic power distance, and (ii) high accelerations and decelerations. Using the GPS measures, the weekly acute load, chronic load, acute: chronic workload ratio, training monotony, and training strain were calculated weekly. Information about the calculus of these outcomes can be found in the external load quantification section.

Table 1. Characterization of congested weeks included in this study.

Variable	CW1	CW2	CW3	CW4	CW5	CW6	CW7
Month	August	September	December		January		February
Week of the season (*n*)	9	14	23	26	27	31	32
Regular weeks before (*n*)	2	2	5	2	0	2	0
Training sessions between matches (*n*)	2	2	2	2	3	3	2
S3M (*n*)	3	4	6	6	2	4	4
S2M (*n*)	6	4	2	3	8	4	6
S1M (*n*)	8	6	2	2	4	6	3

CW: congested week; S3M: starter in three matches; S2M: starter in both matches; S1M: starter in one match.

2.2. Participants

This study analyzed 19 professional men players (26.5 ± 4.3 years old; 75.6 ± 9.6 kg; 180.2 ± 7.3 cm; 7.5 ± 4.3 years of experience) belonging to a Portuguese European First League team. Among the participants, three were external defenders, four were central defenders, six were midfielders, four were wingers, and two were strikers. The inclusion criteria consisted of the following: (i) classified starters participated in at least 50% of the matches and 90% of training sessions in the three weeks before each analyzed congested week; (ii) none of the players were injured or ill in the congested weeks and in the three weeks preceding them; and (iii) none of the players were injured for more than four consecutive weeks during the entire season. A preliminary introduction to the study design and experimental approach was presented to the players. After their agreement, they signed a free written consent. The ethical standards of the Declaration of Helsinki for the study in humans were followed.

2.3. External Load Quantification

Players were daily monitored with an 18-Hz GPS unit integrating a 100-Hz gyroscope, 100-Hz tri-axial accelerometer, and 10-Hz magnetometer (STATSports, Apex, Newry, Northern Ireland). The GPS revealed good validity and reliability levels [21,22]. An exclusive GPS unit was attributed to each player during the season, aiming to reduce the interunit variability. Players wore a specific vest with a bag placed on the upper back (interscapular line, T2–T4 vertebrae) with the GPS unit positioned inside. During data collection, the number of satellites varied between 18 and 21. The data collected in training sessions and matches were uploaded and treated in the STATSport Apex software (version 5.0).

The accelerometry-based measures collected daily were: (i) high metabolic load distance (high metabolic load distance (HMLD): corresponding to the distance covered at a speed greater than 5.5 m/s and while accelerating/decelerating at a magnitude of 2 m/s^2 or above); (ii) high accelerations and decelerations (high accelerations (HA) and high decelerations (HD): the number of accelerations and decelerations with a magnitude of 3 m/s^2 or above maintained for at least half of a second). The volume (total meters or number in each session) of each external load measure (during the session or match) was collected first for each player. After that, and for each subsequent week, the following indices were calculated: (i) acute load (wAL: corresponding to the sum of the load during a week); (ii) acute: chronic workload ratio (ACWL: representing the division of the wAL by the rolling average of accumulated training load in the previous four weeks—coupled version) [23]; (iii) training monotony (TM: corresponding to the mean of training load during the seven days of the week divided by the standard deviation of the days); (iv) training strain (TS: the multiplication of wAL by the TM) (Foster et al., 2001). These indices were calculated for each accelerometry-derived measure, resulting in the following variables: (i) wHMLD (weekly HMLD); (ii) acwrHMLD (ACWR of HMLD); (iii) mHMLD (monotony HMLD); (iv) sHMLD (strain HMLD); (v) wHA (weekly HA); (vi) acwrHA (ACWR of HA); (vii) mHA (monotony HA); (viii) sHA (strain HA); (ix) wHD (weekly HD); (x) acwrHD (ACWR of HD); (xi) mHD (monotony HD); and (xii) sHD (strain HD).

2.4. Statistical Procedures

The normality of the sample was assumed based on the central limit theorem, after being tested with the Kolmogorov–Smirnov test. Data were tested for his homogeneity using the Levene ($p > 0.05$). Descriptive statistics were presented in the form of tables and figures reporting the mean and standard deviation. The analysis of variation of the workload measures between types of participation was executed using mixed ANOVA. Tukey was used for pairwise comparisons since the sample was greater than 30. Statistical analysis was executed in the SPSS software (version 25.0, IBM, Chicago, IL, USA) for a $p < 0.05$. Effect size (ES) calculation was made following the Cohen's approach (d) for a 95% confidence interval (95% CI). The magnitude of changes was interpreted based on the following thresholds [24]: 0.00 to 0.19, trivial; 0.20 to 0.59, small; 0.60 to 1.19, moderate; 1.20 to 1.99, large; >2.00, very large.

3. Results

Meaningful differences were found between type of participation in the congested weeks for the accelerometry-based workload measures (Table 2). The aHMLD was meaningfully greater for S2M than S1M (42%) and was greater for S3M than S1M (44%). Additionally, the mHLMD was meaningfully greater for S3M than S2M (14%). Finally, the sHMLD was meaningfully greater for S2M than S1M (41%).

Table 2. Descriptive and inferential statistics (mean ± SD) of high metabolic load distances workload indices in different levels of participation in matches.

Outcome	S1M (Mean ± SD)	S2M (Mean ± SD)	S3M (Mean ± SD)	*p*	ES
aHMLD (m)	6817 ± 2677	9694 ± 3080	9809 ± 2261	S1M vs. S2M: 0.002 * S1M vs. S3M: 0.001 * S2M vs. S3M: >0.999	S1M vs. S2M: −0.977 moderate ¶ S1M vs. S3M: −1.231 large # S2M vs. S3M: −0.042 trivial
acwrHMLD (A.U.)	1.0 ± 0.5	1.0 ± 0.3	1.0 ± 0.3	S1M vs. S2M: >0.999 S1M vs. S3M: >0.999 S2M vs. S3M: >0.999	S1M vs. S2M: 0.000 trivial S1M vs. S3M: 0.000 trivial S2M vs. S3M: 0.000 trivial
mHMLD (A.U.)	0.8 ± 0.2	0.8 ± 0.3	0.7 ± 0.1	S1M vs. S2M: >0.999 S1M vs. S3M: 0.128 S2M vs. S3M: 0.010 *	S1M vs. S2M: 0.000 trivial S1M vs. S3M: 0.687 moderate ¶ S2M vs. S3M: 0.438 small &
sHMLD (A.U.)	5922 ± 3200	8328 ± 3680	6666 ± 2269	S1M vs. S2M: 0.033 * S1M vs. S3M: >0.999 S2M vs. S3M: 0.130	S1M vs. S2M: −0.684 moderate ¶ S1M vs. S3M: −0.2789 small & S2M vs. S3M: 0.535 small &

aHMLD: weekly acute load of high metabolic load distance; acwrHMLD: acute: chronic workload ratio of total distance; mHMLD: training monotony of total distance; sHMLD: training strain of total distance; S1M: starter in one match; S2M: starter in two matches; S3M: starter in three matches; *: *p*-value < 0.05; &: small ES; ¶: moderate ES; #: large ES; ES: effect size (standardized effect size of Cohen: d).

Table 3 presents the differences between S1M, S2M, and S3M for aHA, acwrHA, mHA, and sHA. The aHA (25%), mHA (33%), and sHA (44%) were meaningfully greater for S2M than S1M.

The analysis of variation for aHD, acwrHD, mHD, and sHD can be observed in Table 4. The mHD was meaningfully greater for S2M than S3M (25%).

Table 3. Descriptive and inferential statistics (mean ± SD) of high accelerations workload indices in different levels of participation in matches.

Outcome	S1M (Mean ± SD)	S2M (Mean ± SD)	S3M (Mean ± SD)	*p*	ES
aHA (m)	1134 ± 374	1423 ± 403	1348 ± 282	S1M vs. S2M: 0.023 * S1M vs. S3M: 0.155 S2M vs. S3M: >0.999	S1M vs. S2M: −0.735 moderate ¶ S1M vs. S3M: −0.667 moderate ¶ S2M vs. S3M: 0.213 small &
acwrHA (A.U.)	1.1 ± 0.5	1.0 ± 0.2	1.0 ± 0.3	S1M vs. S2M: >0.999 S1M vs. S3M: >0.999 S2M vs. S3M: >0.999	S1M vs. S2M: 0.300 small & S1M vs. S3M: 0.255 small & S2M vs. S3M: 0.000 trivial
mHA (A.U.)	1.1 ± 0.4	1.2 ± 0.4	0.9 ± 0.2	S1M vs. S2M: 0.323 S1M vs. S3M: 0.187 S2M vs. S3M: <0.001 *	S1M vs. S2M: −0.250 small & S1M vs. S3M: 0.681 moderate ¶ S2M vs. S3M: 0.930 moderate ¶
sHA (A.U.)	1274 ± 734	1752 ± 809	1213 ± 448	S1M vs. S2M: 0.060 S1M vs. S3M: >0.999 S2M vs. S3M: 0.009 *	S1M vs. S2M: −0.610 moderate ¶ S1M vs. S3M: 0.106 trivial S2M vs. S3M: 0.810 moderate ¶

aHA: the weekly acute load of high accelerations; acwrHA: acute: chronic workload ratio of high accelerations; mHA: training monotony of high accelerations; sHA: training strain of high accelerations; S1M: starter in one match; S2M: starter in two matches; S3M: starter in three matches; *: *p*-value < 0.05; &: small ES; ¶: moderate ES; ES: effect size (standardized effect size of Cohen: d).

Table 4. Descriptive and inferential statistics (mean ± SD) of high decelerations workload indices in different levels of participation in matches.

Outcome	S1M (Mean ± SD)	S2M (Mean ± SD)	S3M (Mean ± SD)	*p*	ES
aHD (m)	966 ± 343	1201 ± 370	1166 ± 277	S1M vs. S2M: 0.057 S1M vs. S3M: 0.151 S2M vs. S3M: >0.999	S1M vs. S2M: −0.652 moderate ¶ S1M vs. S3M: −0.658 moderate ¶ S2M vs. S3M: 0.106 trivial
acwrHD (A.U.)	1.0 ± 0.5	1.0 ± 0.2	1.0 ± 0.3	S1M vs. S2M: >0.999 S1M vs. S3M: >0.999 S2M vs. S3M: >0.999	S1M vs. S2M: 0.000 trivial S1M vs. S3M: 0.000 trivial S2M vs. S3M: 0.000 trivial
mHD (A.U.)	0.9 ± 0.3	1.0 ± 0.3	0.8 ± 0.2	S1M vs. S2M: 0.568 S1M vs. S3M: 0.268 S2M vs. S3M: 0.002 *	S1M vs. S2M: −0.333 small $^{\&}$ S1M vs. S3M: 0.411 small $^{\&}$ S2M vs. S3M: 0.774 moderate ¶
sHD (A.U.)	947 ± 546	1290 ± 670	956 ± 384	S1M vs. S2M: 0.116 S1M vs. S3M: >0.999 S2M vs. S3M: 0.067	S1M vs. S2M: −0.545 small $^{\&}$ S1M vs. S3M: −0.020 trivial S2M vs. S3M: 0.601 moderate ¶

aHD: weekly acute load of high decelerations; acwrHD: acute: chronic workload ratio of high decelerations; mHD: training monotony of high decelerations; sHD: training strain of high decelerations; S1M: starter in one match; S2M: starter in two matches; S3M: starter in three matches; *: *p*-value < 0.05; $^{\&}$: small ES; ¶: moderate ES; ES: effect size (standardized effect size of Cohen: d).

4. Discussion

This study aimed to analyze the variations of AL, ACWR, TM, and TS for accelerometry-based GPS measures at different levels of match participation among professional soccer players. The main evidence indicates that there are no significant differences between S1M, S2M, and S3M for ACWR for all measures. Meanwhile, S2M and S3M had greater ALs than S1M for all accelerometry-based measures.

Considering HMLD, it was found that S3M presented the greatest ALs. Additionally, S2M had the greatest TM and TS, while no significant differences were found for ACWR. HMLD is measured by the amount of high-speed running performed, combined with acceleration and deceleration distances [25]. This variable seems to be position-dependent [26,27]. Although there is a lack of evidence on the effects of accelerometry measures in congested periods [28], it has been demonstrated that distance-based measures are not dependent on congested periods [29,30]. This contrasts with our findings, in which weekly accumulated HMLD ALs seemed to be affected by congestion fixtures.

In a study conducted on 28 elite soccer players, it was found that in a regular week, players reached ~6000 m of HMLD [31], which is in line with the S1M group of our study. However, for players who started in two or three matches, HMLD reached 9809 m. As training sessions may be reduced (2–3 sessions) and are mainly related to recovery training sessions between matches in congested weeks [15], load variability was expected, which was reflected in the lower TM found in this study. Despite the lower TM and balanced ACWR found throughout the congested period, coaches should be aware of high strain values, such as those found in the S2M group (8328 A.U.), as it has been reported that the lower threshold that favors illness is ~6000 A.U. [32].

For HA comparisons, our results showed that S2M had greater AL, TM, and TS values than S1M and S3M, while no significant differences were found for ACWR. Arruda et al. [28] found that the number of accelerations decreased after a congested fixture. However, the authors did not consider HA separately, which might have skewed the results. In contrast, our study showed that S2M and S3M covered greater HA distances than S1M. These comparisons must be analyzed with caution since the authors of the aforementioned study did not distinguish starters from non-starters, despite using players with an expert level. In fact, in shorter periods (i.e., during a match), it was reported that HA decreased due to fatigue during the final minutes of the match [33,34]. However, the same trend was not observed in longer periods (i.e., accumulated matches), in which the ALs of HA increased significantly, mainly in S2M. Although fatigue does not seem to negatively affect

HA performance in congested weeks, attention should be given to augmented TS values. Increased metabolic loads (due to the high metabolic demands of HA) and accumulated loads may increase the risk of injury [35–37].

Regarding the HD measure, it was found that S2M presented significantly greater TS values than S3M, while no significant differences were found for AL, ACWR, or TS between S1M, S2M, and S3M. Previous research showed that soccer teams complete greater HD than HA during matches than during training sessions [38]. However, there is a lack of research regarding weekly variations in congested fixtures, namely, considering important information such as the influence of playing position. Interestingly, in the present study, HD was lower than HA, both in regular and congested weeks. HD is closely related to mechanical work [39] and loading cycles are related to mechanical fatigue due to accumulated workloads [40]. However, recent research has warned that contrary to the damage caused by successive loads of mechanical work (such as HD), it is expected that human tissue is likely to cope with mechanical loads and augmented TS when applied for short periods [41]. Indeed, in the present study, it seemed that S2M and S3M were not affected by mechanical fatigue as they were able to withstand greater ALs and TS of HD; however, further research is needed to investigate the likelihood of an injury occurring in these cases. This can give coaches new insights about augmented HD TLs as a protective factor against injuries.

Our study had some limitations. The most evident was related to the sample size, as only one team was analyzed. Another limitation was that we did not consider other accelerometry measures, such as impact and fatigue indexes, which could give more detailed information about mechanical effects. Finally, playing positions were not considered due to the small sample. Future studies may provide more detailed information about positional dependencies, as well as the likelihood of injury occurring with increased loading cycles of HD distances in congested fixtures. Providing information about an entire session is certainly one of the strengths of this study. This issue represents a huge effort in terms of assuring external validity of the data under the real demands of a competitive soccer schedule, since it seems impossible to replicate in controlled environments (for example, in the laboratory).

Considering that ALs and TS for the overall accelerometry-based measures are expected to increase in congested fixtures, it is important to consider the proper management and preparation for this event. This may include a progressive overload in previous weeks to achieve a minimal spike in the week in which such a load will occur (congested weeks), as well as to identify exercises that could mitigate exposure to such frequencies during training sessions between matches during the congested period.

5. Conclusions

In this study, accelerometry-based measures were dependent on congested fixtures. The S2M group had the greatest TS values, while S3M had the greatest TM. Interestingly, S1M, S2M, and S3M had greater HA than HD. No significant ACWR changes were found. For these reasons, coaches should consider the effects of mechanical work in starters and non-starters to ensure that athletes can withstand high-intensity biomechanical loading cycle demands.

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Article

Usefulness of Linear Mixed-Effects Models to Assess the Relationship between Objective and Subjective Internal Load in Team Sports

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Abstract: Internal load can be objectively measured by heart rate-based models, such as Edwards' summated heart rate zones, or subjectively by session rating of perceived exertion. The relationship between internal loads assessed via heart rate-based models and session rating of perceived exertion is usually studied through simple correlations, although the Linear Mixed Model could represent a more appropriate statistical procedure to deal with intrasubject variability. This study aimed to compare conventional correlations and the Linear Mixed Model to assess the relationships between objective and subjective measures of internal load in team sports. Thirteen male youth beach handball players (15.9 ± 0.3 years) were monitored (14 training sessions; 7 official matches). Correlation coefficients were used to correlate the objective and subjective internal load. The Linear Mixed Model was used to model the relationship between objective and subjective measures of internal load data by considering each player individual response as random effect. Random intercepts were used and then random slopes were added. The likelihood-ratio test was used to compare statistical models. The correlation coefficient for the overall relationship between the objective and subjective internal data was very large ($r = 0.74$; $\rho = 0.78$). The Linear Mixed Model using both random slopes and random intercepts better explained ($p < 0.001$) the relationship between internal load measures. Researchers are encouraged to apply the Linear Mixed Models rather than correlation to analyze internal load relationships in team sports since it allows for the consideration of the individuality of players.

Keywords: team sports; statistical analysis; correlation; monitoring; RPE; heart rate; beach handball; training load; youth athletes

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1. Introduction

Monitoring athletes' workload is an essential process to understand the level of adaptation to a given training program and it is useful in minimizing the risk of nonfunctional overreaching [1,2]. The workload can be either external and internal, where the external load represents an objective measure of the work performed by the athlete (i.e., total distance covered in different speed zones and the number of sprints, accelerations, and decelerations), while the internal load represents the psychophysiological response of the athlete to a given training stimulus [3].

External load can be assessed by means of Global Positioning Systems (GPS), Inertial Movement Units (IMU) [3], accelerometers [3], and Local Positioning Systems (LPS) [4]. Although these systems are widely used in team sports such as basketball [5–7], handball [8], and beach handball [9], they present several limitations, such as high cost, the need of high technical expertise, and the risk of technical errors leading to a loss of data [10].

Internal load indicates the functional outcome of a given external load and can be used as an inexpensive way of monitoring athletes [11]. Internal load can be measured by means of objective methods such as heart rate (HR), blood lactate concentration, and oxygen uptake, and it is useful for improving performance and evaluating maladaptive responses to training programs [2,12,13]. HR is the most commonly adopted objective parameter used for monitoring internal load in team sports [1], with many HR-based models such as the Summated Heart Rate Zone (SHRZ) model [14]. Internal load can be also evaluated subjectively using questionnaires, such as the session Rating of Perceived Exertion (sRPE), which is among the most commonly used in team sports [3,15]. The advantages of using the sRPE include its ease of use and interpretation and its ability to provide information not only on the physiological responses to the prescribed load but also the psychological responses [16]. Moreover, the sRPE represents a valid tool for monitoring internal load when HR monitoring is not possible [17]. To use the sRPE as an alternative to HR-based methods, it is warranted to assess its validity, which represents the extent to which method results are associated with those of other accepted methods that measure the same parameter [18]. For this purpose, simple correlations have been previously adopted as main statistical tests to assess the concurrent validity of objective and subjective methods for monitoring the internal load, proving that the sRPE method is a valid, alternative tool to HR-based methods. However, when using simple correlation analyses, the within-subject variability it is not considered [19].

One way to overcome this limitation and improve the statistical analysis is the use of Linear Mixed Model (LMM) [20], which involves a generalization of linear regression but with both fixed and random effects. Fixed effects are analogous to the linear predictor from a standard linear regression, while the random effects are not directly estimated but are summarized according to their estimated variances and covariances. This structure gives additional flexibility to the statistical model, making it possible to model the random intercept and random slope as independent, correlated, or independent with equal variances [21]. In addition, LMMs make it possible to handle missing data instead of withdrawing subjects from the analysis. However, to the best of our knowledge, no previous study has applied LMMs to analyze the relationship between the subjective and objective methods used for monitoring the process of internal load in team sports. Therefore, the present study aims to (1) assess the correlation between objective and subjective internal load measures in team sports and (2) investigate these relationships by taking into account the individuality of players by means of LMMs.

2. Materials and Methods

2.1. Participants

Thirteen youth male players were recruited from the Lithuanian Under 17 beach handball team and volunteered to participate to this study. All players were novice to beach handball, but they had regularly trained for at least 5 years in indoor handball. Prior to the beginning of the study, all players, their parents, and the coaching staff were informed about the study aim, procedures, potential risks, and benefits associated with participation, and informed consent was obtained from participants' parents. The study was approved by the Institutional Review Board of the Department of Human Sciences, Society and Health of the University of Cassino and Lazio Meridionale (approval number: 3R1B.2019.05.06) according to principles outlined in the Declaration of Helsinki.

2.2. Experimental Design

Players' internal loads were monitored across 2 training camps (14 training sessions) and during the Young Age Category 17 European Beach Handball tournament held in Stare Jabløнki (Poland) from the 27 to 30 June 2019 where players were involved in 7 matches. Data were excluded from the analysis if players did not complete the entire session due to possible injuries. In total, data were collected across 21 sessions, resulting in 192 (136 trainings and 57 matches) individual values. The average temperature of the training sessions and matches was 20.5 ± 3.5 °C and the relative humidity was 65 ± 17.7%. To provide ecological conditions during the training sessions, the team's coaching staff freely planned their workouts without any intervention from the research staff. Since beach handball tournaments usually encompass 2 daily matches, the training regimen during the training camps encompassed 1 daily morning session mainly focused on sand-based physical conditioning and individual technical skills and 1 daily afternoon session mainly focused on team tactical trainings and small-sided games. All training sessions lasted ~1.5 h and they were composed by ~15 min of warm-up without and with balls, ~1 h of specific work, and ~15 min of cool-down and stretching exercises.

2.3. Procedures

During each experimental session, the workload was objectively recorded by means of HR monitors (H7, Polar Team System, Kempele, Finland). The duration of each training session was recorded to successively recognize the HR corresponding to the training activities. For matches, the entire playing time was considered. The 30 min of standardized warm-up preceding each match and the between-halves rest times were excluded from the analysis. After each session, the HR data were exported in 1 s epochs via proprietary software and the individual workload was calculated according to the SHRZ method [14]. This methodology allowed us to identify the individual workload score by calculating the product of the accumulated session duration (min) of 5 HR zones by a coefficient relative to each zone (50–59.9% of HRmax = 1, 60–69.9% of HRmax = 2, 70–79.9% of HRmax = 3, 80–89.9% of HRmax = 4, 90–100% of HRmax = 5). Then, the SHRZ workload (in AU) was calculated by summating the results. According to previous methodology used in sand-based sports [22,23] and other team sports [24], the peak HR registered across training sessions and matches was considered for the calculation of the SHRZ workload [24]. Data were subsequently expressed as percentages of the HRpeak.

Furthermore, the workload was subjectively assessed by means of the sRPE method [17,25]. Since recent evidence has suggested that RPE scales are interchangeable [26,27], in the present study, the category-ratio 10 (CR10) scale modified by Foster et al. [25] was administered by asking each player: "How hard was your training/match?" within 30 min after the completion of each training session and each match. The sRPE workload was then calculated by multiplying the individual score of the CR10 scale for the duration (min) of the training/match [25].

2.4. Preliminary Analysis

Means and standard deviations were calculated for each analyzed variable. Normal distribution was verified by the Shapiro–Wilk test. The Shapiro–Wilk test showed that the sRPE and SHRZ were not normally distributed when all of the sessions were combined. However, the sRPE and SHRZ showed different distribution patterns when training and matches were split. These results highlight that, in team sports, data could vary between subjects and sessions. Thus, the intersubject variability should be considered when analyzing data in order to avoid inaccurate results emerging from an over- or under-estimation of statistical significance in repeated measures of the study design [28].

2.5. Statistical Analysis

The overall relationship between the SHRZ and sRPE methods was assessed by means of the Pearson product moment and Spearman correlations, and then with linear regression. The sample was analyzed by combining all of the sessions and subsequently dividing trainings and matches. The magnitude of correlations was defined by the following criteria: trivial (<0.1), small (from 0.1 to 0.29), moderate (from 0.3 to 0.49), large (from 0.5 to 0.69), very large (from 0.7 to 0.89), and almost perfect (from $\geq$0.9 to 1) [29,30]. Additionally, the relationships between the SHRZ and sRPE methods were analyzed via LMM using the sRPE and SHRZ values as fixed effects while the random effects were represented by the individual response of each player. First, the models were fitted with only random intercepts for each player. However, by merely fitting the random intercept at the subject level, the variability of each player between sessions was not taken into consideration. Therefore, subsequently random slopes of the relationship between the SHRZ and sRPE were fitted into the models. Bryk/Raudenbush R-squared (R^2) values were calculated for each random intercepts LMM. Finally, the likelihood-ratio test was used to compare the each LMM developed with the linear regression analysis and to compare the 2 LMMs with only random intercepts, and with random intercepts and random slopes. Statistical analysis was performed using STATA statistical software version 15.1 (StataCorp, College Station, TX, USA) and the level of significance was set at $p < 0.05$.

3. Results

Descriptive characteristics of players are presented in Table 1.

Table 1. Players' descriptive characteristics. Values represent mean ± standard deviation (SD).

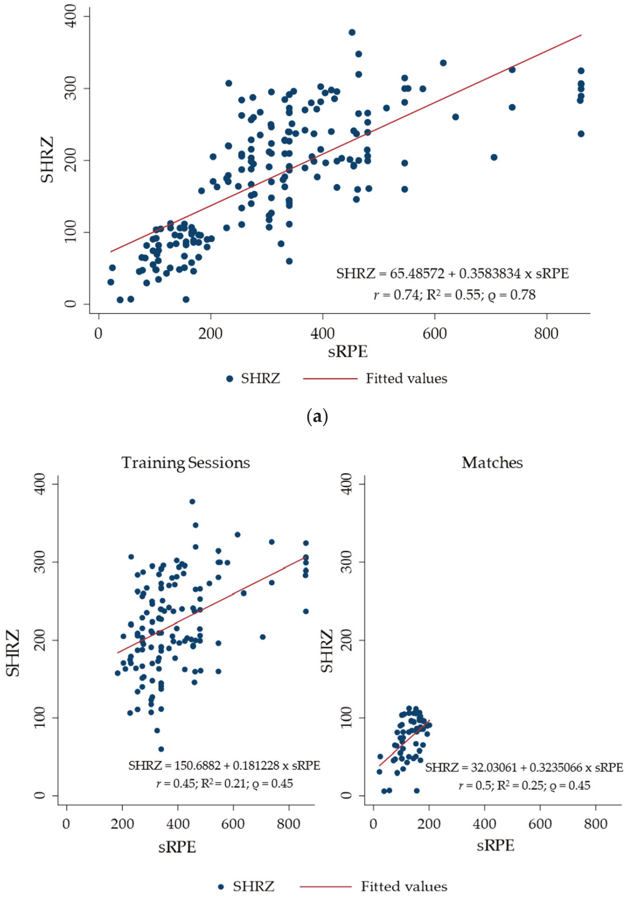
Characteristics	Mean ± SD	[95% CI]
Age (years)	15.9 ± 0.3	15.8–16.1
Weight (kg)	67.4 ± 6.8	62.2–72.7
Height (m)	1.8 ± 0.1	1.8–1.9
BMI ($kg \cdot m^{-2}$)	20.4 ± 1.5	19.2–21.6
Heart Rate Peak ($beat \cdot min^{-1}$)	195.9 ± 8	191–200.7

Note: CI: Confidence Interval; BMI: Body Mass Index; Heart Rate peak: Peak heart rate registered across training sessions and matches.

When combining training sessions and matches, results revealed a %HRpeak of 71.3 ± 8 (training sessions: 70.1 ± 6.5 %HRpeak; matches: 74.2 ± 10.5 %HRpeak), a SHRZ workload of 178.8 ± 13.2 AU (training sessions: 222 ± 61.0 AU; matches: 73.2 ± 27.9 AU), and a sRPE workload of 315.4 ± 178.2 AU (training sessions: 392.9 ± 153.1 AU; matches: 127.1 ± 42.8 AU). The correlation coefficients for the overall relationship between the SHRZ and sRPE methods were very large ($r = 0.74$; $R^2 = 0.55$; $\rho = 0.78$) when combined training sessions and matches were assessed. When training sessions were studied singularly, moderate ($r = 0.45$; $R^2 = 0.21$; $\rho = 0.45$) correlation coefficients were shown. When only matches were considered, moderate-to-large ($r = 0.5$; $R^2 = 0.25$; $\rho = 0.45$) correlation coefficients were shown. Relationships investigated via linear regression are graphically shown in Figure 1.

The first fitted LMM included random intercepts for each player by adding a random-effects part on the linear regression model for the whole sessions. The estimated standard deviation (SD) of the random intercepts was 28.2 AU (95% confidence interval: 16.8–47.3), with a standard error of 7.4 and $R^2 = 0.61$. The likelihood-ratio test showed that this model offered significant (Chi^2: 25.2; $p < 0.001$) improvement over a linear regression model with only fixed effects, meaning that the intercepts were significantly different between players. When applying the same procedure exclusively to training sessions, the SD of the estimated random intercepts was 34.3 AU (95% confidence interval: 21.8–53.9), with a standard error of 7.4 ($R^2 = 0.33$). Similarly, the likelihood-ratio test proved that this model was significantly (Chi^2: 41.8; $p < 0.001$) better than the linear regression model with only fixed effects. Considering only the matches sessions, the SD of the estimated random intercepts was 15.6 AU (95% confidence interval: 8.8–27.4), with a standard error of 4.5 and $R^2 = 0.39$. Likewise, the likelihood-ratio test proved that this model was significantly (Chi^2: 12.8; $p < 0.001$) better than the linear model with only fixed effects.

Overall, including random slopes into the developed models did not bring significant improvements with respect to the random-only intercepts LMMs when training sessions and matches were separated ($p > 0.05$). However, when considering all of the sessions together, the developed model showed significant ($p < 0.001$) player-to-player variation in the slope coefficients, with a significant improvement ($p < 0.05$) with respect to the only random intercepts model (Table 2).



(**a**)

(**b**)

Figure 1. Relationship between the Summated Heart Rate Zone (SHRZ) (y axis) and session Rating of Perceived Exertion (sRPE) (x axis) for all sessions (**a**) and for training sessions and matches separately (**b**).

Table 2. Comparison of Linear Mixed Models developed for the whole sessions.

	Coef.	**SE**	**z**	***p* > |z|**	**[95% CI]**	
			(A) Random Intercept Model			
sRPE-SHRZ Relationship	0.36	0.02	16.82	0	0.32	0.40
Intercept	70.92	11.05	6.42	0	49.26	92.58
					$p < 0.001$	
			(B) Random Intercept plus Random Slope Model			
sRPE-SHRZ Relationship	0.39	0.03	11.98	0	0.33	0.45
Intercept	61.19	7.65	7.99	0	46.18	76.19
					$p < 0.001$	
			Likelihood-Ratio test (Model A vs. Model B): $p < 0.05$			

Note: sRPE: Session Rating of Perceived Exertion; SHRZ: Summated Heart Rate Zone; coef.: Coefficient; SE: Standard errors; CI: Confidence Interval.

Visual representation of the relationships between the SHRZ and sRPE with different intercepts and slopes across each player for the whole sessions are displayed in Figure 2.

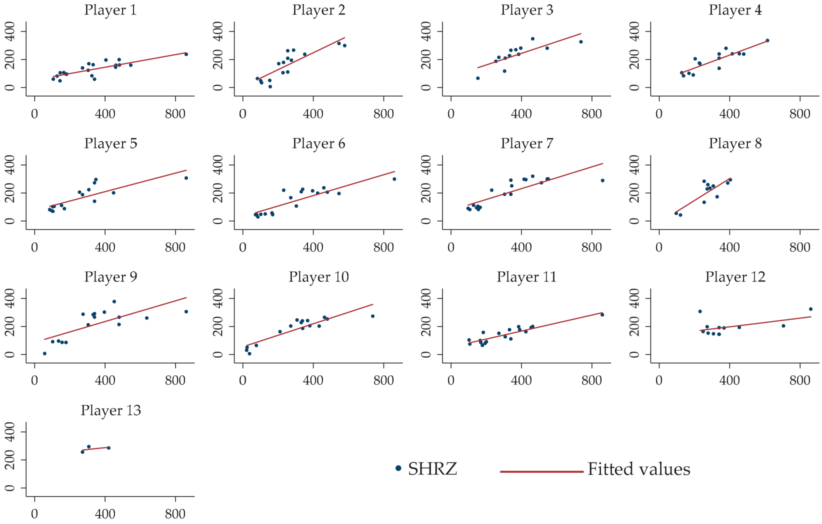


Figure 2. Relationship between the SHRZ (y axis) and sRPE for the individual players' responses for all the sessions.

Random intercepts and slope coefficients for each player based on the whole session LMM are reported in Table 3.

Table 3. Random intercepts and random slope coefficients for each player based on the whole session Linear Mixed Model.

Player	Random Slope (Mean)	Random Intercept (Mean)
1	−0.16	−2.02
2	0.04	−2.23
3	0.05	1.02
4	0.03	−0.17
5	−0.02	0.88
6	−0.07	−2.91
7	0.03	1.30
8	0.11	0.61
9	0.03	1.81
10	0.01	−0.30
11	−0.11	−1.64
12	−0.07	1.63
13	0.12	2.01

To clarify the relationship between the SHRZ and sRPE, Equation (1), combining the fixed and random slopes sRPE, was developed:

$$\text{SHRZ} = 61.19 + (\text{u1j} + 0.39)\ \text{sRPEij} + \text{U0j} + \epsilon\text{i} \quad (1)$$

In other words, the slope for player equals the fixed-effect slope for the whole sample plus the random-effect slope for that player. Figure 3 displays the calculated 13 combined slopes for each player. For player number 8, for instance, the combined slope was u1j (+0.11 for player 8) + 0.39 = 0.5.

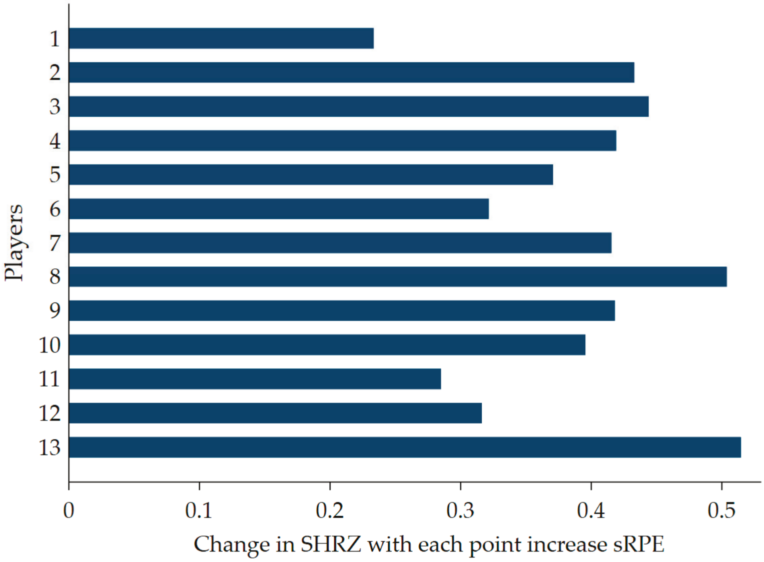


Figure 3. Interindividual variability of the relationship between the sRPE and SHRZ workloads. In some players (for example, 13 and 8), the SHRZ increased most steeply as the sRPE increased, whereas, in player 1, the increase was about the half of the abovementioned players.

4. Discussion

The present study aimed to assess the correlation between objective and subjective measures of internal load in team sports, such as beach handball, and to investigate this relationship by considering the individuality of players by means of LMM. Results showed that LMM can give more powerful and appropriate information regarding the relationship between SHRZ and sRPE workloads rather than the usual procedure using correlations and linear regression with only fixed effects.

In line with studies investigating the indoor handball characteristics [8,31–33], many aspects of beach handball, such as physiological parameters [22,34], individual and team performance [35,36], and shooting actions [37–39], have been investigated. However, no previous study has investigated the relationship between the objective (SHRZ) and subjective (sRPE) methods used for assessing the players' internal load.

Our results showed a very large relationship between the SHRZ and sRPE methods, independently from the type of session. When looking at training sessions and matches separately, this relationship was moderate and moderate-to-large, respectively. The trend was confirmed by the results of the linear regression analysis, showing a large relationship when the sessions were analyzed as a whole and small relationships when the training sessions and matches were analyzed separately. For other team sports, correlation coefficients have shown a strong [40], high [41], or very high relationship [42], promoting the sRPE as a useful method for monitoring internal load in youth trainings. However, in the case of team sports, not only the team as a whole has to be considered, but also the interindividual variability when analyzing workload data. The response to exercise training may not only differ between athlete, but also within the same athlete on different sessions. Previous studies have indicated that correlation coefficients for the relationship between internal load assessed using HR-based methods and via sRPE ranged between $r = 0.71$ for soccer [42] and $r = 0.85$ for basketball [40] when the team was analyzed as a whole. When within-athlete correlation coefficients were calculated, values ranged between $r = 0.8$ and $r = 0.96$ for basketball [40], $r = 0.5$ and $r = 0.77$ for soccer [42], and $r = 0.62$ and $r = 0.93$ for beach volleyball [43]. However, when multiple players are monitored across multiple sessions, the tendency to summarize the data with a single number may lead to the exclusion of intra- and intersubject variability from the analysis [19]. In fact, for team sports, models based on physiological parameters might underestimate the internal load during anaerobic and high-intensity activities, underlying the higher sensitivity of the sRPE method to workload changes, especially during the transition from base to higher intensities of conditioning programs [44]. Thus, simply measuring the strength of a relationship using correlations, without taking into account changes in an individual predictor variable, may lead to a misinterpretation of the relationship between two variables [19]. Furthermore, one of the most common issues occurring during data collection is represented by missing data [45]. For this reason, LMMs should be used, since they have the advantage to handle missing data without removing participants from the analysis [46].

This study aimed to analyze the relationship between SHRZ and sRPE by means of LMM. For the analysis, only random intercepts were initially used. However, the SHRZ workload increased as the sRPE workload increased (Figure 1), with different individual responses (Figure 2). To overcome the issue of interindividual variability, it was hypothesized that adding random slopes to the model would help to deeply investigate the relationship. Currently, the use of mixed models is becoming popular among sport science research. Govus et al. [47] used the LMM to analyze the relationship between subjective wellness score and external load, between external load and sRPE, and between subjective wellness score and sRPE in American college football players. For the LMM, the authors used the random intercept for athletes (to calculate the intraindividual variability) and the random slope for training sessions (to model a separate slope for the different types of training sessions). LMMs have also been used to evaluate the effects of individual characteristics (i.e., playing position, playing time, or playing experience) and contextual factors (i.e., season phases, previous game outcome, or opponent level) on three dependent variables (weekly training load, pre-game recovery, and performance index rating) in basketball [48] and to investigate [49] workload and well-being across games played on consecutive days during the in-season phase in basketball players, with the game day as the fixed effect and players, opposition rank, location, and score difference as random effects. It is therefore evident that LMMs are more commonly applied when analyzing data of relative workload in team sports.

Although this study provides interesting insights for coaches and sport scientists, some limitations should be acknowledged. First, the sample encompasses only youth beach handball male players. Therefore, future research should be carried out to investigate any potential difference in the internal load in players of different ages and/or gender. Moreover, the use of LMMs is becoming more common when analyzing team sports data, for example, to assess the relationships between external and internal load [47] or between workload and well-being data [49]. However, no previous study has used LMMs to correlate subjective and objective measures of internal load. Thus, no comparisons were allowed, and it should be verified whether the proposed statistical model could also be meaningful in other team sports.

5. Conclusions

The main findings suggest that subjective perception of internal load experienced by youth beach handball players increases with the objective internal load. However, the increase varies between players and sessions. To correlate those two measures to monitor the internal load, simple correlation is usually performed. However, correlation does not allow for the consideration of the intra- and interindividual variability which occurs when working with team sports, and it is not possible to handle missing data, resulting in a loss of information. To overcome with these issues, LMMs represent a more appropriate and powerful statistical approach for providing a more comprehensive view of the players’ responses to a given training stimulus. Therefore, researchers are encouraged to apply LMMs rather than simple correlations to analyze internal load.

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Informed Consent Statement: Informed consent was obtained from all subjects' parents involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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Article

The Relationship between Dynamic Balance and Jumping Tests among Adolescent Amateur Rugby Players. A Preliminary Study

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Abstract: Rugby is a demanding contact sport. In light of research, poor balance, reduced jumping ability, muscle strength, and incorrect landing patterns might contribute to the increased risk of injury in athletes. Investigating the relationship between tests assessing these abilities might not only allow for the skillful programming of preventive training but also helps in assessing the risk of injury to athletes. Thus, the main purpose of this study was to investigate the relationship between dynamic balance, vertical and horizontal jumps, and jump-landings movement patterns. Thirty-one healthy amateur adolescent rugby players (age: 14.3 ± 1.6 years, height 171.4 ± 9.7 cm, body mass 80 ± 26 kg) participated in the study. Data were collected by the Y-balance Test (YBT), Counter Movement Jump (CMJ), Single Leg Hop for Distance (SLHD), and Landing Error Score System (LESS). Significant positive correlations were found between SLHD both legs (SLHDb) and YBT Composite both legs (COMb) ($r = 0.51$, $p = 0.0037$) and between SLHDb and CMJ ($r = 0.72$, $p < 0.0001$). A relationship was also observed between the CMJ and YBT COMb test ($r = 0.51$, $p = 0.006$). Moderate positive correlations were found between the dominant legs in SLHD and the posterolateral ($r = 0.40$, $p = 0.027$), posteromedial ($r = 0.43$, $p = 0.014$), and composite ($r = 0.48$, $p = 0.006$) directions of the YBT. These results indicate that variables that are dependent on each other can support in the assessment of injury-risk and in enhancing sports performance of young athletes.

Keywords: team sport performance; injury risk screening; athletes assessment; landing error score system; counter movement jump

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1. Introduction

Rugby union is a demanding team sport in which players must undoubtedly have adequate physical attributes. During matches and training, players perform many activities such as acceleration, jumping and landing, changing the direction of running, and maintaining body balance in various planes [1–3]. Rugby players should have the qualities of strength, power, acceleration, and speed, as well as the appropriate stability and balance [4]. There is a general acceptance that due to the specificity of this sport, the participants are exposed to musculoskeletal injuries [5]. In a prospective cohort study by Haseler et al., 2010, regarding injuries among young English rugby players, an overall injury rate of 24/1000 h player was found [5]. Although injuries in youth rugby are rarer and less severe than in adult rugby, the risk of injury increases with age [5]. Moreover, limitation of balance and strength in the lower limbs are described as significant internal risk factors for injury among adolescents [6,7]. Therefore, it is important to test these factors in athletes and to investigate the relationship between them. These are challenges for trainers, sports scientists, physiotherapists, and strength and conditioning practitioners, to skillfully manage the development of adolescent rugby players.

Dynamic balance as one of the most important skills in rugby is defined as the ability to perform a task while maintaining a stable posture, most often using a single leg support base [4,8]. A popular, reliable, easy-to-use balance assessment tool is the Y-Balance Test (YBT) [9]. Studies demonstrated a link between the YBT score and potential lower limb injuries in various populations [4,10,11]. Importantly, the study by Johnston et al. 2019 revealed that the worse dynamic balance measured by the YBT among rugby union players increases the relative-risk, sports-related concussion [12]. Research supports the thesis that control of the dynamic balance might be affected by some features of neuromuscular performance, such as lower extremities strength [13], core stability [14], and range of motion [15].

Furthermore, a deficit in muscle strength and power is considered as a risk factor for injury among adolescents [6]. A common method for the evaluation of the explosive power of the lower limbs is the Counter Movement Jump (CMJ), where the maximum vertical jump is assessed [16]. Moreover, to assess the horizontal jump and explosive power of a single leg, the single leg hop for distance (SLHD) test is often used [17]. According to a study by Goosens et al., 2015 lower results in the SLHD test might be a risk factor for hamstring injuries [18].

Several publications examined the relationship between balance and hop performance tests for the power of lower limbs, however, current results are inconsistent [19,20]. Erkmen et al., 2010 present a significant correlation between the single-leg balance and vertical jumping and the relationship between the double-leg jump and the total balance score in young adult football players. The researchers concluded that activities that require lower limb power might reflect the ability to stabilize the body posture [19]. In contrast, Granacher and Gollhofer 2011 found no relationship between vertical jumping and static/reactive balance among adolescent students [20]. Another possibly intrinsic injury-risk factor is the incorrect patterns of movement during jump-landing tasks. A commonly used test among trainers and researchers to evaluate the jump-landing pattern is the Landing Error Score System (LESS) [21,22]. Participants with a lower score (higher score) demonstrate jump-landing technique errors in the frontal and sagittal plane [21]. For example, youth soccer players with poor landing patterns are more likely to sustain injuries [21,22].

The relationship between the power and balance of the lower extremities might be due to similar neuropsychological structures responsible for controlling the posture and power of lower extremities. The same information path (from Ia afferents) acting on the motor neuron is responsible for the production of muscle power and maintaining balance. Moreover, both voluntary muscle activity and the control of long latency reflex during balance tasks are driven by cortical excitability [23,24]. In addition, mechanoreceptors located in the muscles (muscle spindles) and the tendons (Golgi tendon organ) that perform reflex functions support the positioning (e.g., axial) of the lower limbs during movement tasks [25].

The use of tests to assess the dynamic balance, jumping abilities and landing patterns as injury risk factors seem to be justified in terms of injury prevention in athletes. To effectively support the development of interventions that reduce the risk of injury, it is important to know the association between the assessed neuromuscular abilities [23,26]. Therefore, this study aimed to determine the relationship between dynamic balance and jumping tests in adolescent male rugby players. The hypothesis assumed a significant relationship between these variables, which could help in assessing the risk of injuries and in designing preventive interventions and improving sports performance in young athletes.

2. Materials and Methods

2.1. Participants

The study involved 31 healthy adolescent male (age: 14.3 ± 1.6 years, height 171.4 ± 9.7 cm, body mass 80 ± 26 kg) amateur rugby players from a rugby club in Poland. Participants were excluded when they had an injury or limitation preventing them from playing sports and implementing a test procedure for the purposes of the study.

The subjects and their parents/guardians were informed and gave their written consent for the participation of their children in the study. The study was approved by the Independent Bioethical Committee for Scientific Research at the Gdańsk Medical University (resolution NKBBN/697/2019-2020/).

2.2. Procedures

All tests were carried out at the premises of the National Rugby Stadium in Gdynia, Poland.

The tests took place over three days, free of training and matches (before the start of the league games, in the afternoon, from 12:00 to 5:00 p.m.) in February 2020, in a sports hall at room temperature in the rugby training complex. Before starting each test, the participants obtained the necessary information and a demonstration of the test, correctly performed by an experienced physiotherapist and performance trainer. Basic anthropometric data (body mass, BMI, height) were collected from a body composition analyzer (InBody 270, InBody Co., Seoul, Korea). The author’s questionnaire allowed obtaining data regarding the dominant leg, position on the field, training experience (Table 1).

Table 1. Anthropometric characteristics, rugby experience, position, and dominant leg.

	Mean		Std Dev
Age (years)	14.3		1.6
Height (cm)	171.4		9.7
Body mass (kg)	80		26
BMI (m/kg)	27		7
Rugby training experience (years)	4		3
Dominant leg		right = 27 left = 4	
Position on the pitch		Forward =18 Backs = 13	

Abbreviations: BMI—Body Mass Index.

2.2.1. Dynamic Balance

The Y-Balance Test kit (Move2Perform, Evansville, IN, USA) was used to measure the quantitative values of lower limb dynamic balance [9]. Participants standing single-legged on the platform moved the blocks as far as they could, with their free limb, in the direction of the anterior (ANT), posterolateral (PL), and posteromedial (PM). The test was performed with procedures and instructions for standardization, following the protocol of Plisky et al., 2008 (video and verbal instructions before the start, participants are without shoes, 6 practice tests in each direction to minimize the learning effect). The tests were repeated if the participant lost his balance, leaned on the ground with his foot, kicked the platform, or raised his heels while moving the block [9,27]. The test consisted of 3 correct attempts for the left and right lower limbs. An experienced tester evaluated the sample for errors and recorded the result in centimeters, for each direction. Then, the participants were evaluated for lower limb length in a supine position (from the anterior superior iliac spine to medial tibial malleolus).

The maximum distance of each direction for the dominant and non-dominant leg was used for the analysis, which was normalized to the length of the lower limbs, divided by the length of the lower limbs and then multiplied by 100 (LL%). Composite (COM) reach distance for each lower limb was calculated as the sum of 3 directions divided by 3 times the length of the lower limbs and multiplied by 100 [9]. COMb (Composite—both legs) was defined as the average of the COM results of the dominant and non-dominant legs. YBT indicated good interrater and intrarater reliability in previous studies [9,27].

2.2.2. Countermovement Jump (CMJ)

The countermovement jump (CMJ) was used to investigate the explosive power of the lower extremities [16]. The study participants were requested to stand with both feet on a contact mat (Fusion Sport Smart Jump mat, Fusion Sport, 2 Henley ST, Coopers Plains, QLD, 4108, Australia). The subjects were instructed to keep their hands on their hips (for controlling arm contribution), before and during the jump [28]. The countermovement jump was established as the preferred self-selected depth position in previous research [29,30]. The correct attempt was when the participant had straightened his knee joints during flight and initial landing contact. There was a 2-min break between jumps [13]. Highest jump (cm) from three maximal attempts were selected for data analysis [28]. CMJ is a reliable and valid flight-time-based method that allowed the assessment of the maximal vertical jump height [16].

2.2.3. Single Leg Hop for Distance (SLHD)

Subjects standing on one leg with hands resting on hips in front of the starting line. Immediately after the tester’s signal, they made a forward leap as far as they could and landed on the same leg. The tests were performed alternately for the left and right legs, with a 30-s break between tests. The attempt was correct when the participant kept his balance without supporting himself with another limb for at least 2 s. The distance obtained was measured in centimeters. The best result of 3 jumps for the dominant and non-dominant leg was taken for analysis. SLHDb (SLHD—both legs) was defined as the average of the maximum jumps of the dominant and non-dominant lower limb [31]. SLHD exhibited excellent test–retest reliability, in a recent study [17].

2.2.4. Landing Error Score System (LESS)

LESS is a clinical assessment tool for finding incorrect movement patterns (errors). Participants make a horizontal double-leg jump from a 30 cm box beyond the designated line (distance 50% of the participant’s height). Immediately after landing, they made the maximum vertical jump. Several (typically 3) practice jumps were allowed to perform the task successfully. Then, the participants performed 3 jump-landing tasks with a 2-min break between them. Two video cameras (GoProHero 4, GoPro, Inc., San Mateo, CA, USA) were set up in front and to the side, 3 m from the participant performing the jump-landing task [21,22].

Recording from the camera allowed an accurate assessment of the movement patterns (errors) to be made, and determination of the score. The LESS tool contains 17 sections to assess the characteristics of the landing in the frontal and sagittal planes. A larger result suggests a worse technique and more landing pattern errors. On the same day, an experienced physiotherapist who did not take part in the study assessed the record of jumps-landings from cameras, using the Kinovea® program (beta-version 0.8.26, Bordeaux, France). From the three samples, the best (smallest result) was taken for analysis.

2.3. Statistical Analysis

All variables were examined by the Shapiro–Wilk distribution normality test. Means and standard deviations were calculated for all variables. Pearson correlation coefficients were calculated between the CMJ, LESS, SLHD, and Y-Balance Test. To determine the strength, the correlation coefficient was used (r): strong ($0.50 \leq r \leq 1.0$), moderate ($0.3 \leq r < 0.5$), and weak relationship ($r < 0.3$) [32]. Independent-samples T-test was used to analyze the differences between the dominant and non-dominant leg in the YBT (ANT, PL, PM, COM) SLHD tests. The linear regression model was used to estimate the impact of the YBT dominant results (directions COM, PL, PM) on the SLHD dominant leg.

Statistical data were processed with the Statistica software (Statistica 12). Significance was set a priori at the $p < 0.05$ level.

3. Results

3.1. The Characteristics and Association between Legs in the YBT and SLHD of the Studied Group of Adolescent Rugby Players

The characteristics of the studied group of adolescent rugby players are presented in Table 1.

There was no significant difference between the YBT and SLHD results for the dominant leg and non-dominant leg test ($p > 0.05$), among adolescent amateur rugby players. For this reason, the dominant leg results were used for further statistical analyses of variables derived from single-legged tests. The data in Table 2 show all means and standard deviations of the variables.

Table 2. Variables and association between dominant and non-dominant legs in YBT and SLHD. Results for dominant and non-dominant leg in the YBT and SLHD, and LESS and CMJ tests.

Variable		Dominant	Nondominant	*p*-Value *
Y-Balance Test LL%	ANT	60.63 ± 7.21	59.40 ± 7.58	0.51
	PL	96.27 ± 8.55	95.08 ± 8.90	0.59
	PM	92.13 ± 8.78	94.53 ± 11.55	0.36
	COM	82.99 ± 6.62	82.99 ± 7.35	0.99
SLHD (cm)		127.26 ± 29.25	129.87 ± 30.73	0.73
Y-Balance Test LL% mean both legs	COMb	83.02 ± 6.80		
SLHD mean both legs (cm)	SLHDb	128.59 ± 29.53		
LESS (points)		5.52 ± 1.52		
CMJ (cm)		28.75 ± 6.14		

Abbreviations: LL%—Limb Length%, SLHD—Single Leg Hop for Distance, LESS—Landing Error Score System, CMJ—Counter Movement Jump, *p*-value *—T-test for Independent Samples.

3.2. The Correlations between the Hop Tests and YBT COMb

There were strong positive correlations between SLHDb and YBT COMb (r = 0.51, $p = 0.0037$) and moderate correlations between the CMJ and YBT COMb test (r = 0.48, $p = 0.006$) among adolescent amateur rugby players. A strong relationship also occurred between SLHDb and CMJ (r = 0.72, $p < 0.0001$); Table 3, Figure 1. However, no significant correlations were found between LESS and the other variables (CMJ, SLHD, YBT) among adolescent amateur rugby players (Table 3).

Table 3. Pearson's correlations between hop tests and YBT COMb.

	CMJ	SLHD	LESS
CMJ			
SLHDb	0.72 *		
LESS	0.06	−0.1	
COMb	0.48 *	0.51 *	0.19

Abbreviations: SLHD—Single Leg Hop for Distance, LESS—Landing Error Score System, CMJ—Counter Movement Jump, * $p < 0.05$.

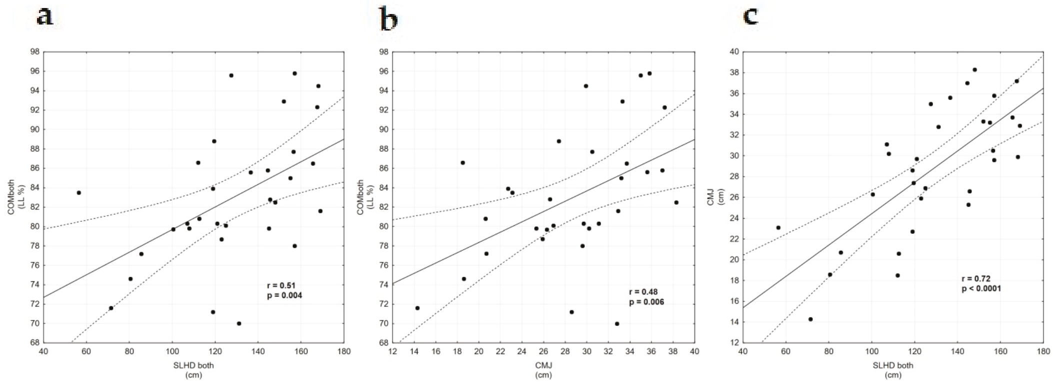

Figure 1. (**a**) Correlation between Y-Balance Test Composite both leg and CMJ. (**b**) Correlation between Y-Balance Test Composite both leg and SLHD both legs. (**c**) Correlation between CMJ and SLHD both legs. Abbreviations: CMJ—Counter Movement Jump, and SLHD—Single Leg Hop for Distance.

3.3. Linear Regression Model and Correlations for Dominant Leg SLHD and Dominant Leg YBT

The linear regression models and correlations are illustrated in Table 4 and Figure 2. Pearson's moderate positive correlation was statistically significant for the dominant leg between the SLHD and YBT PM (r = 0.44), PL (r = 0.40), and Composite (r = 0.48), but not for ANT (r = 0.32, p = 0.73). It was found that the strongest predictor of the Composite YBT dominant was the SLHD dominant (adjusted r2 = 0.20, p = 0.006). Thus, the SLHD accounted for 20% of the variation in the Composite YBT.

Table 4. Linear regression model with Pearson's correlation between the dominant leg SLHD and dominant leg YBT.

	R	**Adj r2**	***p*-Value**	**Strength**
SLHD				
Y-Balance Test				
ANT	0.32	0.07	0.73	Moderate
PL	0.4	0.13	0.027 *	Moderate
PM	0.44	0.16	0.014 *	Moderate
COM	0.48	0.2	0.006 *	Moderate

Abbreviations: ANT—Anterior, PL—Posterolateral, PM—Posteromedial, and COM—Composite, * $p < 0.05$.

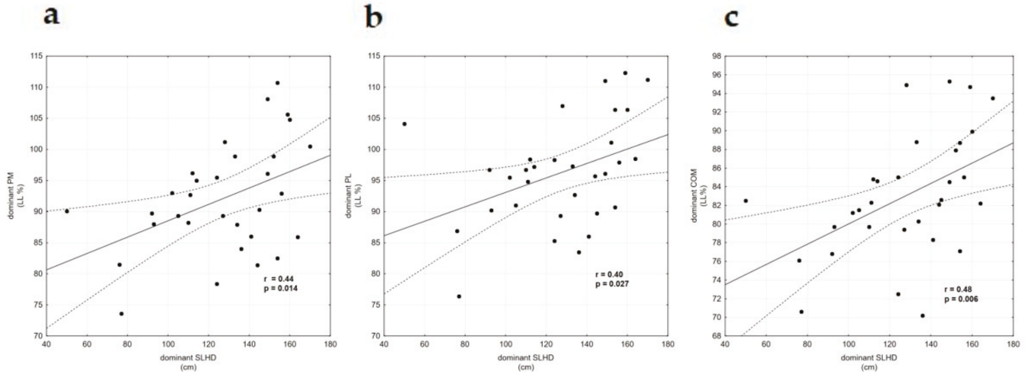

Figure 2. (**a**) Correlation between Y-Balance Test dominant PM and dominant SLHD. (**b**) Correlation between Y-Balance Test dominant PL and dominant SLHD. (**c**) Correlation between Y-Balance Test dominant COM and dominant SLHD. Abbreviations: PM—Posteromedial, SLHD—Single Leg Hop for Distance, PL—Posterolateral, and COM—Composite.

4. Discussion

In this study, we examined the relationship between dynamic balance, errors in the landing pattern, and jump abilities during the countermovement jump and the horizontal single-leg jump among young rugby players. A major finding was that the dynamic balance (YBT Composite) was significantly correlated with the power of the lower limbs, as measured by the CMJ (r = 0.48) and SLHD (r = 0.51) tests. The above positive correlations prove that the participants with better dynamic balance have lower limb power.

Moreover, there is evidence from other research demonstrating interventions to increase strength after balance training, and vice versa, balance training to increase balance [20,33,34].

Similar results are presented by Booysen et al., 2015 demonstrating the relationship between power and dynamic balance using the same Y-Balance and CMJ tests. Significant moderate correlations were observed in the adult university and professional football group, but only for the use of the non-dominant leg for the stance in both tests [13]. By measuring the same characteristics, but with different test methods, Erkmen et al. demonstrated a negative correlation between balance (Balance Error Score System) and the power of the lower extremities (Vertical Jump Test) [19]. Contrary to our results, Granacher and Gollhofer 2011 found no relationship between the CMJ test results and static and reactive balance in adolescent students [20]. The reason for the different results of Granacher and Gollhofer and our research can be found in the various research methods used. In our study, we used the specific Y-balance Test for dynamic balance assessment, while Granacher and Gollhofer used the center of pressure (COP) displacements on the balance platform assessment method measured in millimeters.

Moreover, we observed a relationship between the measurements of the CMJ and SLHD in the group of adolescent rugby players. This predicted result is probably due to the involvement of the muscle power responsible for performing the maximum jumps in both tests. The observed strong correlation (r = 0.72) between the vertical jump and the horizontal jump is similar to the results described in the literature [35–37].

However, no statistically significant correlations were detected between power measurements, dynamic balance, and jump-landing movement pattern errors, among our adolescent amateur rugby players. This suggests that the errors in the biomechanics of the jump-landing are not related to the balance and power of the lower limbs in our study. The lack of significant correlations of the LESS test in adolescent amateur rugby players could be due to the specificity of the LESS test (a large number of variances, most items on a dichotomous scale), which might make it difficult to compare the tests with each other. The lack of a significant relationship between the LESS test and the composite reach YBT of both lower limbs also occurred in the study by de la Motte et al., 2016, where research showed no correlation in young adult male military applicants. In contrast, however, there was a negative correlation between these variables in the female population. Unfortunately, these results cannot be directly compared with ours, due to the modification of the LESS scoring rubric (adding additional test error evaluation points) [38].

Our study did not demonstrate any differences between the dominant leg and non-dominant leg in unilateral SLHD and YBT tests, among adolescent amateur rugby players. This result suggests no significant asymmetry between the rugby players' legs. This allowed only the dominant limb to be selected for analysis. Considering the results for the dominant leg, significant moderate positive correlations were found between the SLHD dominant and all directions of the YBT test, except for the ANT direction. Linear regression analysis showed that the composite direction of the dominant leg was the strongest predictor responsible for 20% of the SLHD dominant leg variation.

Correlations between unilateral hop tests and single-leg dynamic balance can be explained by the strategy of developing the ability to maximally develop the strength of the lower limbs. In both tests, the best results require the use of strong ankle, knee, and hip extensor contractions, to withstand high torques and flexor torques during the flexion phase [39,40]. The extensor muscle groups of the hip and knee are responsible for controlling movement, while reaching the maximum distance in all directions of the YBT test, and assists in returning to the stable starting position of the test [13]. Moreover, it is worth noting that to pass the SLHD test, the participant is required to maintain a stable position (not lose balance) for at least 2 s. Such a rule undoubtedly requires participants to have the ability of dynamic equilibrium immediately after landing in a position similar to squat one-leg, which is observed during the YBT tests.

To our knowledge, this is the first study examining the relationship between the presented tests among youth amateur rugby players. Participants in our study obtained a composite reach score of 83% for both the dominant and non-dominant leg (normalized to the length of the lower limbs). There is evidence that a composite on the Star Excursion Balance Test (a precursor of the YBT) score of less than 94% is associated with an increased risk of injury [41]. In addition, the result of the jump-landing task Landing Error Score System in our study present an average result of 5.5 points, which indicates "poor" landing techniques. According to Padua et al., 2015, a LESS test score of 5 or more could increase the risk of ACL injury for elite youth football players [22]. Additionally, among the elite female basketball players, Šiupšinskas et al., 2019 concluded from their research that the "poor" result might indicate a higher risk of injury [42]. The above evidence might suggest that the players in this study might be at risk of an injury. Moreover, CMJ scores were significantly lower than in the adolescent (16.9 ± 0.4 years) rugby union players from the UK (33.80 ± 5.20 cm) [43] and adolescents (15.3 ± 0.65 years) in the Italian national rugby team level (32.6 ± 5.3 cm) [44]. For the above reasons, extrapolation to other sport groups might be the limit of our study and their comparison should be carried out with a certain degree of caution. Furthermore, no kinematic knee flexion assessment was used to standardize flexion during the CMJ and SLHD test, which could be regarded as confounders. The small number of study participants was also considered a limitation. Therefore, the study was marked as "A Preliminary Study". Future research should be carried out on a larger number of populations, at different levels of rugby experience.

Significant relationships between dynamic balance and power of the lower limbs in our study indicate that they are dependent on each other. These results can be used in future research on both the implementation of preventive training and the strengthening of individual characteristics of the performance of the sport. Thereby affecting the reduction and complexity of training interventions. Importantly, all limitations of the study should be considered for practical implications.

5. Conclusions

The findings of the current study demonstrated significant moderate to strong positive correlation between dynamic balance, and the power of lower extremities in adolescent rugby players. All Y-Balance Test directions, except the anterior, are moderate predictors of the horizontal jump in the Single Leg Hop for Distance Test. In addition, the results of this study suggest that incorrect jump-landing task patterns in the LESS test do not have a significant relationship with the dynamic balance and power of the lower extremities.

The relationship between power and balance can have several practical implications. First, the variables that are dependent on each other, can help in the assessment of risk of injury in young athletes. Second, it will help in designing preventive injury interventions and increasing sports performance. For example, by reducing the volume, amount, and time of exercise by focusing more accurately, e.g., on lower limb power training, thus, increasing the results of the dynamic balance in young athletes.

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Influence of Players' Maximum Running Speed on the Team's Ranking Position at the End of the Spanish *LaLiga*

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Abstract: The maximum running speed that a football player can attain during match play has become one of the most popular variables to assess a player's physical talent. However, the influence of a player's maximum running speed on football performance has not yet been properly investigated. The aim of this study was to determine the influence of a player's peak/maximum running speed on the team's ranking position at the end of a national league. A second aim was to investigate differences in maximum running speed among playing positions. To fulfil this aim, the peak/maximum running speeds of 475 male professional football players were recorded for 38 fixtures of the Spanish first-division league (*LaLiga*) from the 2017–2018 season (7838 data points). Players' peak running speeds in each match were assessed with a validated multicamera tracking system and associated software (Mediacoach®). Players' maximum running speed was established as the fastest running speed they attained during the entire season. Most players (53.5% of the total) had a maximum running speed in the range of 32.0–33.9 km/h, with only three players (0.6%) with a maximum running speed of over 35.0 km/h. Overall, forwards were faster than defenders and both types of players were faster than midfielders (33.03 ± 1.35 > 32.72 ± 1.32 > 32.08 ± 1.63 km/h; $p < 0.001$). There was no association between teams' maximum running speed and ranking position at the end of the league ($r = -0.356$, $p = 0.135$). The correlations between teams' maximum speeds and ranking position were low for defenders ($r = -0.334$, $p = 0.163$), midfielders ($r = 0.125$, $p = 0.610$), and forwards ($r = -0.065$, $p = 0.791$). As a result, the variance in the ranking position at the end of the season explained by a team's maximum speed was of only 7.5%. Finally, as an average for all teams, players' peak running speeds remained stable at ~30.7 ± 0.6 km/h throughout the whole season. These results suggest that successful and less successful football teams have squads with players able to obtain similar maximum running speeds during match play throughout the season. Hence, players' maximum running speeds have a poor association with the team's ranking position at the end of the Spanish professional national league.

Keywords: soccer; match analysis; team sports performance; exercise training; velocity

1. Introduction

Modern professional football (soccer) is a highly demanding team sport characterized by a succession of high intensity actions performed intermittently. These actions, particularly the ones performed in close proximity to the ball, require high values of speed, strength, power, and agility [1]. However, football performance also depends on a variety of individual technical and tactical skills, and on constant interaction with teammates. Therefore, several physical, technical, and tactical capabilities must be well developed to become a successful professional player [2]. In the last few years, research has shifted the focus of the physical determinants in football, conceding more relevance to anaerobic-based actions instead of the traditional view of football as an aerobic-based team sport. In this regard, high intensity running and sprinting account for only ~10% of the total distance covered during a match [3,4], but high-intensity running is a key element to discriminate between elite football players and players of a lower competitive level [5]. Professional football players have become faster over time [2], with a greater capacity to cover a large volume of running at high intensity during matches [6]. On the other hand, players' aerobic capacity has slightly decreased over the time [7]. Additionally, through the use of principal component analysis (PCA), a technique to discriminate the physical performance variables which are more relevant for football performance, it has been demonstrated that high speed running is within the variables that best describe the profile of the physical demands during an official match [8,9]. Overall, this information suggests that a player's capacity to cover a high volume of running at high intensity is a crucial determinant of modern football success.

During a competitive match, football players perform a high intensity action every 30 to 90 s, and each high-intensity action lasts, on average, from 2 to 4 s [10]. Hence, from a physical perspective, players perform short-term but continuous high intensity actions interspersed with recovery periods that may vary depending on the evolution of the game. In elite football, players can perform more than 150 intense actions during a match [4], but most of them are not performed at maximum speed. The number of these actions increases with the level of play [2], varies with the playing position on the field [5] with a higher number of sprints and distance at sprint velocity in wide midfielders than in other positions [11], and rises over the course of a season [12]. Interestingly, straight sprinting is the most frequent action prior to scoring a goal [13] and the possession of a high value of maximum running speed is key for overtaking opponents and winning disputed balls. Furthermore, high values of maximum running speed may also reduce the relative neuromuscular load during a match [14] as any action at a given running speed will represent a lower fraction of a player's maximum speed. Still, it is important to note that the distance covered at high intensity during the competition is not a unique factor associated to football success. In fact, some researchers have suggested that the contribution of the distance covered at high intensity to overall performance is very limited [15], while the distance covered with the possession of the ball is more relevant [16]. Last, the relevance of high intensity running for performance may vary from match to match due to contextual variables such as match location, match outcome, or the level of the opponent [9].

Match-play situations requiring maximum or near-to-maximum running speeds are rarely produced during the game, although they are performed at critical moments. For this reason, the maximum running speed that a football player can attain during match play has become one of the most popular variables to assess a player's physical performance. Overall, the mean of maximum sprinting velocity of professional football players is normally between 31 and 32 km/h [5], but there are professional players with running speeds ranging from 29 to 33 km/h [17]. However, the majority of high intensity runs in football are shorter than 20 m, which precludes reaching maximum running speeds. Hence, the value of maximum running speed and the distance that a player could cover at high intensity are sometimes unrelated. For example, wide midfielders and external defenders perform more high-intensity running and sprinting [10], but the fastest players are usually the forwards [18]. To date, the influence of players' maximum running speed on the overall team's football performance has not yet been properly investigated. As mentioned above, it is clear that the possession of a high running speed and the capacity to repeat sprints over the time during a competitive match are both potentially beneficial factors for football performance. Nevertheless, to date, it is unknown if it is better to direct players' physical conditioning to obtain formidable high maximum speeds or to direct training to obtain players able to produce sprints of lower/submaximal velocity but with a higher capacity of repeating them over time. For this reason, the aim of this study was to determine the influence of players' maximum running speed on the team's ranking at the end of a national league. This objective was intended to evaluate the relevance of players' maximum speed on football performance during a national football league. A second aim was to investigate differences in maximum running speed among playing positions. We hypothesized that more successful football teams (i.e., the ones in the first ranking positions at the end of the season) would have squads with the fastest players in all field positions, in comparison to worse-ranked teams. Additionally, forwards will be faster than any other field position.

2. Materials and Methods

2.1. Participants

The study sample was composed of 475 football players competing in the Spanish first-division football league (*LaLiga*) during the 2017–2018 season. This corresponds to the entire population of professional football players that competed at least for 30 min in the 2017–2018 season. From the total, 175 players were defenders, 196 were midfielders, and 105 were forwards (36.8/41.3/21.9%, respectively). The number of players per team and per playing position in the field, in addition to their maximum running speeds during the season, are detailed in Table 1. Of note, data from the players competing in the team classified in 13th position were not used in this investigation, as none of the matches played in its stadium reported data on running actions during the 2017–2018 season. In accordance with *LaLiga*'s ethical guidelines, this investigation does not include information that identifies football players. The Institutional Review Board of the Camilo José Cela University approved this study, which is in accordance with the latest version of the Declaration of Helsinki.

Table 1. Number of players and players' maximum running speed according to the team's ranking in the 2017–2018 season of *LaLiga* championship.

Ranking	Total	Defender	Midfielder	Forward
1st	22 32.8 ± 1.2	9 33.1 ± 1.0	8 32.0 ± 1.3	5 33.5 ± 1.0
2nd	23 32.8 ± 1.6	8 33.1 ± 1.1	9 31.8 ± 2.0	6 33.8 ± 0.7
3rd	21 33.4 ± 1.5	8 34.1 ± 1.0	9 32.8 ± 1.5	4 33.1 ± 1.8
4th	23 33.0 ± 1.2	9 33.0 ± 0.5	11 32.9 ± 1.5	3 33.9 ± 1.4
5th	27 32.0 ± 1.6	9 32.2 ± 1.5	12 31.5 ± 1.7	6 32.9 ± 1.3
6th	24 32.7 ± 1.3	9 33.2 ± 0.8	7 32.5 ± 0.8	8 32.4 ± 1.9
7th	28 32.1 ± 1.7	10 32.0 ± 1.3	13 31.9 ± 2.0	5 32.8 ± 1.4
8th	26 32.1 ± 1.6	10 32.1 ± 1.5	9 31.0 ± 1.4	7 33.5 ± 1.2
9th	23 32.8 ± 1.6	8 32.8 ± 1.4	11 32.6 ± 2.0	4 33.1 ± 0.9
10th	20 32.8 ± 1.3	8 33.0 ± 1.5	8 32.3 ± 1.4	4 33.3 ± 0.8
11th	23 32.4 ± 1.4	8 32.4 ± 1.7	11 32.0 ± 1.2	4 33.4 ± 1.0
12th	22 32.3 ± 1.7	9 32.2 ± 2.1	7 32.4 ± 1.2	6 32.4 ± 1.9
14th	27 32.5 ± 1.5	8 32.8 ± 1.4	12 32.1 ± 1.7	7 32.6 ± 1.3

Table 1. *Cont.*

Ranking	Total	Defender	Midfielder	Forward
15th	29 32.6 ± 1.4	9 33.3 ± 0.7	11 32.5 ± 1.8	9 31.9 ± 1.1
16th	23 32.6 ± 1.2	11 32.9 ± 1.1	8 31.9 ± 1.1	4 33.3 ± 1.1
17th	23 32.8 ± 1.7	9 32.9 ± 1.1	10 32.2 ± 2.1	4 34.3 ± 0.7
18th	27 32.2 ± 1.8	11 32.1 ± 1.7	13 31.8 ± 1.8	3 34.1 ± 0.2
19th	33 32.5 ± 1.3	11 32.6 ± 1.0	15 31.9 ± 1.4	7 33.4 ± 0.8
20th	31 32.3 ± 1.5	11 32.3 ± 1.2	12 32.0 ± 1.8	8 32.6 ± 1.7

Note: There were no data for the team classified in 13th position.

2.2. Procedures

This investigation is a descriptive and comparative analysis to determine the importance of players' maximum/peak running speeds on football performance. Data were obtained from *LaLiga*, which authorized the use of the variables included in this investigation. The Spanish national first-division football league is composed of 20 teams competing in a total of 38 fixtures (for a total of 380 matches for season). Data from the matches of the team classified in 13th position were excluded from the investigation because the multicamera tracking system was not installed in its stadium during the season under investigation. Hence, this investigation contains data on 361 matches played across 38 fixtures. In each fixture, players' peak running speed, defined as the highest running speed attained in a particular match, was obtained and recorded for all the field players, for a total of 7838 values across the season. Only peak running speeds of players competing during at least 30 min in the match were considered for analysis to ensure that the players had time to produce a football action at high/peak intensity. Maximum running speed was defined as the highest running speed obtained by a player during the entire season, using all the values recorded by this player during all the matches he participated in for at least 30 min. The data on goalkeepers were excluded due to the different nature of their movement patterns during the game. To determine the influence of players' peak/maximum running speeds on football performance, a comparison was made of the individual and team average running speeds (1) according to the ranking position at the end of the season and (2) according to ranking categories as follows: the league champion (1st); teams classified for the Champions League (2nd–4th); teams classified for the Europa League (5th and 6th); teams in the middle of the ranking (7th–17th); and the relegated teams (18th–20th). An analysis of teams' maximum speeds depending on the playing position was also performed by using three positions: defenders, midfielders, and forwards.

2.3. Instrument

Data on peak/maximum running speeds were extracted using the match statistics software Mediacoach® (*LaLiga*, Madrid, Spain), a multicamera tracking system that can accurately assess the instantaneous running speed of all the players on the field. Briefly, Mediacoach® records the position of each player at 25 frames per second using a stereo multicamera system composed of two multicamera units placed at either side of the midfield line. Each multicamera unit contains three cameras with a resolution of 1920 × 1080 pixels, which are synchronized to provide a stitched panoramic picture. The panoramic picture is then employed to create the stereoscopic view that allows triangulating of all the players on the field and the ball. In the case of a lack of location of a player due to occlusions by another player, an experienced operator manually corrected the position during measurement. This correction is common in corners and fouls but rarely occurs during actions where players obtained their peak/maximum running speeds. Hence, the manual corrections had minimal relevance for the objectives of this investigation. The validity of this software to assess movement demands during match play has been obtained through high agreement with the data obtained with GPS [19,20] and with data obtained from a reference camera system (i.e., VICON motion capture system [21]).

2.4. Statistical Analysis

We set the significance level for the statistical analysis at $p < 0.05$ and all analyses and calculations were performed using the SPSS v.20 software package (IBM, Armonk, NY, USA). Initially, we used the Levene test to verify sample homogeneity and the Kolmogorov–Smirnov test to verify the normality of peak/maximum running speeds. Descriptive means and standard deviations were calculated in each team and for each playing position (Table 1). We used a one-way analysis of variance (ANOVA) of repeated measures to compare peak running speeds among the 38 fixtures that comprised the championship. We used a two-way ANOVA (fixture x ranking category) to determine differences in the evolution of maximum running speed across the season among the ranking groups. The number and distribution of players according to their maximum running speeds were calculated using 1.0 km/h intervals. A two-way ANOVA (playing position x ranking) was used to search for differences among teams in the maximum running speed for any playing position. In the case of a significant F value in the ANOVAs, the differences between groups were identified by Tukey post hoc tests. For the differences in maximum running speed between playing positions, the effect size was calculated in Cohen's d units [22]. Pearson's correlation coefficients (r) were used to assess the association between a team's maximum running speed and ranking position at the end of the season. The size of a correlation coefficient was evaluated following Hinkle et al. [23]. Then, a multiple regression analysis was carried out in a stepwise interactive mode to assess the influence that a team's maximum running speed had on the ranking position the end of the league. In the regression analysis, all match statistics were introduced based on their correlation with the residual ($p < 0.1$) and their intercorrelation with variables that already existed in the equation. The r^2 values were adjusted for the number of cases and parameters included in the analysis [24].

3. Results

Figure 1 depicts the peak running speeds obtained by the football teams during the season. In the upper panel, the data include the mean of all teams competing in *LaLiga* in each of the 38 fixtures that comprised the championship, and the one-way ANOVA revealed no statistically significant differences in the values of peak running speed among the different fixtures (F = 1.282; $p = 0.372$). In the lower panel, peak running speeds are presented according to different ranking groups. The two-way ANOVA revealed no main effect of the ranking group in the maximum running speeds obtained during the season (F = 2.191; $p = 0.134$).

The number of players distributed according to their maximum running speeds during the 2017–2018 season is presented in Figure 2. Most players (53.5%) were in the range of 32.0–33.9 km/h, with 71 players (14.9%) surpassing 34.0 km/h and only 3 players (0.6%) with maximum running speeds of over 35.0 km/h. Still, there were 27 players (5.7%) who did not reach 30.0 km/h during the competitive season. Nevertheless, teams' maximum speeds were unrelated to the end of season ranking position obtained, as the one-way ANOVA revealed no differences in the maximum running speed values among the different teams competing in *LaLiga* (F = 1.308; $p = 0.177$). Additionally, the correlation coefficient between teams' maximum speeds and ranking position was low (r = −0.356, $p = 0.135$).

There was a main effect of the playing position on maximum running speed (F = 18.765; $p < 0.001$). Overall, forwards were the fastest players (33.03 ± 1.35 km/h) with a higher maximum running speed than defenders (32.72 ± 1.32 km/h; $p = 0.025$, $d = 0.23$) and midfielders (32.08 ± 1.63 km/h; $p < 0.001$, $d = 0.63$). Defenders were also faster than midfielders (Figure 3; $p < 0.001$, $d = 0.43$). However, there was not any interaction between the ranking position of the team and the playing position (Table 1; F = 0.897; $p = 0.643$). The correlation coefficient between teams' maximum speeds and ranking position was low for defenders (r = −0.334, $p = 0.163$) and small for midfielders (r = −0.125, $p = 0.610$) and forwards (r = −0.065, p = 0.791). Finally, the variance in the ranking position obtained at the end of the league as explained by the team's maximum speed was of only 7.5% (contribution r^2 adjusted = 0.075, p = 0.427).

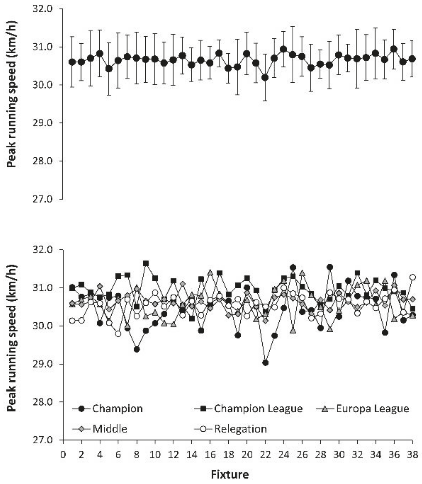

Figure 1. Peak running speed (**upper panel**) and peak running speed in teams with different ranking categories (**lower panel**) across *LaLiga* 2017–2018.

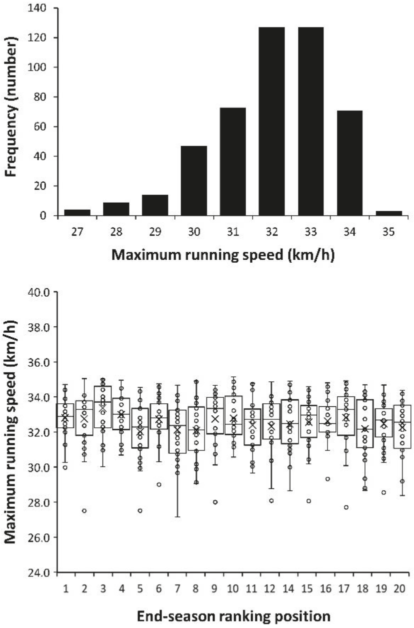

Figure 2. Number of players according to their maximum running speed (**upper panel**) and individual maximum running speed according to the end-season ranking position of the teams competing in *LaLiga* 2017–2018 (**lower panel**). Data represent the maximum running speed obtained by each player in the 2017–2018 season. Note: There were no data for the team classified in 13th position.

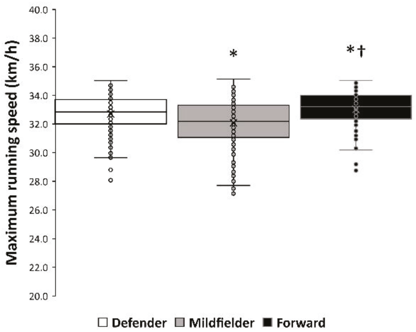

Figure 3. Individual maximum running speed according to the playing position in the field in *LaLiga* 2017–2018. (*) Different from defender at $p < 0.05$. (†) Different from midfielder at $p < 0.05$.

4. Discussion

With the incorporation of microtechnology into elite football (mainly, the use of Global Positioning System devices and multicamera tracking systems), sport scientists and physical trainers are now analyzing a high number of physical and physiological variables that may have the potential to contribute to overall football performance. This represents, in most cases, an excess of data that complicates the understanding of what variables are important for the game [8]. Additionally, the existence of a high number of variables may lead to oversimplification of the game by using them to categorize players. In this regard, the maximum running speed that a player can obtain during a match has become a widely used variable to assess a player's physical talent, despite the evidence to argue that this variable is important for a player's and team's performance being scarce. Peak/maximum running speed represents one single action during the match, while professional football players perform more than 150 intense actions during match play [4]. Hence, the potential evaluation of a player's physical talent, by using only one action during match play, may lead to incorrect assumptions, at least in elite football. Despite the popularity of this performance variable, we are not aware of any previous investigations that have aimed to determine the influence of players' peak/maximum running speeds on the team's overall football performance. The current investigation presents an analysis of the fluctuations of peak running speeds obtained during matches throughout a complete season of *LaLiga*. In addition, the players' maximum running speeds have been compared to the ranking obtained at the end of the championship, while differences in maximum running speed among playing positions have been analyzed. Overall, the current investigation demonstrates that peak running speed was maintained relatively constant throughout the championship, a characteristic shared by the Champion, the teams classified for the Champions League, the teams classified for the Europa League, middle teams, and the relegated teams (Figure 1). Additionally, all teams competing in *LaLiga* had squads with comparable maximum running speeds, irrespective of their ranking position at the end of the championship (Figure 2). The similarity in maximum running speeds among teams was equally present in defenders, midfielders, and forwards (Table 1), although forwards were the fastest players in each team (Figure 3). In addition, the correlation coefficient between teams' maximum speed and ranking position was low and the variance in the ranking position obtained at the end of the league explained by team's maximum speed was of only 7.5%. Together, this information points towards a poor association between players' maximum/peak running speeds and the team's overall football performance during a national league. This notion does not dispute the importance of covering high volumes at high intensity for football performance but suggests that most, if not all, professional teams in *LaLiga* possess players able to reach over 30 km/h, limiting the discriminatory utility of maximum running speeds to distinguish between better- and worse-ranked teams.

Recently, it has been found that football teams competing in a national football league needed 8–10 fixtures from the beginning of the season until they reached a plateau in match running performance [12]. The necessity of competing in 8–10 matches before reaching a steady-state physical performance was evident for the running distance at over 24 km/h and for the number of running actions performed above this threshold. However, the current analysis indicates that on average for all the teams competing in *LaLiga*, players' peak running speeds were 30.6 ± 0.7 km/h for the first fixture, and a comparable value was obtained throughout the competition (Figure 1). This result suggests that professional football players are able to reach maximum or near-to-maximum running velocities from the first competitive match, even when they are not ready to perform a large volume of high intensity running. While maximum running speed during a match is mainly related to mechanical determinants aimed to produce great vertical ground reaction forces per unit of body mass [25,26], the capacity to produce a high amount of running actions at high intensity is more related to metabolic parameters such as the capacity to supply energy from different pathways during the running action and during the recovery, and the ability to reduce the intramuscular accumulation of metabolic by-products [27,28]. Therefore, it seems that professional football players possess the mechanical capacity to perform at least one running action at very high speed from the beginning of the championship, but they need several fixtures to obtain the physiological adaptations to produce high values of running distance at high intensity and sprinting velocities.

Peak running speed and the amount of running performed at high intensity are physical variables that represent different performance outcomes during a match [17]. Peak running speed is normally obtained during an offensive or defensive football action without the ball and in a field position that allows the distance necessary to obtain appropriate acceleration and maximum velocity. Players obtain their peak running speed during a critical action of the game but this represents only one of the hundreds of high intensity actions and dozens of sprints performed during a match [2,4]. Accordingly, while several previous investigations have coincided in establishing the importance of high intensity running during a match for overall football performance [2,4,5], the current investigation suggests that players' peak/maximum running speeds are comparable in all teams competing in *LaLiga*, irrespective of their ranking and competitive level.

In this regard, the distance covered at over 21 km/h during a national league has a modest capacity to discriminate between successful and less successful teams, especially if the distance is covered with the ball [16]. However, the utility of the physical demands during a match to predict football performance is lower when compared to match statistics such as shooting accuracy, the number of shots performed, and the capacity to prevent the rival from shooting [29,30]. All this information points towards a poor capacity of teams' maximum running speeds to anticipate the football performance of a squad. From a practical perspective, this information also suggests the convenience of focusing training on more useful determinants of football performance like the development of a high capacity to repeat sprints during a match and tactical and strategic interventions to enhance shooting efficacy, reducing the time devoted to improving players' maximum running speeds.

The upper panel in Figure 2 indicates that 94.3% of players (448 out of 475) competing in *LaLiga* are capable of running at over 30.0 km/h. Only three players were able to run at over 35.0 km/h, while the fastest players reached 35.2 km/h. Overall, most players were able to obtain sprinting velocities between 32 and 33 km/h (Figure 2). Although these values of maximum running speed are excellent for football players [5,17], they are much lower than the peak velocity obtained by elite-level athletes during sprint events [2]. Furthermore, the presence of this high number of players running at over 30 km/h hinders the capacity of using maximum speed actions to overcome rivals during match play. Midfielders and defenders perform more high-intensity running and sprinting [10] but, as previously suggested, the fastest players are usually the forwards [18]. This pattern was found in most teams in the present investigation (Table 1) and suggests that the playing field position of a defender has evolved to become a position with fast players to increase their aptitude to defend against fast forward players, and vice versa.

The current investigation presents some limitations that should be discussed to improve the applicability of its outcomes to overall football performance. First, this investigation contains a notational analysis of peak/maximum running speed in a sample of professional football players competing in a national league (*LaLiga*). By using different statistics (e.g., simple and multiple correlations and groups comparison), we have contrasted team peak/maximum running speed of successful and less successful football teams in *LaLiga*. While this analysis is useful to understand the relevance of players' maximal running speed on the ranking position obtained in the competition, football performance is a complex construct that is influenced by a myriad of intrinsic and extrinsic factors, the one analyzed here being only one of them. In fact, it may be argued that the current analysis is reductionist because it omits the "why", "where", and "how" of the actions that lead to peak/maximum running speed [31]. In this regard, football actions requiring maximum or peak running speeds represent a low portion of the total number of high-intensity actions executed during a match, but the context in which they are performed is critical because it demands the player to obtain his/her maximal effort. Future investigations with more ecological approaches should be carried out to establish the relevance of peak/maximum running speeds in a more complex dynamic environment [32], including the cause of the sprint action, the location on the pitch of the sprint action, the main outcome of the sprint action, and the interactions of the player performing the sprint action with his/her teammates and rivals.

From a practical perspective, and of the opinion of the authors of the current research, physical training in elite football should be more focused on enhancing the ability to repeat sprints of sub-maximum intensity (e.g., between 21 and 30 km/h) to obtain high volumes of running distance at >24 km/h, rather than on improving players' maximum running speed. This is important as the training routines used for such objectives may be substantially different. Additionally, a key portion of physical and conditioning training should be devoted to increasing a player's capacity to accelerate/decelerate in short distances as they perform four times as many accelerations as reported sprints per match [33]. Lastly, the physical training devoted to developing maximum running speed could be focused on ensuring that players obtain at least 30–32 km/h of peak velocity during match play, as this is the peak running speed that most players produce during a game. The obtaining of higher velocities will likely impact on a few actions during the game, but as suggested by the results of this study, they will have low influence on the overall team performance at the end of the league. Of note, the utility of possessing a team squad with players able to obtain high peak/maximum running speeds may depend on the playing style. It is probable that teams with direct play when attacking and exerting high pressure while defending may benefit from faster players.

5. Conclusions

In summary, successful and less successful football teams competing in *LaLiga* have squads with players able to obtain similarly high maximum running speeds during match play. In addition, players of successful and less successful teams are capable of obtaining peak running speeds from the first fixture of the competition and maintain it across the season. Although football is a sport with a relatively low number of goals, and the goals are habitually preceded by power and speed actions [13], players' maximum running speeds had minimal impact on the team's ranking position at the end of the Spanish national league. In fact, the variance in the ranking position obtained at the end of the season explained by the team's maximum speed was of only 7.5%.

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Heart Rate Variability Responses to a Training Cycle in Female Youth Rowers

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Abstract: Heart rate variability (HRV) is a reputable estimate of cardiac autonomic function used across multiple athletic populations to document the cardiac autonomic responses to sport demands. However, there is a knowledge gap of HRV responses in female youth rowers. Thus, the purpose of this study was to measure HRV weekly, over a 15-week training period, covering pre-season and up to competition in youth female rowers, in order to understand the physiological response to long-term training and discern how fluctuations in HRV may relate to performance in this population. Measures of heart rate and heart rate variability were recorded before training each Friday over the monitoring period in seven athletes. Analysis of heart rate variability focused on time domain indices, the standard deviation of all normal to normal R–R wave intervals, and the root mean square of successive differences as markers of cardiac parasympathetic modulation. Training load was quantified by multiplying the rating of perceived exertion of the weeks training and training duration. A decrease was identified in cardiac parasympathetic modulation as the season progressed (Effect Size (Cohen's d) = −0.34 to −0.8, weeks 6 and 11–15), despite no significant relationship between training load and heart rate variability. Factors outside of training may further compound the reduction in heart rate variability, with further monitoring of external stressors (e.g., school) in adolescent athletes.

Keywords: autonomic nervous system; cardiac autonomic; vagal tone; adolescents; training load

1. Introduction

In a sustained effort to maximize human performance, coaches and sports scientists aim to understand how individual athletes respond to training. If training is effectively monitored, programs may be adjusted to prevent training maladaptation and ultimately, improve performance [1]. An assessment that has shown potential in monitoring training and maladaptation in athletic populations is the measurement of heart rate variability [HRV] [2,3], the non-invasive estimate of cardiac autonomic nervous system activity at rest [4,5] and following exercise [6–8].

Heart rate variability may represent the fine tuning of impulses from the sympathetic and parasympathetic nervous systems [4,9], and has been shown to reflect training load in athletes [10,11]. While not always the case [12,13], vagal indices of HRV are often reduced during periods of intense training [11,14,15]. Accordingly, HRV has been utilized to non-invasively monitor fluctuations associated with altered cardiac autonomic activity in athletic populations during seasonal training. Oliveira et al. measured the HRV of male futsal players before a pre-season training period, after pre-season, and during their competitive season, finding that HRV was increased due to training, and this increase was reflected by performance measures [16]. In addition, Edmonds et al. conducted weekly HRV measurements within a cohort of Paralympic swimmers over a 14-week training and competitive season [17]. Although Edmonds et al. [17] found that HRV was relatively stable during the athletes training cycle, only reducing following an early season competition, all athletes recorded personal best times, a potential indication that training workload was well managed. This also potentially eludes to the notion that stable HRV is favorable, suggesting that weekly measurement of HRV may be useful in different athletic populations.

It is also valuable for coaches and sports scientists to assess an athlete's readiness to perform, with increased estimates of cardiac parasympathetic nervous system activity associated with increased athletic performance [2,18,19]. Previous research in swimmers has shown that increased estimates of parasympathetic activity following a taper correlated highly with increased swimming performance [18,19]. Comparable results were found by Cataldo et al. in youth male soccer players, as higher peak power during repeated sprint exercise was highly correlated with indicators of parasympathetic activity [20]. Research has also identified negative correlations between vagal indices of HRV following training and performance, with lower parasympathetic modulation (i.e., increased sympathetic modulation) shortly following training associated with improved performance [21]. These findings suggest that HRV could also be used to evaluate whether an athlete is primed for performance; however, little work has been done on youth athletes and females in particular.

Currently, HRV has been researched in a variety of elite sports [2,22,23], yet rowing—another sport that requires a high training load and intensity—has been sparingly investigated. An early long-term study of male Italian Olympic rowers, while potentially limited by its sole analysis of frequency domain measures, reported that changes in training load affect HRV, likely through variations in cardiac sympathetic activation over a short period (~20 days) [24]. More recently, a study indicated a relationship between training load and HRV in male and female Olympic rowers, showing that periods of training with increased intensity suppress parasympathetic activity, while periods of low-intensity training preserve, and often increase, vagal activity [25]. Again, in elite male rowers, alterations in heart rate variability leading up to world championships suggested athlete-dependent effects, but 3 of 4 athletes displayed an increase in estimated cardiac parasympathetic activity [26]. However, these investigations evaluated exclusively elite, mostly male, rowers with advanced coaches, sports scientists, and monitoring, potentially limiting its applicability to amateur, and/or youth athletes. Indeed, research in youth athletes without such resources, specifically females, has been limited to date. To this end, recent work in youth female rowers explored the impact of travel to, and response to, a week-long intense training camp, and found that travel and the increased training load acutely reduced HRV [27]. Although, much less is known about how long-term training influences cardiac autonomic activity in these young female rowing athletes, and how HRV may or may not relate to rowing performance.

As such, the purpose of this study was to measure HRV, once a week, during a 15-week training period, from pre-season up to the competition phase, to provide insight into the physiological responses to long term training in high performing youth female rowers. Additionally, we sought to examine the relationship between cardiac autonomic function and rowing performance (2000 m ergometer time trial).

2. Materials and Methods

2.1. Participants

Participants in the study were recruited from the largest team in a 100-mile radius (~180 athletes). To best minimize confounding factors, such as sex, age, and training age, paired with the lack of studies in females, recruitment was limited to experienced varsity female rowers. To maintain homogeneity, participants were recruited from a pool of twenty-five female varsity rowers who were members of a local competitive high school rowing program. This program had consistently won or challenged for national titles. Seven rowers (Table 1) enrolled in the study and were on average 16.6 (±1.0) years old, with an average height of 173.9 (±7.6) cm and weight of 67.6 (±10.3) kg. The rowers were all experienced, training six or more times a week, and had been rowing competitively for at least three seasons. The average 2000 m ergometer performance times for these athletes was 468 ± 28 s, which placed these athletes within a "high performance" level of rowing ability, when compared against US rowing junior performance standards. Written informed assent was obtained from all participants and their legal guardians prior to participation in this study. This study was approved by the local Institutional Review Board (IRB# 1605-515) in accordance with the ethical standards set forth in the Declaration of Helsinki.

Table 1. Individual participant characteristics.

Athlete	Age (years)	Height (cm)	Weight (kg)
1	15	175	74.8
2	17	178	65.8
3	17	175	69.4
4	18	168	71.7
5	16	178	64.8
6	17	183	79.4
7	16	160	47.2
Mean (±sd)	16.6 (±1.0)	173.9 (±7.6)	67.6 (±10.3)

2.2. Experimental Design

Heart rate recordings took place once each week over a 15-week winter training season, which included transitions from pre-season to in-season to competition preparation, culminating in the spring racing season. The first race of the season occurred the weekend after the last week of training (week 15). The measurement from the first week of training was classified as a baseline recording, taken as described below. During week 6 of the training period, there was a week-long training camp in which training frequency was increased (10 sessions per week compared to 6), and the HRV response to such overload was described previously in a similar population [27]. All HRV measurements were recorded once a week, on the Friday of each training week, and at a consistent time of day (3:00 p.m.) to eliminate any circadian effect on HRV [28,29]. While daily HR recording within elite athlete populations is considered the "gold standard" for HRV assessment [1], research has also shown similar weekly HRV assessment may be all that is necessary in highly trained athletes [17,30], and even daily measures are often reported by week in longer-term studies [26]. Given issues with the practicality of daily HRV assessment, an afternoon, single pre-training recording was used in order to assess the athlete's state immediately prior to their last session of the week. Heart rate was recorded over a 10-min period using the Zephyr BioHarness (Zephyr Technology, Annapolis, MD, USA) with recordings sampled at 1000 Hz for determination of RR intervals. In line with previous studies, the first five minutes of monitoring was used as a stabilization period to ensure athletes were rested, with HRV calculated from the final five minutes [31,32]. To maintain uniformity, HR measurements were obtained in a seated position [3], and breathing was spontaneous [32]. Rating of perceived exertion for the week of training was measured before every HR recording using the modified Borg's scale (RPE; 1–10) [33], and was used to calculate training load, as originally described [34]. This method has since been used in similar studies [27], and has been systematically reviewed, supporting its use as a standalone approach [35].

Three 2000 m rowing performance tests were also performed during the training period, at the end of weeks 4, 8, and 12 (Table 2). Rowing performance tests were also performed on Fridays, importantly, only after HRV recordings. The gold standard performance test in rowing (2000 m time trial) was performed on the Concept2 rowing ergometer (Model D, Concept2, VT, USA) in accordance with Junior National team suggested guidelines (e.g., drag factor, etc.) and requirements (e.g., open rating, stationary, and confirmed by coach).

Table 2. Timeline of the HR and HRV monitoring period with 2000 m ergometer trials.

	Week													
Baseline	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
x	x	x	x 2k	x	x	x	x 2k	x	x	x	x 2k	x	x	x

X—HRV recording; 2k—2000 m ergometer trial.

2.3. Data and Statistical Analysis

All RR interval recordings were analyzed using Kubios HRV software (v2.2, University of Kuopio, Kuopio, Finland) with HRV calculated from the last 5 min of the 10-min recording period based on previously established guidelines (Task Force, 1996). Prior to analysis, any artifact or ectopic beats were corrected via Kubios' in-built cubic spline interpolation [36] with an artifact correction threshold set at very low. Coupled with mean HR, analysis of HRV included the standard deviation of all normal to normal RR intervals (SDNN), a marker of global autonomic nervous activity at the heart, and the root mean square of successive differences (RMSSD), which is thought to represent parasympathetic influence. Previous research has used both RMSSD and SDNN as estimates of cardiac autonomic activity in athletic populations [2,37–39].

Given the small sample size, meaningful changes from pre-training camp (baseline) values were assessed using magnitude-based decisions (MBD) [40]. In line with previous research, magnitude-based decisions were undertaken by defining the smallest worthwhile change from baseline (±3%) [31]. In line with a previously outlined framework [40], the chances of meaningful negative, trivial, or positive changes were determined qualitatively as follows: almost certainly (99.5%); very likely (99.5–95%); likely (95–75%); possibly (75–25%); unlikely (25–5%); very unlikely (5–0.5%); almost certainly not (<0.5%). If the chances of having a positive and negative change were both greater than 5%, the true difference was deemed unclear. In line with previous research, the observed changes were standardized following Cohen's effect size principle (i.e., changes in the mean divided by the between-athlete SD of baseline data) [31]. The magnitude of the weekly change from baseline (pre-season) during the training camp was determined using Cohen's d (i.e., Effect Size, ES) with threshold values established as small (0.2), moderate (0.6), large (1.2), and very large (2.0) [40]. Differences in performance (2000 m time trial) over time were assessed using a one-way analysis of variance, with an alpha level of $p < 0.05$ and times expressed as mean (± SD). In addition, differences in mean HR, HRV, training load, and rowing performance were examined using a repeated measures analysis of variance (ANOVA), with a Bonferroni post hoc test, to identify potential differences over the 15-week monitoring period, with an alpha level established at $p < 0.05$ for all analyses.

Pearson correlations were also examined using the Statistical Package for Social Sciences (SPSS) software (v23, SPSS INC., Chicago, WI, USA) to identify relationships, using individual data, between mean HR, HRV, and training load, at each rowing time trial timepoint (week 4, 8, and 12).

3. Results

3.1. Training Load

Training load was likely higher in week 6 (ES = 0.54) (Table 3, Figure 1A). Additionally, training load was very likely higher in week 12 (ES = 1.13) compared to baseline (Figure 1A). In contrast, training load was likely lower in week 5 (ES = −0.50) compared to baseline (Figure 1A).

Training load at week 12 (2286.0 ± 219.9) was significantly higher compared to week 5 (1520.0 ± 474.3, $p = 0.04$, $d = -2.65$) and week 8 (1425.0 ± 329.1, $p = 0.02$, $d = -2.96$). There were no other differences reported for training load over the monitoring period.

Table 3. Mean values ± standard deviation, variance (95% CI) from baseline, Effect Size (ES), and qualitative inferences for heart rate and heart rate variability during the 15-week monitoring period.

		Week													
	Baseline	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Mean HR [bpm]	76.4 ± 11.5	74.6 ± 4.3	77.1 ± 7.3	77.4 ± 7.4	70.2 ± 10.7	74.5 ± 7.4	74.2 ± 8.5	76.9 ± 10.5	76.1 ± 8.6	73.5 ± 8.4	76.2 ± 5.6	85.5 ± 6.8	74.0 ± 2.8	75.0 ± 8.0	73.5 ± 8.0
%∆ [95% CI]		−1.5 [−14.4, 13.3]	1.6 [−13.9, 19.9]	1.9 [−13.2, 19.7]	−8.2 [−21.6, 7.7]	−2.0 [−15.1, 13.1]	−2.5 [−14.0, 10.5]	0.8 [−9.2, 12.0]	0.1 [−8.0, 8.9]	−3.4 [−15.0, 9.9]	0.5 [−14.2, 17.7]	12.8 [−5.0, 33.9]	−2.2 [−14.6, 12.1]	−1.4 [−12.5, 11.2]	−3.3 [−16.1, 11.6]
ES		−0.08	0.08	0.10	−0.46	−0.11	−0.14	0.05	0.00	−0.19	0.03	0.66	−0.12	−0.07	−0.18
QI		Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Likely	Unclear	Unclear	Unclear
RMSSD [ms]	105.3 ± 45.4	84.9 ± 38.2	83.8 ± 36.7	86.4 ± 37.1	101.7 ± 51.2	81.2 ± 40.9	96.4 ± 43.1	89.8 ± 26.9	83.6 ± 40.8	80.9 ± 27.4	56.8 ± 34.8	52.4 ± 29.9	72.6 ± 17.3	71.0 ± 24.3	78.4 ± 33.9
%∆ [95% CI]		−19.0 [−55.8, 48.5]	−20.9 [−64.0, 73.7]	−18.3 [−65.1, 91.2]	−5.0 [−47.2, 70.8]	−27.0 [−55.0, 18.4]	−10.0 [−52.1, 69.2]	−9.8 [−41.0, 37.8]	−19.8 [−48.0, 23.5]	−20.7 [−58.5, 51.4]	−48.2 [−71.6, −5.4]	−52.7 [−74.4, −12.6]	−25.8 [−55.0, 22.4]	−29.7 [−54.8, 9.3]	−27.6 [−53.8, 13.4]
ES		−0.23	−0.25	−0.22	−0.06	−0.34	−0.11	−0.11	−0.24	−0.25	−0.70	−0.80	−0.32	−0.38	−0.35
QI		Unclear	Unclear	Unclear	Unclear	Likely	Unclear	Unclear	Unclear	Unclear	Very Likely	Very Likely	Possibly	Likely	Likely
SDNN [ms]	100.1 ± 38.9	82.3 ± 21.6	90.1 ± 26.0	88.4 ± 24.7	98.9 ± 33.0	76.0 ± 31.2	78.9 ± 36.7	84.6 ± 25.6	75.9 ± 20.1	70.9 ± 27.4	56.7 ± 28.2	52.8 ± 25.1	69.5 ± 19.6	70.6 ± 22.0	72.2 ± 27.2
%∆ [95% CI]		−14.8 [−42.6, 26.4]	−8.0 [−41.4, 44.5]	−9.2 [−49.6, 63.8]	1.4 [−34.9, 58.0]	−25.6 [−46.4, 3.2]	−22.4 [−48.0, 15.6]	−13.7 [−37.2, 18.7]	−21.7 [−49.0, 20.2]	−28.0 [−45.1, −5.5]	−44.9 [−64.9, −13.5]	−48.8 [−69.2, −14.9]	−28.0 [−53.9, 12.5]	−27.6 [−51.3, 7.6]	−28.3 [−49.2, 1.3]
ES		−0.26	−0.14	−0.16	0.02	−0.49	−0.42	−0.24	−0.40	−0.54	−0.98	−1.11	−0.54	−0.53	−0.55
QI		Unclear	Unclear	Unclear	Unclear	Likely	Likely	Unclear	Unclear	Very Likely	Very Likely	Very Likely	Likely	Likely	Likely

HR—heart rate; RMSSD—root mean square of successive differences; SDNN—standard deviation of normal to normal RR intervals; % ∆—percent variance from baseline; CI—confidence interval; ES—effect size; QI—qualitative inference.

Over the monitoring period, athlete #3 (2029.5 ± 519.4) reported a significantly higher training load when compared to compared to athlete #4 (1415.5 ± 435.2, $p = 0.02$, $d = 1.03$) and athlete #5 (1460.1 ± 354.4, $p = 0.006$, $d = 1.23$). Training load was similar between all other athletes over the monitoring period.

There were no correlations observed between training load and mean HR, RMSSD, or SDNN at any time point during the monitoring period (all $p > 0.05$).

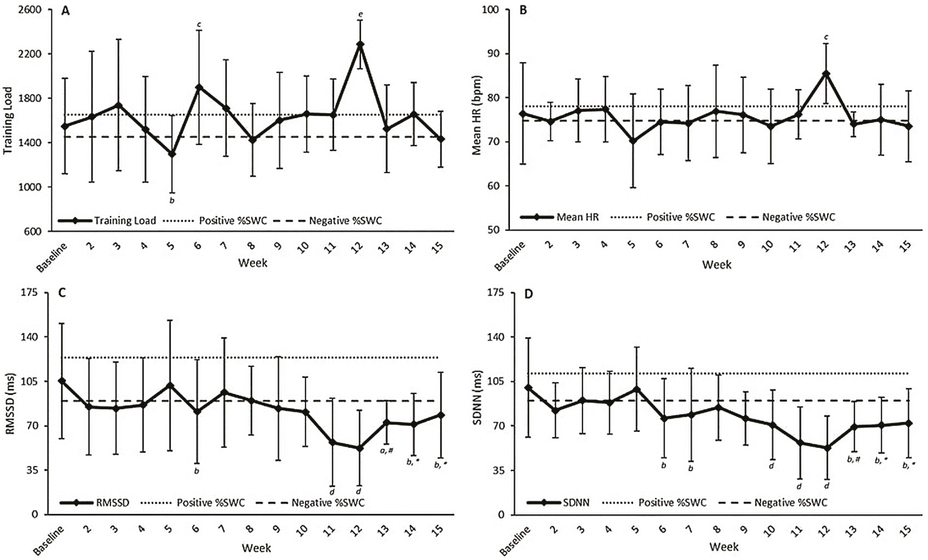

Figure 1. Changes from baseline over the 15-week monitoring period for (**A**) training load, (**B**) mean heart rate, (**C**) root mean square of successive RR interval differences (RMSSD), and (**D**) the standard deviation of all normal to normal RR intervals (SDNN). Data are presented as means ± SD, with dashed lines representing the positive and negative percentage smallest worthwhile change (%SWC, 3%) from baseline [31]. a indicates possibly lower compared to baseline. b indicates likely lower compared to baseline. c indicates likely higher compared to baseline. d indicates very likely lower compared to baseline. e indicates very likely higher compared to baseline. * indicates likely higher compared to week 12. # indicates very likely higher compared to week 12.

3.2. Heart Rate and Heart Rate Variability

Mean HR was likely higher at week 12 (ES = 0.66) compared to baseline (Figure 1B, Table 3). Excluding week 12, variation in mean HR across the monitoring period was unclear (Table 3).

A significant difference ($p = 0.047$, $n^2 = 0.234$) in mean HR was observed over the 15-week monitoring period; however, the Bonferroni post hoc test was unable to identify where that difference was. Athlete #7 (65.6 ± 7.8 bpm) had a significantly lower ($p < 0.01$) mean HR compared to all other athletes during monitoring period.

RMSSD was possibly lower at week 13 (ES = −0.38) compared to baseline (Table 3, Figure 1C). Additionally, RMSSD was likely lower at week 6 (ES = −0.34), week 14 (ES = −0.38), and week 15 (ES = −0.35) compared to baseline (Table 3, Figure 1C). Finally, changes in RMSSD were very likely lower at week 11 (ES = −0.70), and week 12 (ES = −0.80) compared to baseline (Table 3, Figure 1C). Interestingly, RMSSD was very likely higher at week 13 (ES = 0.51), and likely higher at week 14 (ES = 0.45) and week 15 (ES = 0.48) when compared to week 12 (its lowest over the 15 weeks) (Figure 1C).

A significant difference ($p = 0.03$, $n^2 = 0.247$) in RMSSD was reported during the 15-week monitoring period; however, the Bonferroni post hoc test was unable to identify where the difference was. Significant differences in RMSSD were also observed between athletes over the 15-week monitoring period. Athlete #1 (49.4 ± 28.2 ms) reported a significantly lower RMSSD when compared to athlete #2 (107.9 ± 20.6 ms), athlete #3 (101.6 ± 21.2 ms), athlete #4 (89.1 ± 25.9 ms), and athlete #7 (103.0 ± 48.9 ms). In contrast, athlete #2 and athlete #3 both had a significantly higher RMSSD when compared to athlete #5 (53.4 ± 28.3 ms) and athlete #6 (67.3 ± 21.5 ms).

SDNN was likely lower at week 6 (ES = −0.49), week 7 (ES = −0.42), week 13 (ES = −0.54), week 14 (ES = −0.53), and week 15 (ES = −0.55) (Figure 1D). SDNN was also very likely lower at week 10 (ES = −0.54), week 11 (ES = −0.98), and week 12 (ES = −1.11) compared to baseline (Figure 1D). Like RMSSD, SDNN was very likely higher at week 13 (ES = 0.49), and likely higher at week 14 (ES = 0.50) and week 15 (ES = 0.49) when compared to week 12 (its lowest over the 15 weeks) (Figure 1D).

A significant difference (p = 0.04, n^2 = 0.302) in SDNN was reported during the 15-week monitoring period; however, the Bonferroni post hoc test was unable to identify where the difference was. There were also significant differences for SDNN observed between athletes over the monitoring period. Athlete #1 (54.0 ± 21.3 ms) reported significantly lower SDNN when compared to athlete #2 (93.6 ± 16.8 ms), athlete #3 (87.2 ± 16.5 ms), athlete #4 (82.8 ± 19.1 ms), and athlete #7 (98.1 ± 35.2 ms). Likewise, athlete #5 (55.1 ± 26.1 ms) also had a significantly lower SDNN when compared to athlete #2, athlete #3, and athlete #4.

3.3. Rowing Performance

Group mean 2000m rowing times were similar (p = 0.571) in all three trials (Trial 1—472.1 ± 24.1 s vs. Trial 2—470.1 ± 24.0 s vs. Trial 3—471.2 ± 28.3) for the squad. Each athlete also reported similar 2000 m rowing times between each trial. Expectedly, there were significant differences in 2000 m rowing times between individual athletes.

There were no significant correlations reported between 2000 m ergometer performance and mean HR, RMSSD, SDNN, and training load (all p >0.05) at any time point.

4. Discussion

The purpose of the current study was to document the weekly fluctuations in cardiac autonomic function in response to varied training load over a winter season (pre-season to start of competitive season), and examine the relationships between training load, heart rate variability, and rowing performance, in competitive female youth rowers. The results from this study reveal a downward trend in HRV estimates of cardiac parasympathetic activity over the course of the season, but not HR, followed by an increase during the final 3 weeks of training as competition approached. In contrast to previous studies, the current study reported no clear relationship between indices of cardiac autonomic activity and training load or rowing performance within this female youth population. Lastly, though measuring resting HR may have value [41], in line with our prior study [27], HRV (RMSSD) may be more sensitive than HR alone in reflecting physiological responses to training in youth athlete populations, whom may have already undergone significant adaptation, as in the present study, changes in HR were less clear. Thus, it might be advisable for youth rowing coaches to monitor HRV, and not just resting HR, to allow for a greater understanding of athlete response to training workload over time and may aid in training planning and management.

4.1. Training Load and HRV

The current study shows a downward tendency in HRV-based estimates of cardiac vagal activity (RMSSD, SDNN), but not HR, as the season transitioned from pre-season to in-season training and progressed towards the first competition of the season. Intriguingly, and in line previous research [25], this reduction in RMSSD was not significantly related to changes in training load, and only modest relations were observed. While training load did vary throughout the training season, there was no discernable relationship observed between the variation in training load and the variance in HRV. While this lack of apparent relationship between training load and indices of cardiac autonomic function may be attributed to the way in which training load was quantified in the current study (subjectively by means of RPE), it is also important to note that athletes are subjected to other various stressors outside of training. Given these additional stressors, such as school workload, it is possible that this reduction in vagal modulation was compounded by stressors outside of training, thus limiting the influence of a purely subjective measure of training load on HRV. Few studies have reported the acute effect of psychological stressors on cardiac autonomic function, with a clear link between increased psychological stress and reduced vagal modulation [42–44]. However, given the current study did not quantify these potential additional stressors, it is difficult to establish the exact mechanism behind the accumulative reduction in HRV estimated vagal modulation. Likewise, there is also merit in coaches using a more objective measure of training load such as those previously described by Plews and colleagues [25]. Nonetheless, given the previously reported relationship between HRV-based estimates of vagal activity and performance [18,19,31,45], this shift in estimated cardiac autonomic function provides valuable information for coaches working with youth athletes. Future research examining cardiac autonomic function, either directly or indirectly via HRV, in younger athletes, may benefit from additional psychological assessment throughout the monitoring period to ensure a more holistic approach to youth athlete management. Results from the current study (i.e., likely reductions in RMSSD and SDNN) highlight the importance of monitoring stressors external to sport (e.g., psychological, sleep, etc.), in addition to training workload, that might be altering HRV in youth athlete populations, to allow for favorable performance improvements. Further, coaches may be able to tailor team training load based upon alterations in HRV; for example, if athletes, en masse, display significant drops in HRV, the coach may wish to reduce training volume and/or intensity to allow the athletes to better recover and ultimately, avoid maladaptation.

4.2. Performance and HRV

As mentioned previously, prior studies have reported a relationship between HRV estimated cardiac vagal modulation and performance in adults [18,19,31,45]. Alternatively, in the current study, no relationships were observed between HRV and rowing performance, with no change in performance times across the three trials in youth athletes. Moreover, results indicate that, despite comparable performance times, RMSSD was reduced at the third rowing trial compared to the first two trials, potentially reflecting a heightened level of pre-time trial anxiety, or anxiety associated with upcoming boat/seat selection and/or proximity to on the water racing. Previous studies have linked pre-competition anxiety to a reduction in vagal modulation [46,47]. A similar reduction was apparent in the third time trial performance in the current study when compared to the first two trials. Interestingly, this reduction in vagal modulation, as assessed by HRV, did not appear to influence performance either negatively or positively, as times across the three trials were similar. While this reduction in HRV-based parasympathetic modulation immediately prior to competition may allow for a greater intensity (i.e., arousal), and as such, enhanced performance [31], performance across the three trials within this athlete population was similar. Alternatively, the lack of relationship between cardiac autonomic activity and rowing performance might be influenced by the time of day [21], though consistent, or incomplete biological maturation as autonomic activity seems to be altered during development [48]. Relatedly, ongoing athletic development (skill improvement) and mental status (e.g., stress, anxiety about boat/seat selection) might also be altering the nature of the relationship between HRV and performance. Further work is needed with larger samples with varied biological and training age, over longer observation periods including more frequent (perhaps daily) assessments of HRV to substantiate these hypotheses. Specific to the unique sport of rowing and potential utility of HRV, future work should explore boat (pair/double, four/quad, or eight) HRV and on the water performance, as rowing is a highly technical sport where high level physical fitness can be amplified or muted by technical proficiency and/or synchronicity of the team.

4.3. Experimental Considerations

Participants in the present study were recruited from the largest team in a 100-mile radius (~180 athletes), but to minimize confounding factors, such as sex, age, and training age, coupled with the paucity of studies in females, experienced varsity female rowers were recruited. Due to selectivity factors (experience and sex), the pool of potential participants was 25, and due to the voluntary nature of the study and requiring parental consent, the sample size in the current study was relatively small (n = 7). However, the sample of participants was relatively homogenous and representative of a typical successful youth female varsity (experienced secondary school) rowing squad. Given the success evidenced by either winning or medaling at previous national championship rowing events, the squad was classed as high performing. Further, the statistical approaches employed were chosen to provide alternative assessment beyond the archetypal null hypothesis testing.

5. Conclusions

The current study sought to document changes in cardiac autonomic activity over a training season, determine the potential impact of training load on these responses, and ultimately, the impacts on rowing performance. Measures of HRV, but not HR, were found to be reduced over the training season, but were not overtly related to training load or performance. Further work is needed in the youth rowing athlete population to describe HRV-based cardiac autonomic changes over a yearly training program. Youth rowing coaches should consider monitoring HRV of their athletes to potentially modify training magnitude to prevent training maladaptation and ultimately, improve performance.

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Article

Effects of Unloaded vs. Ankle-Loaded Plyometric Training on the Physical Fitness of U-17 Male Soccer Players

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Abstract: The aim of this study was to compare the impact of two differing plyometric training programs (loaded plyometrics (with 2.5% of body mass placed above the ankle joint) vs. unloaded plyometrics), performed biweekly for 10 weeks, on the physical fitness of elite junior male soccer players. Participants aged 16.0 ± 0.5 years were randomly assigned between unloaded plyometrics (UP; n = 12), loaded plyometrics (LP; n = 14) and control (C; n = 12) groups. Two-way analyses of performance (group x time) were assessed by 40-m sprint times; 9–3–6–3–9 m sprints with 180° turns (S180°); 9–3–6–3–9 m sprints with backward and forward running (SBF); and 4 × 5 m sprints (S4 × 5 m); four jump tests; measures of static and dynamic balance; repeated change of direction tests and the Yo-Yo intermittent recovery test. Both LP and UP enhanced sprinting performance relative to C ($p < 0.05$) but performance increased more in LP relative to UP ($p < 0.05$) in all sprints except 40 m. Change of direction times were also significantly shortened by LP relative to UP ($p < 0.05$) and C ($p < 0.01$) in all tests, with no significant differences between UP and C. Jumps heights increased similarly in both LP and UP relative to C ($p < 0.05$), with no significance between LP and UP. LP and UP also enhanced repeated change of direction scores relative to C ($p < 0.01$) with greater changes in LP than in UP ($p < 0.01$). Finally, LP enhanced some balance scores relative to UP ($p < 0.05$) and C ($p < 0.05$). We conclude that the introduction of 10 weeks of in-season loaded plyometrics into the regimen of U17 male soccer players yields gains in several physical performance scores relative to either unloaded plyometrics or the control training regimen.

Keywords: stretch-shortening cycle; additional weight; ability-to-change-direction; speed; balance; repeated change of direction

1. Introduction

Soccer players need a combination of strength and power to win ball possession, score, and assist or prevent goals [1,2]. Among tactics adopted to improve their jumping and sprinting abilities [3,4], plyometric training has proven one of the more effective ways of improving the rate of force development, sprinting and jumping [5–9]. Plyometric training is an exercise in which an eccentric muscle contraction is quickly followed by a concentric muscle contraction [10–12]. This is a type of strength training, and it is currently very popular in training for many sports such as soccer, handball, and basketball [5,13,14].

It involves performing bodyweight jumping-type exercises and throwing medicine balls, exploiting the so-called stretch–shortening cycle (SSC) of muscle action [5]. The SSC enhances the ability of the neural and musculotendinous systems to produce maximal force in the shortest amount of time, prompting the use of plyometric exercise as a bridge between strength and speed [15]. In this regard, plyometric exercises has been used extensively as a method of augmenting dynamic athletic actions such as sprinting, change of direction and jumping performance [5,13,14]. Several articles have discussed the use of plyometric training with additional external loading. Thus, Cronin et al. [16] demonstrated larger improvements in jumping performance when using this approach, attributing this to greater ground reaction forces. Rosas et al. [17] also compared the effects on jumping with or without haltere-type hand-held loading; after 6 weeks of training, gains in both vertical and horizontal jumping ability were greater for the loaded group. However, Kobal et al. [18] found that neither type of plyometric training yielded worthwhile improvements in maximal speed and power, blaming this poor response on interference from concurrent activities. All of these studies loaded the upper limbs, and none loaded the ankles. Nevertheless, this practice has been adopted in rehabilitation, and by those seeking to lose weight or increase other aspects of sports performance. Today, many people do not hesitate to use weights from 500 g to several kilos when skipping, jogging, and even playing basketball or tennis.

Few previous studies have examined the impact of combined forms of plyometrics on soccer players [17,18], and this is the first report to have examined the effect of ankle-loaded plyometric training (2.5% of body mass) upon repeated change of direction ability. Our study compared loaded versus unloaded plyometric training in terms of gains in sprinting performance, ability to change direction repeatedly, static and dynamic balance, vertical jumping, and maximal aerobic power. It was hypothesized that there would be a superior effect of loaded as compared to unloaded plyometric training.

2. Materials and Methods

2.1. Ethical Approval

All procedures were approved by the Institute's Committee on Research for the Medical Sciences (Manouba University Ethics Committee: UR17JS01) and performed in accordance with the current national laws and regulations and the Declaration of Helsinki. Informed consent was gained from all participants and their parents or guardians after a verbal and a written explanation of the experimental protocol and its potential risks and benefits. Participants were assured that they could withdraw from the trial without penalty at any time.

2.2. Participants

The study aimed to compare the effects of 10 weeks of biweekly unloaded versus loaded (2.5% of body mass, placed above the ankle joint) plyometric training on sprinting, jumping, ability to change direction, balance, repeated changes of direction, and aerobic power in elite junior male soccer players. Using the PEDRO scale [19], a group of experienced elite male soccer players (38 players; 3 goalkeepers and 35 field players) was assigned randomly (Table 1) between unloaded plyometric training (UP; n = 12; age = 16.2 ± 0.2 years; body mass = 59.8 ± 2.8 kg; height = 1.78 ± 0.21 m; body fat = 10.7 ± 3.0%), loaded plyometric training (LP; n = 14; age = 16.3 ± 0.4 years; body mass = 60.9 ± 3.4 kg; height = 1.77 ± 0.31 m; body fat = 11.1 ± 2.1%), and controls (who continued with the standard in-season regimen) (C; n = 12; age = 16.4 ± 0.2 years; body mass = 58.9 ± 3.7 kg; height = 1.78 ± 0.32 m; body fat = 10.4 ± 2.6%). Each group contained one goalkeeper and the remainder were field players. The maturity status of each participant was calculated as a maturity offset [20]:

$$\begin{aligned}\text{Maturity Offset} = -9.236 + 0.000278\ \text{leg length} \times \text{sitting height} - 0.001663\ \text{age} \times \text{leg length} \\ + 0.007216\ \text{age} \times \text{sitting height} + 0.02292\ \text{weight} \times \text{height (years).}\end{aligned} \tag{1}$$

Table 1. The used PEDro scale for reporting the three randomized divided groups.

1	Eligibility criteria	yes
2	Randomized allocation	yes
3	Concealed allocation	yes
4	Comparable at baseline	yes
5	Blinded subjects	no
6	Blinded therapist	yes
7	Blinded assessors	no
8	Adequate follow up	yes
9	Intention to treat analysis	no
10	Between group comparisons	yes
11	Point ability estimates and variance	yes
	Total Score	7/10

The age at peak height velocity was 14.1 ± 0.3, 14.1 ± 0.4 and 14.2 ± 0.4 years for LP, UP and C respectively. All three groups (LP, UP and CG) belonged to the same football team. All participants were engaged in soccer training 6–7 times per week, played one official game per week from the beginning of the competitive season (September) until the end of the trial period (March), and also undertook a weekly two-hour physical education course. Standard training sessions lasted 90–100 min, emphasizing skill activities at various intensities, offensive and defensive strategies, and 25 to 30 min of soccer play with only brief interruptions by the coach. Each Sunday, the team played either an official match (11 and 16 players) or engaged in a friendly match. Thus, all participants engaged in the same duration of weekly training activity.

2.3. Experimental Design

Two weeks before the initial experimental measurements, all participants completed two familiarization trials of all procedures except the repeated change of direction test (which was only practiced once) and the anthropometric assessments (which required no familiarization). Figure 1 presents a revised CONSORT diagram of the levels of reporting and explaining participant flow. The initial definitive measurements were made four months into the playing season, during the first two weeks of January (which was a rest period for all players), and tests were repeated after completing the 10-week intervention, 5–9 days after the last training session. On both occasions, participants undertook 40 m sprints, three change of direction tests (sprinting 9–3–6–3–9 m with 180° turns; sprinting 9–3–6–3–9 m with backward and forward running; sprint 4 × 5 m), a repeated change of direction (RCOD) test, four jump tests (squat jump, countermovement jump, countermovement jump with aimed arms and five jump tests); measures of static and dynamic balance, and an estimate of maximal aerobic power.

Before the start of the study, participants had practiced soccer for 8 years and participated in many international tournaments (From U10 to U17). All had achieved a good level of physical preparation at the beginning of the season (seven training sessions per week for 2 months). When the season began (September) we emphasized resistance strength training with light loads (block working for 2 months), then we completed the first phase (first place) and qualified to the play-off phase. The present investigation was undertaken during the second phase of the national championships (January to April).

Testing sessions were carried out at a consistent time of the day, and under the same experimental conditions (tartan surfaced stadium), at least 3 days after the most recent competition. Players maintained their normal intake of food and fluids during assessments. However, they drank no caffeine-containing beverages during the 4 h preceding testing, and ate no food for 2 h. Verbal encouragement was provided by the experimenters throughout.

The 38 elite male soccer players were examined by the team physician, focusing on conditions that might preclude resistance training and all were in good health. The three assigned groups were well-matched in terms of their initial physical characteristics, with no statistically significant inter-group differences.

All participants were engaged in soccer training 6–7 times per week, played one official game per week from the beginning of the competitive season (September) until the end of the trial (March), and also had a weekly two hours of physical education course. Standard training sessions lasted 90–100 min; emphasizing skill activities at various intensities, offensive and defensive strategies, and 25 to 30 min of soccer play with only brief interruptions by the coach.

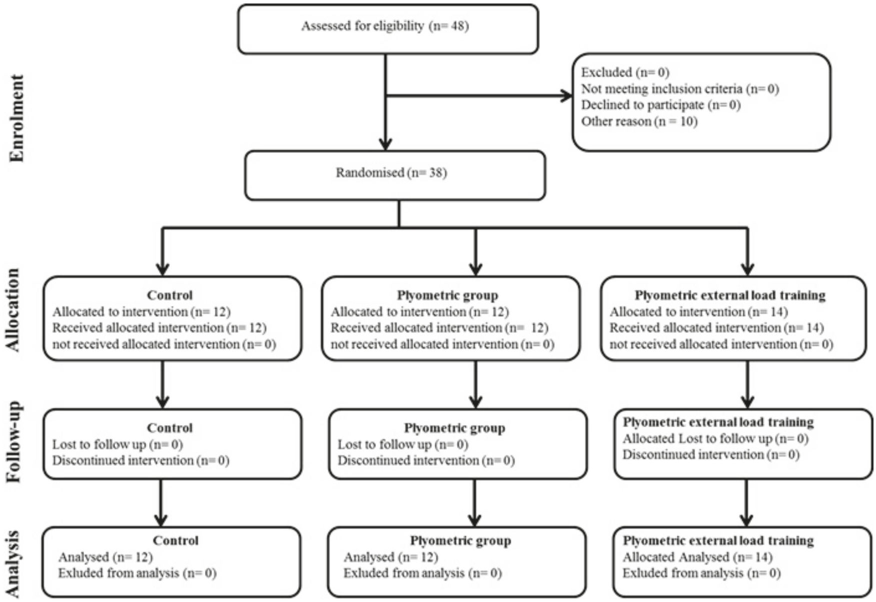

Figure 1. The diagram (The CONSORT: Consolidated Standards of Reporting Trials) includes detailed information on the interventions received.

2.4. Details of Standard and Modified Plyometric Training

Details of the two plyometric regimens are given in Table 2. Each Tuesday and Thursday for 10 weeks, the two experimental groups replaced the initial part of their standard training program (10–15% of regular soccer training times) with plyometric exercises (vertical and horizontal directions) in stable surface, intended to yield an optimal increase in muscle strength, followed by an increase in muscle power. Programs comprising four principal exercises included hopping, hurdles and horizontal jumps, finishing with a 20 m sprint. Each exercise set comprised 6 jumps (6 contacts) and a sprint of 20 m [14]. The recovery time was 30 s between sets and one minute between exercises. The inclusion of sprinting during training sessions is considered a transfer exercise and has been included from the discipline analysis.

Table 2. Details of two types of plyometric training.

	Weeks 1 and 2	**Weeks 3 and 4**	**Weeks 5 and 6**	**Weeks 7 and 8**	**Weeks 9 and 10**
Exercise 1: 3 hops to the right then 3 hops to the left (6 ground contacts), finally sprint 20 m.	2 Repetitions	3 Repetitions	4 Repetitions	5 Repetitions	6 Repetitions
Exercise 2: 6 lateral 0.3 m hurdle jumps (3 to left and 3 to right) (6 ground contacts), then sprint 20 m.	2 Repetitions	3 Repetitions	4 Repetitions	5 Repetitions	6 Repetitions
Exercise 3: 6 horizontal jumps (three bell feet horizontal with the right leg follows from three bell feet horizontal with the left leg) (6 ground contacts), then sprint 20 m.	2 Repetitions	3 Repetitions	4 Repetitions	5 Repetitions	6 Repetitions
Exercise 4: 6 × 0.4 m hurdle jumps (6 ground contacts), then sprint 20 m.	2 Repetitions	3 Repetitions	4 Repetitions	5 Repetitions	6 Repetitions
Total jump per each session	48 (36 unilateral jump + 12 bilateral jump)	72 (54 unilateral jump + 18 bilateral jump)	96 (72 unilateral jump + 24 bilateral jump)	120 (90 unilateral jump + 30 bilateral jump)	144 (98 unilateral jump + 36 bilateral jump)

The plyometric program began with 48 contacts and ended with 144 contacts per session. The loaded plyometric group modified the standard plyometric routine by placing a load (2.5% of body mass) above the ankle joint. Maximal effort was encouraged verbally during all training sessions.

2.5. Testing Procedures

All field tests were performed on a tartan surface. Measurements were performed in a fixed order over four days, always preceded by a standardized warm-up. On the first test day, participants sprinted 40 m and then carried out two change-of-direction tests. On the second day, anthropometric measurements were followed by the two remaining change-of-direction tests. On the third day, the jump tests were followed by a Y-balance test, and on the final day the stork balance test and shuttle-run tests were performed. All tests were performed on a wooden surface. The warm-up for all tests included 5 min of submaximal running with change of direction exercises, 10 min of submaximal plyometrics (two jump exercises of 20 vertical (i.e., CMJ) and 10 horizontal jumps (i.e., two-footed ankle hop forward)), dynamic stretching exercises, and 5 min of a sprint-specific warm-up.

2.5.1. Day 1

40-m Sprint

Subjects ran 40 m from a standing position, with times over 5 m, 10 m, 20 m, 30 m and 40 m recorded by paired photocells (Microgate, Bolzano, Italy). Three trials were separated by 6–8 min of recovery, with the fastest times noted for each distance.

Sprint 9–3–6–3–9 m with 180° Turns (S 180°)

During this test [21], subjects ran 9 m from the starting line to line A. Touching this line with one foot, they then made an 180° left- or right-hand turn. All subsequent turns were made in the same direction. They ran 3 m to line B, made another 180° turn, and ran 6 m forward. Then they made another 180° turn and ran a further 3 m forward, before making the final turn and running 9 m to the finish line (Figure 2).

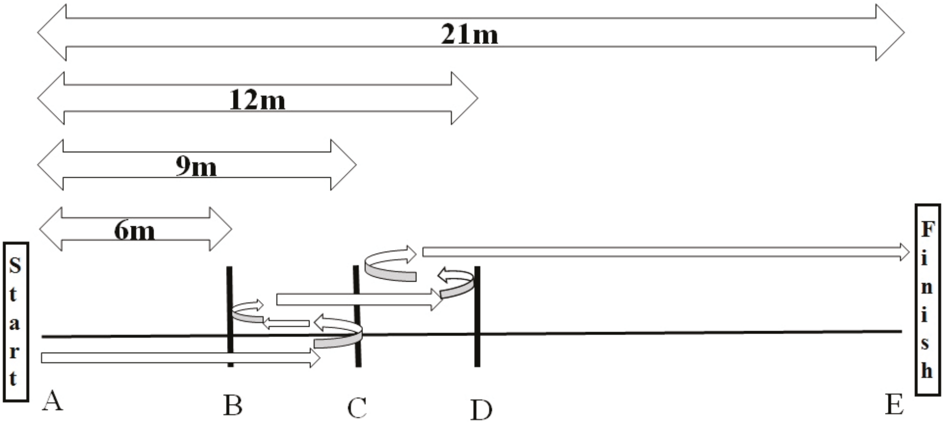

Figure 2. Design of the sprint 9–3–6–3–9 m with 180° turns (S180°) or with backward and forward running (SBF). A and E are start and finish lines respectively. B, C and D are lines of change of direction.

Sprint 4 × 5 m (S4 × 5 m)

Five cones were set 5 m apart [21]. Subjects stood with their feet apart and a cone between their legs. At an acoustic signal, they ran 5 m to point A; there, they made a 90° turn to the right and ran 5 m to point B. After a second 90° turn, they ran to point C, where they made an 180° turn and ran back to the finish line (Figure 3).

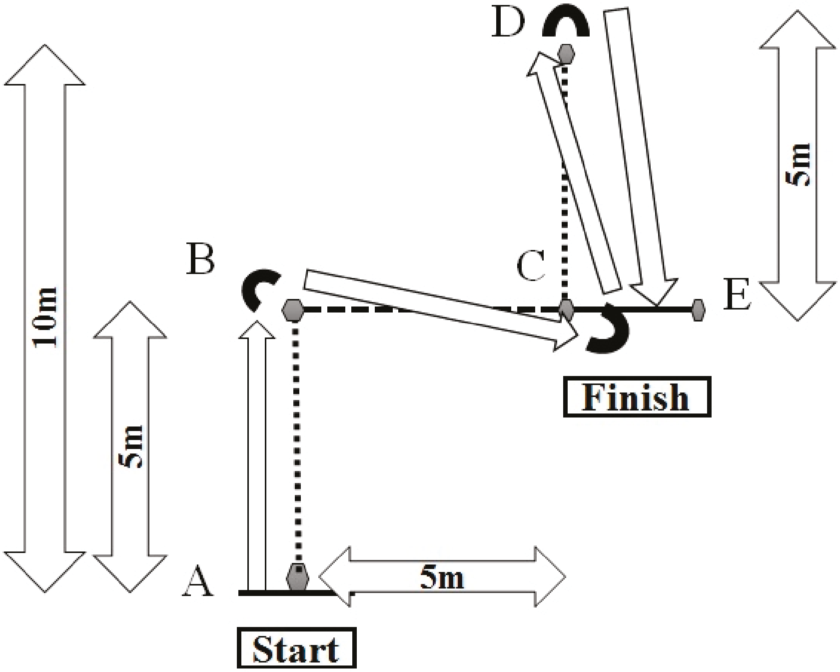

Figure 3. Design of the sprint 4 × 5 m (S4 × 5 m). A and E are start and finish lines respectively. B, C and D are lines of change of direction.

2.5.2. Day 2

Anthropometry

Anthropometric measurements included standing and sitting height (Holtain stadiometer, Crosswell, Crymych, GM, UK, accuracy 0.1 cm) and body mass (Tanita scales, BF683W, Sindelfingen, Germany, accuracy 0.1 kg). The overall percentage of body fat was estimated from the biceps, triceps, subscapular, and supra iliac skin-folds, using the equations of Durnin and Womersley for adolescent males aged 16.0-19.9 years [22]:

$$\% \text{ Body fat} = [4.95/(\text{Density} - 4.5)] \times 100 \qquad (2)$$

where D = 1.162 − 0.063 (Log sum of four skinfolds).

Repeated Change of Direction Test

This test comprised 6 × 20 m sprints, each beginning from a standing position (Figure 4), 0.2 m behind the sensor, with 25-s active recovery intervals [23]. Times were measured using infrared sensors (Microgate, Bolzano, Italy) located 0.5 m above the ground at the start and finish lines. Four 100° turns were made at 4 m intervals. During the active recovery phase, subjects jogged slowly back to the starting line. The best time in a single trial (BT), the average time for the 6 × 20 m sprints (MT), and the total time for the six sprints (TT) were recorded, and the decrement (DEC) was calculated according to the formula [24]:

$$\text{DEC} = 100 \times (\text{total sprint time} \div \text{ideal sprint}) - 100 \tag{3}$$

where:

Total sprint = sum of sprint times from all sprints
Ideal sprint = the number of sprints × best sprint time

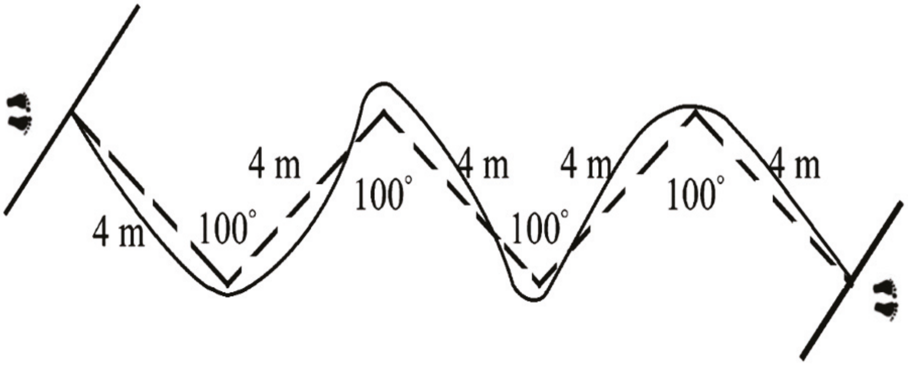

Figure 4. Design of the repeated change-of-direction (RCOD) test.

Sprint 9–3–6–3–9 m with Backward and Forward Running (SBF)

Participants covered the same distance as in the S180° (Figure 2) test, but instead of making a turn, they shifted from forward to backward running. After the starting signal, they ran 9 m from the starting line to line B. Having touched line B with one foot, they ran 3 m backwards to line C and there changed to forward running. After 6 m, they ran 3 m backward and then ran the final 9 m forward to the finish line [21]. Each test was carried out three times, with a pause of 3 min between trials. The pause between the two tests was 7.5 min. The fastest values were recorded.

2.5.3. Day 3

Vertical JUMP

After a 15-min warm-up, jump height was assessed using an infrared photocell mat connected to a digital computer (Opto-jump System, Microgate SARL, Bonzano, Italy). Contact and flight times were measured with a precision of 1 ms. The squat jump began at a knee angle of 90 degrees; avoiding any downward movement, subjects performed a vertical jump by pushing upwards, keeping their legs straight throughout. The counter-movement jump began from an upright position, with subjects making a rapid downward movement to a knee angle of 90° degrees and simultaneously beginning to push-off. During the third test, the subjects freely used their hands while jumping. One minute of rest was allowed between each of three trials, the highest values for each jump being used in subsequent analyses.

Five Jump Test

From an upright standing position, participants tried to cover as much distance as possible with five forward jumps by alternating left- and right-leg ground contacts. Distances were measured to the nearest 1 cm using a tape measure.

Dynamic Balance (Y-Balance Test)

The Y-balance protocol was similar to that described previously, and has a high reliability [13]. Reach directions were evaluated by affixing tape measures to the floor, one oriented anteriorly, and the other two running at 135° in the posterior-medial and posterior-lateral directions. All testing was conducted barefoot. Subjects stood on the dominant leg, with the most distal aspect of their great toe at the center of the grid. They then reached in the specified direction, while maintaining a single-limb stance. Tests were classified as invalid if the participants (1) did not touch the line with the reach foot while maintaining weight bearing on the stance leg, (2) lifted the stance foot from the center grid, (3) lost balance at any point during the trial, (4) did not maintain start and return positions for one full second, or (5) touched the reach foot down to gain support. The average maximum reach across the three directions (normalized for leg length) was calculated as a composite score for each subject [25]. After a demonstration, the participant completed four practice trials in each direction. Following a two-minute rest period, three definitive trials were made in each direction.

2.5.4. Day 4

Static (Stork) Balance Test

On command, the subject raised the heel of one foot from the floor and placed it against the inside of the supporting knee, with both hands on the hips, maintaining balance for as long as possible. The trial ended if the participant moved his hands from his hips, if the ball of the dominant foot moved from its original position, or if the heel touched the floor. This test was carried out on the dominant leg, with the eyes open. The stopwatch-recorded score was the best of three attempts. Previous test–retest reliability scores with a similar adolescent population have been high (error of measurement 0.3 to 3.2%).

Yo-Yo Intermittent Recovery Test Level 1

A 20-m shuttle run was performed at increasing velocities to exhaustion, with 10 s of active recovery between runs. The test ended when the player twice failed to arrive within 2 m of the end line in the allotted time. The total distance (m) covered (including the last incomplete shuttle) was scored.

2.6. Statistical Analyses

Statistical analyses were carried out using the SPSS 23 program for Windows (SPSS, Inc., Armonk, NY, USA, IBM Corp). Means and SDs were calculated. Training-related effects were assessed by ANOVA (2-way analyses of variance (group × time)). If a significant F value was observed, Tukey's post hoc procedure located pair-wise differences. Effect sizes were determined by converting partial eta-squared to Cohen's d [26]; classified as small ($0.00 \leq d \leq 0.49$), medium ($0.50 \leq d \leq 0.79$), and large ($d \geq 0.80$). Percentage changes were calculated as ([post-training value-pre-training value]/pre-training value) × 100, with the exception that for sprinting and the three change of direction tests percentage changes were calculated as ([pre-training value-post-training value]/pre-training value) × 100. The reliabilities of ability to change direction tests and sprint running performance measurements were assessed using intra-class correlation coefficients (ICC) [27]; all measurements of ability to change direction and sprinting reaching an acceptable reliability ($r > 0.80$) (Table 3). We accepted $p \leq 0.05$ as our criterion of statistical significance.

Table 3. Inter-class correlation coefficient (ICC) and coefficient of variation (CV), showing acceptable reliability for measures of track running velocity, change of direction, jump tests, static and dynamic balance tests.

Parameters	ICC	CV
Sprint		
5 m	0.90	1.8
10 m	0.87	0.9
20 m	0.89	1.8
30 m	0.85	1.4
40 m	0.90	1.6
Change of direction		
Sprint time over 9–3–6–3–9 m with 180° turns	0.91	1.8
Sprint time over 9–3–6–3–9 m with backward and forward running	0.89	1.5
Sprint time over 4 × 5 m	0.89	2.1
Jump tests		
Squat jump	0.86	5.1
Countermovement jump	0.87	5.0
Countermovement jump aimed arms	0.86	4.6
Five jump test	0.87	5.5
Y Balance Test		
Right support leg		
Right leg/Left	0.98	9.5
Right leg/Back	0.97	7.5
Right leg/Right	0.98	19.2
Left support leg		
Left leg/Left	0.98	10.3
Left leg/Back	0.98	7.6
Left leg/Right	0.97	18.2
Stork Balance Test		
Right leg	0.76	69.5
Left leg	0.88	70.6

3. Results

No pain, soreness or injury was observed during training. Test results before and after interventions are summarized in Tables 3–5 and Figures 5–7. The loaded plyometric group developed significant shortening of all sprint times relative to the control and unloaded plyometric training groups, except over a distance of 40 m (where changes were similar for the two types of plyometrics). The unloaded plyometric program yielded increases relative to control over 5 and 30 m distances.

The loaded plyometrics enhanced ability to change direction on all three tests (Table 4; Figure 5), whereas no change of performance was seen in either the unloaded plyometrics or the control groups. Both forms of plyometric training enhanced jump performance relative to controls, with no differences between the two experimental groups (Figure 6). In terms of repeated change of direction (Table 5; Figure 7), best times, decrements and total times were largely enhanced in both experimental groups relative to the controls, but the loaded plyometric training also achieved shorter mean times relative to unloaded plyometrics. In contrast, the shuttle run scores remained unchanged for all groups. The stork balance scores increased with loaded plyometrics, but the unloaded plyometric training did not enhance static balance relative to controls (Table 6). Finally, the Y-balance scores remained unchanged for all three groups.

Table 4. Inter-group comparison of sprint running, change of direction and jump performances before (pre) and after (post) the 10-week trial.

	Variables	Group	Pre-Trial	Post-Trial	p Value	d (Cohen)
Sprint	5 m (s)	Loaded plyometric group	1.17 ± 0.02	1.05 ± 0.06 $^{***,+}$	<0.001 a	1.36 (large)
		Unloaded plyometric group	1.16 ± 0.02	1.12 ± 0.05 ^{o}	<0.001 b	1.26 (large)
		Control	1.17 ± 0.02	1.18 ± 0.05	<0.001 c	1.42 (large)
	10 m (s)	Loaded plyometric group	2.12 ± 0.02	1.94 ± 0.08 $^{***,+++}$	<0.001 a	1.51 (large)
		Unloaded plyometric group	2.12 ± 0.02	2.10 ± 0.08	<0.001 b	1.34 (large)
		Control	2.12 ± 0.02	2.12 ± 0.06	<0.001 c	1.58 (large)
	20 m (s)	Loaded plyometric group	3.26 ± 0.05	3.07 ± 0.09 $^{**,+}$	0.003 a	0.85 (large)
		Unloaded plyometric group	3.27 ± 0.06	3.08 ± 0.1	<0.001 b	1.04 (large)
		Control	3.24 ± 0.07	3.25 ± 0.08	<0.001 c	1.17 (large)
	30 m (s)	Loaded plyometric group	4.55 ± 0.06	4.27 ± 0.08 $^{***,++}$	<0.001 a	1.74 (large)
		Unloaded plyometric group	4.56 ± 0.05	4.42 ± 0.15 ^{ooo}	<0.001 b	1.29 (large)
		Control	4.53 ± 0.07	4.62 ± 0.12	<0.001 c	1.5 (large)
	40 m (s)	Loaded plyometric group	5.85 ± 0.10	5.55 ± 0.13 *	0.021 a	0.68 (medium)
		Unloaded plyometric group	5.87 ± 0.09	5.68 ± 0.15	<0.001 b	1.42 (large)
		Control	5.85 ± 0.08	5.79 ± 0.24	0.027 c	0.65 (medium)
Change of direction	Sprint time over 9–3–6–3–9 m with 180° turns (s)	Loaded plyometric group	8.73 ± 0.14	8.30 ± 0.14 $^{***,++}$	<0.001 a	1.19 (large)
		Unloaded plyometric group	8.78 ± 0.14	8.54 ± 0.14	<0.001 b	1.62 (large)
		Control	8.71 ± 0.19	8.70 ± 0.13	<0.001 c	1.22 (large)
	Sprint time over 9–3–6–3–9 m with backward and forward running (s)	Loaded plyometric group	8.62 ± 0.14	8.26 ± 0.17 $^{***,++}$	<0.001 a	1.06 (large)
		Unloaded plyometric group	8.67 ± 0.14	8.47 ± 0.14	<0.001 b	1.44 (large)
		Control	8.65 ± 0.13	8.57 ± 0.13	0.004 c	0.82 (large)
	Sprint time over 4 × 5 m (s)	Loaded plyometric group	6.33 ± 0.16	6.08 ± 0.18 $^{**,+}$	0.003 a	0.85 (large)
		Unloaded plyometric group	6.38 ± 0.14	6.26 ± 0.23	0.004 b	0.71 (medium)
		Control	6.36 ± 0.13	6.37 ± 0.20	0.026 c	0.66 (medium)
Jump tests	Squat jump (cm)	Loaded plyometric group	33.7 ± 1.7	39.6 ± 2.8 ***	<0.001 a	1.03 (large)
		Unloaded plyometric group	33.4 ± 1.9	40.0 ± 2.8 ^{ooo}	<0.001 b	2.18 (large)
		Control	33.6 ± 1.7	35.0 ± 2.0	<0.001 c	1.06 (large)
	Contermovement jump (cm)	Loaded plyometric group	35.5 ± 1.7	40.2 ± 4.4 *	0.010 a	0.75 (medium)
		Unloaded plyometric group	35.2 ± 1.9	41.7 ± 3.4 ^{o}	<0.001 b	1.37 (large)
		Control	35.7 ± 1.8	36.1 ± 3.2	0.002 c	0.88 (large)
	Contermovement jump aimed arms (cm)	Loaded plyometric group	37.3 ± 1.7	44.3 ± 2.9 **	0.005 a	0.80 (large)
		Unloaded plyometric group	36.7 ± 1.6	43.9 ± 3.7 ^{o}	<0.001 b	1.87 (large)
		Control	37.5 ± 1.8	38.9 ± 4.5	0.001 c	0.94 (large)
	Five jump test (m)	Loaded plyometric group	11.5 ± 0.8	13.2 ± 0.7 **	0.005 a	0.81 (large)
		Unloaded plyometric group	11.4 ± 0.5	13.0 ± 0.8 ^{o}	<0.001 b	1.82 (large)
		Control	11.4 ± 0.6	12.0 ± 0.9	0.016 c	0.71 (large)

s = seconds; * = denotes a significant difference between loaded and control groups; + = denotes a significant difference between loaded and unloaded groups; o = denotes a significant difference between unloaded and control groups; a = denotes a main effect of group, b = denotes a main effect of time; c = denote a group × time interaction. *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$; $^{+}$: $p < 0.05$; $^{++}$: $p < 0.01$; $^{+++}$: $p < 0.001$; ^{o}: $p < 0.05$; ^{ooo}: $p < 0.001$.

Table 5. Comparison of repeated change of direction and YYIRTL1 performance between groups before (pre) and after (post) the 10-week trial.

Variables		Group	Pre-Trial	Post-Trial	*p* Value	d (Cohen)
Repeated change of direction test	Repeated change of direction-BT (s)	Loaded plyometric group	6.41 ± 0.07	6.07 ± 0.07 $^{***,+++}$	<0.001 a	2.14 (large)
		Unloaded plyometric group	6.42 ± 0.04	6.21 ± 0.07 ^{ooo}	<0.001 b	3.33 (large)
		Control	6.41 ± 0.05	6.37 ± 0.05	<0.001 c	2.09 (large)
	Repeated change of direction-MT (s)	Loaded plyometric group	6.60 ± 0.07	6.13 ± 0.80 *	0.014 a	0.72 (medium)
		Unloaded plyometric group	6.60 ± 0.07	6.50 ± 0.07	0.041 b	0.50 (medium)
		Control	6.62 ± 0.05	6.68 ± 0.07	0.025 c	0.66 (medium)
	Repeated change of direction-DEC (%)	Loaded plyometric group	4.45 ± 0.95	4.17 ± 0.45 **	0.001 a	0.93 (large)
		Unloaded plyometric group	4.23 ± 0.07	3.99 ± 1.36 ^{ooo}	0.651 b	0.10 (small)
		Control	4.67 ± 1.42	5.47 ± 0.05	0.065 c	0.56 (medium)
	Repeated change of direction-TT (s)	Loaded plyometric group	39.60 ± 0.45	38.13 ± 0.41 $^{***,++}$	<0.001 a	1.94 (large)
		Unloaded plyometric group	39.51 ± 0.48	39.07 ± 0.50 ^{ooo}	<0.001 b	1.22 (large)
		Control	39.66 ± 0.41	40.03 ± 0.34	<0.001 c	1.82 (large)
Yo-Yo intermittent recovery test level 1	Aerobic maximum speed (km.h^{-1})	Loaded plyometric group	16.5 ± 0.5	17.0 ± 0.4	0.054 a	0.58 (medium)
		Unloaded plyometric group	16.4 ± 0.4	17.0 ± 0.7	<0.001 b	0.89 (large)
		Control	16.3 ± 0.7	16.5 ± 0.5	0.609 c	0.23 (small)
	Total distance covered (m)	Loaded plyometric group	1851 ± 247	2197 ± 348	0.01 a	0.75 (medium)
		Unloaded plyometric group	1950 ± 164	2133 ± 522	0.004 b	0.71(medium)
		Control	1630 ± 427	1860 ± 415	0.715 c	0.20 b(small)

BT = best time; MT = mean time; DEC = decrement; TT = total time; s = second; YYIRTL1=Yo-Yo intermittent recovery test level 1; * = denotes a significant difference between loaded and control groups; + = denotes a significant difference between loaded and unloaded groups; o = denotes a significant difference between unloaded and control groups; a = denotes a main effect of group, b = denotes a main effect of time; c = denote a group × time interaction. *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$; $^{++}$: $p < 0.01$; $^{+++}$: $p < 0.001$; ^{ooo}: $p < 0.001$.

Table 6. Comparison of balance performance between groups before (pre) and after (post) the 10-week trial.

Variables			Group	Pre-Trial	Post-Trial	*p* Value	d (Cohen)
Y Balance Test	Right support leg	Right leg/Left (cm)	Loaded plyometric group	86 ± 8	91 ± 8 *	0.027 a	0.65 (medium)
			Unloaded plyometric group	82 ± 8	86 ± 7	0.097 b	0.40 (small)
			Control	83 ± 8	83 ± 6	0.471 c	0.29 (small)
		Right leg/Back (cm)	Loaded plyometric group	111 ± 7	118 ± 5 $^{+}$	0.014 a	0.71 (medium)
			Unloaded plyometric group	106 ± 10	110 ± 9	0.015 b	0.59 (medium)
			Control	109 ± 8	112 ± 7	0.679 c	0.21 (small)
		Right leg/Right (cm)	Loaded plyometric group	55 ± 9	60 ± 9	0.185 a	0.44 (small)
			Unloaded plyometric group	53 ± 12	53 ± 12	0.522 b	0.15 (small)
			Control	52 ± 10	52 ± 10	0.554 c	0.26 (small)
	Left support leg	Left leg/Left (cm)	Loaded plyometric group	88 ± 10	93 ± 10 $^{+}$	0.011 a	0.74 (medium)
			Unloaded plyometric group	82 ± 8	85 ± 5	0.066 b	0.44 (small)
			Control	84 ± 7	87 ± 7	0.873 c	0.12 (small)
		Left leg/Back (cm)	Loaded plyometric group	114 ± 6	121 ± 5 ***	0.001 a	0.98 (large)
			Unloaded plyometric group	109 ± 12	108 ± 10	0.286 b	0.25 (small)
			Control	113 ± 6	112 ± 7	0.155 c	0.46 (small)
		Left leg/Right (cm)	Loaded plyometric group	53 ± 8	55 ± 8	0.196 a	0.43 (small)
			Unloaded plyometric group	55 ± 11	53 ± 11	0.630 b	0.10 (small)
			Control	51 ± 11	47 ± 11	0.435 c	0.31 (small)
Stork Balance Test		Right leg (s)	Loaded plyometric group	2.24 ± 0.76	7.78 ± 4.50 *	0.022 a	0.68 (medium)
			Unloaded plyometric group	3.37 ± 2.94	4.86 ± 3.42	<0.001 b	1.00 (large)
			Control	2.16 ± 0.61	3.35 ± 2.53	0.011 c	0.74 (medium)
		Left leg (s)	Loaded plyometric group	2.08 ± 0.39	10.04 ± 6.79 **	0.008 a	0.76 (medium)
			Unloaded plyometric group	2.99 ± 2.71	6.91 ± 5.74	<0.001 b	1.13 (large)
			Control	1.78 ± 0.51	3.18 ± 3.13	0.017 c	0.70 (medium)

s = second; * = denotes a significant difference between loaded and control groups; + = denotes a significant difference between loaded and unloaded groups; a = denotes a main effect of group, b = denotes a main effect of time; c = denote a group x time interaction; *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$; $^{+}$: $p < 0.05$.

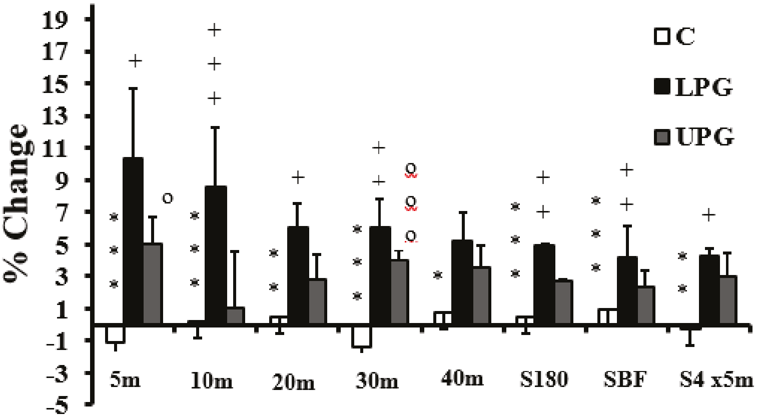

Figure 5. Training associated changes in sprint performance and ability to change direction in loaded plyometric group (LPG), unloaded plyometric group (UPG) and controls (C). S180° = sprint time over 9–3–6–3–9 m with 180° turns; SBF = sprint time over 9–3–6–3–9 m with backward and forward running; S4 × 5 = sprint time over 4 × 5 m; * = denotes a significant difference between LPG and C; + = denotes a significant difference between LPG and PG; o = denotes a significant difference between UPG and C; *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$; +: $p < 0.05$; ++: $p < 0.01$; +++: $p < 0.001$; o: $p < 0.05$; ooo: $p < 0.001$.

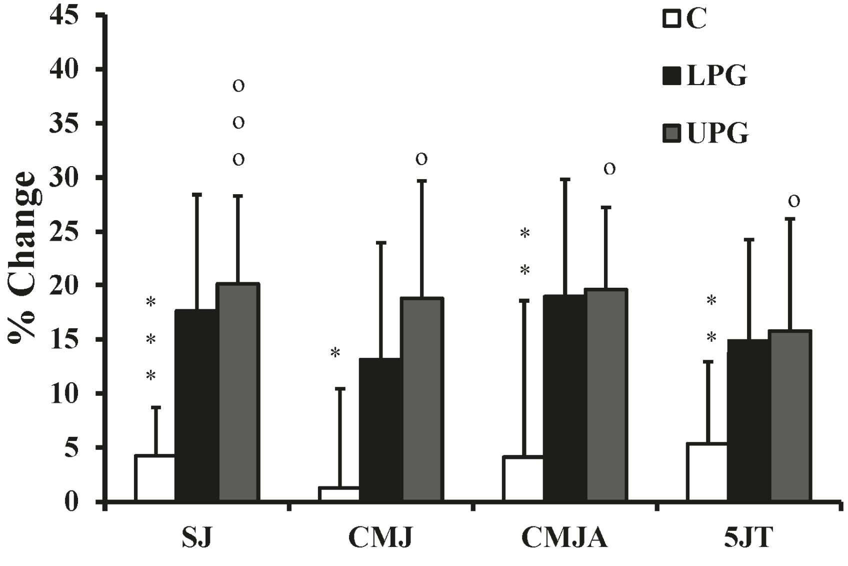

Figure 6. Training associated changes in vertical (SJ: Squat Jump, CMJ: countermovement jump: CMJ; CMJA: countermovement with aimed arms) and horizontal jumps (5JT: Five jump test) in loaded plyometric group (LPG), unloaded plyometric group (UPG) and controls (C). * = denotes a significant difference between LPG and C; + = denotes a significant difference between LPG and UPG; o = denotes a significant difference between UPG and C; *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$; o: $p < 0.05$; ooo: $p < 0.001$.

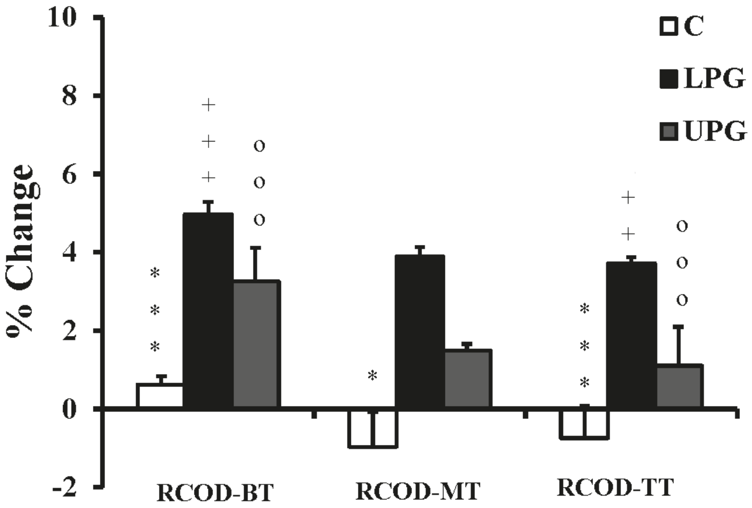

Figure 7. Training associated changes in Repeated Change of Direction (RCOD) test parameters (BT: best time; MT: Mean time; TT: Total time) in loaded plyometric group (LPG), unloaded plyometric group (UPG) and controls (C). * = denotes a significant difference between LPG and C; + = denotes a significant difference between LPG and UPG; o = denotes a significant difference between UPG and C; *: $p < 0.05$; ***: $p < 0.001$; ++: $p < 0.01$; +++: $p < 0.001$; ooo: $p < 0.001$.

4. Discussion

The aim of the present study was to compare the effects of plyometric training with and without external loading on sprinting, ability to change direction, jumping, to make repeated changes of direction, maximal aerobic power and balance of elite U-17 male soccer players at a critical phase in their playing season. On most measures, gains were similar for both experimental groups, but the loaded plyometrics yielded larger gains than unloaded plyometrics for sprinting over short distances, rapid changes of direction and static balance, all qualities useful to the soccer player.

Several previous studies have shown the effectiveness of plyometric training in improving sprint performance [8,9,13], and our present observations suggest that this response can be increased by external loading, probably because greater strength was developed by this tactic; it also seems important to introduce horizontal acceleration (skipping and jumping with horizontal displacements) [28] in order to increase sprint speeds.

Contrary to the gains in change of direction ability noted for all three tests in this study, Hammami et al. 2016 [13] found no significant change in this skill among U17 soccer players after 8 weeks of plyometric training alone, pointing to the likely value of the external loading that was used here. The rate of force development is a pre-eminent factor when changing direction [29], and the eccentric strength of the thigh muscles is also critical to the deceleration phase of impulsive movement when changing direction [30–32]. Decreased ground reaction times may also increase muscular force output and movement efficiency, positively affecting ability to change direction [29].

Previous authors have shown that combinations of plyometrics with various types of strength training increase vertical jump performance [8,9,13]. The present findings demonstrated higher jump performance in both experimental groups after training. This might be explained by an enhanced motor neuron excitability and neuromuscular adaptations [5], or better use of the stretch-shortening cycle [33].

Like us, Negra et al. 2017 [7] reported an improvement of stork balance test scores when prepubertal male soccer players undertook 8 weeks of plyometric training on a combination of stable and unstable surfaces. This response may be related to either an improved co-contraction of the lower extremity muscles [34] or changes in proprioception and neuromuscular control [6].

The current results found no improvements in predicted maximal aerobic power following the intervention. Likewise, Michailidis et al. 2019 [6] found no significant change in shuttle-run scores when youth soccer players undertook 6 weeks of a combination of soccer training, plyometric training and change of direction exercises, and De Villareal et al. 2015 [35] saw no gains of shuttle-run performance with a combination of plyometric and sprint training. However, Ramirez-Campillo et al. 2020 [8] observed increases of 20-m multistage shuttle running speed when young soccer players undertook plyometric training before or after soccer practice. Where improvements have been observed, these may reflect enhanced running efficiency [36] or an increase of tendon stiffness [5] that allows a faster transfer of force from the contracting muscles, reducing reaction times and improving the ability to change direction [5,36].

The apparent superiority of the externally loaded training probably reflects the overload principle, with the muscles showing a greater adaptive response when stressed beyond their normal capacity [37]. It may be speculated that the external loads enabled players to apply greater amounts of force against the ground over a longer time, generating higher impulses during the jumps [16], and thus facilitating greater adaptations.

Practical Applications

This study underlines that ten weeks of plyometric training with external loading enhances several attributes important to soccer performance to an extent greater than the allocation of a similar time to plyometric training alone. Performance in soccer relies greatly on the strength and power of the lower limbs, and as this study has demonstrated it is practicable to incorporate a substantial volume of plyometric training with external loading into traditional in-season technical and tactical training sessions. Such initiatives induce substantial gains in several performance measures important to the playing potential of soccer players.

5. Conclusions

We conclude that the introduction of 10 weeks of in-season loaded plyometrics into the regimen of U17 male soccer players yields gains in several physical performance test scores relative to either unloaded plyometrics or the control training regimen.

Author Contributions: M.H. designed the study, conducted analyses, and wrote the manuscript. N.G., R.A., R.J.S., and K.S. assisted in acquisition, analysis and interpretation of data, and reviewed and edited the article. M.H. and M.S.C. administered the project. M.S.C. and K.S. made substantial contribution including conception and a critical revision of the article. All authors have read and agreed to the published version of the manuscript.

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Article

Relationship between Anthropometric Parameters and Throwing Speed in Amateur Male Handball Players at Different Ages

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Abstract: The objectives of this study were: (i) to analyse anthropometric parameters and throwing speed from seven meters in amateur male handball players of different ages; (ii) to know the relationship between anthropometric parameters and throwing. One hundred seventy-six male handball players (16.5 ± 5.1 years old) participated in the study, classified according to their age: senior (n = 35), U18 (n = 30), U16 (n = 37), U14 (n = 50) and U12 (n = 24). All participants were evaluated by anthropometric measurements (height, weight, body mass index, arm span, hand width) and throwing speed from 7 m standing. A one-way analysis of variance with a Bonferroni post hoc test was used to establish the differences between teams. Pearson's simple correlation coefficients were calculated between analyse anthropometric parameters and throwing speed. Multiple linear regression was used to predict the throwing speed. Only BMI was related with throwing speed in all age groups ($0.506 > r < 0.813$, $p < 0.05$). Throwing speed was predicted (24–72%) with only one or two variables in each model. The selected variables were: BMI, arm span in U16 model and height U14 model, and the BMI, arm span and height are proved to be good predictors of TS in male handball players.

Keywords: ball throwing; hand size; arm span; motor performance

1. Introduction

Throwing the ball into the opponent's goal is one of the most important actions for the achievement of sporting success in handball [1]. This technical-tactical gesture draws special attention as the goals difference between teams results in winners and losers at the end of a handball game [2–4]. It has been shown that speed and accuracy are the two most important factors while throwing the ball into the goal successfully [5]. The ball deceleration, especially when throwing further from the 9-m line, is considered a key element [6,7]. While several studies show that the increase in speed impairs accuracy [8,9].

Traditionally, it has been estimated that throwing speed (TS) depends on different factors such as technique, temporal coordination of the different body segments, and power of both upper and lower body muscle groups [10]. On the other hand, anthropometric characteristics [7,11,12], speed, and throwing accuracy [8,9] are considered as the most appropriate variables for talent detection [13].

Hand size and fingers length, influence the most on throwing in handball [14–16]. The latter allows a greater and better mastery of the ball [17] and seems to be the best indicator of throwing accuracy and shot due to its positive correlation with the maximum grip strength [18]. Additionally, hand span is commonly used as a reference in models identification in young handball players [19]. It has been reported that that other characteristics such as body size could also have a positive effecting handball [20].

Previous work have considered both throwing distances from 7 m [21–23] and 9 m [24,25]. This is due to their influence on the final result since it has been reported that the efficacy of the throws into the goal is one of the most important distinction between winners and losers [26]. Finally, the throwing from 7 m distances have been selected, since within the rules of handball [27] by simple easy execution and correct systematic repetition. Although there exist studies analyzing the evolution of body morphology over age in handball players, research examining the influence of those features on throwing speed at different ages is limited.

Consequently, the objectives of this study were: (i) to analyse anthropometric parameters and TS from seven meters in male handball players of different ages and, (ii) to know the relationship between anthropometric parameters and throwing speed.

2. Materials and Methods

A descriptive study was developed to clarify the relationship between TS (dependent variable) and anthropometric parameters (independent variables) in amateur male handball players.

2.1. Participants

One hundred seventy-six amateur male handball players participated in the study. Convenience sampling was by non-probability and non-random sampling. The participants were classified in function their age: senior (n = 35, 24.9 ± 5.2 yr), under-18 (n = 30, 17.13 ± 0.35 yr), under-16 (n = 37, 15.32 ± 0.47 yr), under-14 (n = 50, 13.7 ± 0.46 yr) and under-12 (n = 24, 11.25 ± 1.15 yr). All the subjects had knowledge and training experience in handball and in the technical gesture of the throw: senior (15.5 ± 5.6 yr), under-18 (8.2 ± 1, 15 yr), under-16 (7 ± 1.88 yr), under-14 (5.2 ± 1.80 yr) and under-12 (2.7 ± 1.45 yr).

All participants were informed in detail about the research protocol and the basic characteristics of the study as well as the possible risks related to the test execution, and informed consent in accordance with the Declaration of Helsinki was signed by all of them prior to the start of the study. Where needed, parents or other surrogates provided permission for under-18 and younger players. The recruitment was done among different handball teams in Aragon Handball Club, Spain, belonging to the different categories studied in the present study. The present study has the approval of the Alcala University, Spain, ethics committee.

2.2. Procedures

All the participants executed the same protocol under the same circumstances and were guided by a researcher. The measurements of height (m), weight (kg), and BMI (kg/m^2) were found for every participant using a weighing scale (SECA 769; SECA Corp., Hamburg, Germany) provided with a precision stadiometer (SECA 222; SECA Corp., Hamburg, Germany). All the measurements were taken with participants wearing only underwear. The anthropometric assessment followed the guidelines issued by the International Society for the Advancement of Kinanthropometry (ISAK) [28]. All measurements were made by an ISAK Level 2 anthropometrist. A technical intraobserver measurement error of 1% was considered [29]. Arm span was measured and the distance from the edge one arm (measured at the fingertips) to the other was determined by means of a Lufkin metal anthropometric tape, standing against a flat wall, 90° arm abduction, elbows and wrists extended and palms facing forward [30]. Hand span was measured and the distance from the tip of the thumb to the tip of the little finger on the outstretched hand was determined with a metal anthropometric tape (Lufkin W606PM, Apex Tool Group, Maryland, MD, USA). All the measurements have a precision of 0.001 m.

In regards with the measurement of TS, a protocol of nine standing throws was set up using only the best result for analysis. First, a standardized warm-up established by the researchers and technical staff was performed, consisting of five min of low intensity running, three min of mobility exercises and two min of active stretching and ballistic exercises. Finally, warm-up focused on throwing was developed prior to participation. Throws were performed from the seven-meter line, allowing only one foot to be lifted and never stepping on the seven-meter line, simulating a penalty throw in handball [27], with a 30-s rest between each throw, which ensures a complete recovery [31]. The TS was recorded using a high performance sports radar (Stalker Pro 2 Radar Gun, Applied Concepts, Inc./Stalker Radar, Texas, TX, USA) placed at the 9-m line, behind the player throwing the ball, and pointing to the executing arm. Only throws that entered directly into the goal, without touching the ground, were considered as valid. Molten official handballs (Molten Corp., Hiroshima, Japan) were used, (circumference: 50–60 mm; weight: 290–475 g), depending on the regulation size corresponding to the participant's age.

2.3. Statistical Analysis

The basic descriptive statistics mean and standard deviation were calculated. All the variables satisfied the tests of homoskedasticity (Levene variance homogeneity test) and normality (Kolmogorov-Smirnov test) of their distributions. One way of variance (ANOVA) was used to compare means between age groups. As significant variable effects were determined ($\alpha = 0.05$), Bonferroni post-hoc pairwise comparisons were executed to determine where the main effects occurred. The intragroup linear relationships between variables pair was examined using Pearson linear correlation. A multiple linear regression was carried out to obtain the β index stepwise selection. Correlations between arm span, hand span and BMI were found via R^2. TS was used as a dependent variable. The ranges of the variance inflation factor for all the independent variables were between 1.009 and 2.830, and they showed a small influence of collinearity. The Durbin-Watson statistic was calculated and showed that there was no autocorrelation in the residuals (the values of the statistic ranged from 1.378 to 1.627). The analysis was complemented by descriptive statistics, model fitting, estimation and confidence intervals. Relative reliability analysis was examined by the intragroup correlation coefficients (ICC). An ICC equal at or above 0.70 was considered acceptable [32]. The magnitude of between-groups differences was expressed using Cohen's d effect size (ES) [33]. The ES adopted criteria to interpret the magnitude were as follows: trivial (<0.2), small (0.2–0.6), moderate (0.61–1.2), large (>1.2) [33]. Statistical analyses were performed using the SPSS (version 25, SPSS Inc., Chicago, IL, USA, Ill). Power analysis (post-hoc) was done using G*power software, version 3.1. Using a moderate effect size of 0.1, statistical power was 0.89 (1-beta) [34,35].

3. Results

ANOVA analysis provided the differences between contiguous age groups (Table 1). Regarding TS from the 7-m line, significant differences are shown between the U16-14 ($p < 0.001$) and U14-U12 ($p < 0.001$) groups.In the intergroup analysis (Figure 1) between Senior and U18 categories, a most likely evolution is observed in the variables of TS, arm span, weight, and height. In the analysis of the relationship between U18-U16 groups, the development of BMI and weight is considered most likely. The evolution between the variables of U14 and U16 groups is considered most likely for TS, arm span, hand span and height. Ultimately, the development between U12 and U14 is considered most likely for TS, arm span, hand span, weight and height. In the intragroup analysis between Senior and U18, U16-U14 and U14-U12 categories, the relationship is considered most likely evolution. In the analysis of the relationship between U18-U16 the development is considered very likely.

Table 1. Mean (M) and standard deviation (SD) of each variable. A one-way analysis of variance (ANOVA) with Bonferroni post-hot test was used to compare means between groups.

	Senior (n = 35)	**U18 (n = 30)**	**U16 (n = 37)**	**U14 (n = 50)**	**U12 (n = 24)**	**F**	***p***	**Differences [1]**
Height (m)	1.87 ± 0.07	1.80 ± 0.06	1.80 ± 0.05	1.67 ± 0.10	1.49 ± 8.98	100.42	<0.001	U16 > U14 > U12
Weight (kg)	89.27 ± 10.45	82.06 ± 9.29	72.97 ± 11.99	58.70 ± 11.10	44.13 ± 9.52	87.80	<0.001	U16 > U14 > U12
BMI (kg/m^2)	24.65 ± 1.63	22.97 ± 1.74	21.75 ± 1.85	19.32 ± 2.29	15.49 ± 1.67	100.69	<0.001	U16 > U14 > U12
Hand span (cm)	25.35 ± 2.55	25.04 ± 1.78	22.33 ± 3.36	20.90 ± 2.97	19.60 ± 2.94	25.45	<0.001	U18 > U16
Arm span (cm)	191.14 ± 7.71	182.41 ± 10.95	181.84 ± 7.27	170.24 ± 11.08	153.02 ± 6.52	67.05	<0.001	A > U18, U16 > U14 > U12
Throw speed (m/s)	23.78 ± 1.24	23.16 ± 1.09	22.61 ± 1.29	21.37 ± 1.96	18.74 ± 1.62	54.25	<0.001	U16 > U14 > U12

[1] U18 = Under 18 age group; U16 = Under 16 age group; U14 = Under 14 age group; U12 = Under 12 age group; BMI = body mass index.

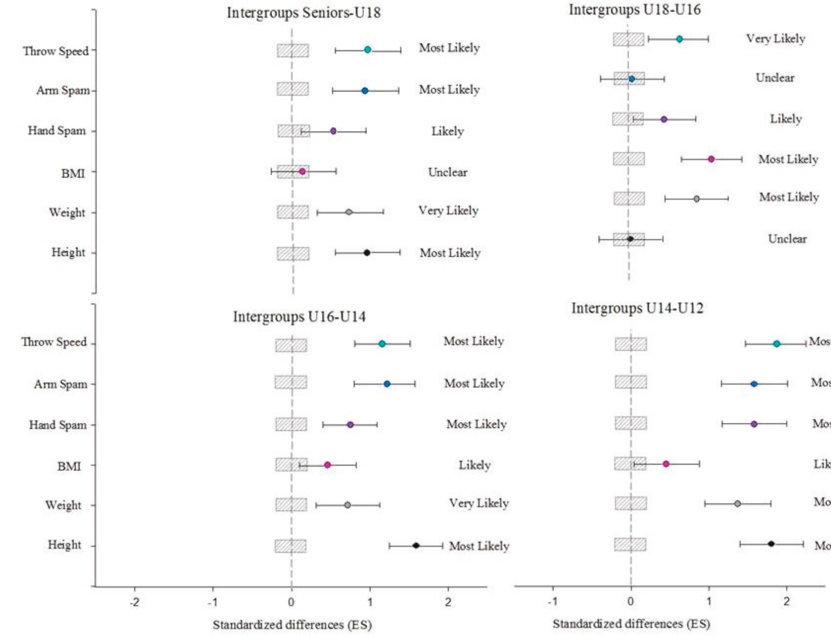

Figure 1. Cohen's d effect size (ES) between-groups.

A linear intragroup correlation (Table 2) was performed to clarify which variables are dependent and predictive of others, within each age group, focusing on the TS variable. In the Senior category, TS shows a significant correlation with the BMI of r = 0.514. Linear intragroup correlation for U18, taking TS as the reference variable (TS) also shows a significant correlation with BMI, with arm span, and height of r = 0.506, r = 0.478 and r = 0.431 respectively. For U16 players TS exhibits a significant correlation with BMI of r = 0.782, and with height of r = 0.55 and weight of r = 0.538. In the U14 group, the main predictor variable of TS is height of r = 0.785, BMI of r = 0.774 and weight of r = 0.576 and arm span r = 0.732 also shows a significant correlation. For U12 players, TS was also determined by the BMI of r = 0.813.

Table 2. Pearson's linear partial correlation for each variable.

Group [1]		Height	Weight	BMI	Hand Span	Arm Span
Senior	Height					
	Weight	0.552 **				
	BMI		0.442 *			
	Hand Span		0.750 **			
	Arm Span	0.886 **	0.563 **			
	TS			0.514 *		
U18	Height					
	Weight	0.440 *				
	BMI	0.450 *				
	Hand Span		0.902 **			
	Arm Span	0.811 **				
	TS	0.431 *		0.506 *		0.478 *
U16	Height					
	Weight	0.665 **				
	BMI	0.665 **	0.485 *			
	Hand Span		0.748 **			
	Arm Span	0.547 *		0.500 *		
	TS	0.550 *	0.538 *	0.782 *		
U14	Height					
	Weight	0.683 **				
	BMI	0.701 **	0.468 **			
	Hand Span		0.797 **			
	Arm Span	0.940 **	0.660 **	0.677 **		
	TS	0.785 **	0.576 **	0.774 **		0.732 **
U12	Height					
	Weight	0.761 **				
	BMI					
	Hand Span		0.907 **			
	Arm Span	0.916 **	0.661 *			
	TS			0.813 **		

[1] U18 = Under 18 age group; U16 = Under 16 age group; U14 = Under 14 age group; U12 = Under 12 age group; BMI = body mass index; TS, throw speed. * $p < 0.005$; ** $p < 0.001$.

The multiple linear regression model used to predict the speed throw (Table 3) the R2 values showed that the correlation between TS and BMI in all age groups studied is confirmed except in the U16. The model predicted the TS in senior group with the BMI ($\beta = 0.514$); in U18 group with the BMI ($\beta = 0.916$); in U16 group with the arm span variable ($\beta = 0.448$); in U14 group with the BMI ($\beta = 0.0514$) and the BMI and arm span ($\beta = 0.384$); in U12 group with the BMI ($\beta = 0.857$).

Table 3. Determinants of TS estimated R^2 in different age groups in male handball players.

Age Group	R^2	Adjusted R^2	Constant	Determinants	Standardized β Coefficient	*p*
Senior	0.265	0.242	14.109	BMI	0.514	<0.01
Under-18	0.838	0.832	9.963	BMI	0.916	<0.01
Under-16	0.201	0.178	8.117	Arm span	0.448	<0.05
Under-14	0.679	0.666	1.315	BMI, arm span	0.514, 0.384	<0.01
Under12	0.735	0.723	3.938	BMI	0.857	<0.01

BMI = body mass index.

4. Discussion

The purpose of the study was to analyse anthropometric parameters and TS from seven meters in amateur male handball players of different ages, to know the relationship between anthropometric parameters and TS.

According to the results obtained to compare age groups, can be seen how the anthropometric variables are more relevant in younger players and gradually lose their value based on their progression in the categories. Previous studies determined the anthropometric parameters at different ages [12,18,36,37]. Likewise, others analysed the relationship between throwing speed and anthropometric variables [11,23,38,39].

With respect to the differences between anthropometry and TS, differences between all age groups are shown. These data are consistent with studied the relationship between anthropometric parameters and age groups in male handball players from greater to lower involvement from the youngest to the oldest players, respectively [18], and female handball players [12,40]. There were differences between U16-U14 groups and between U14-U12 groups. The literature on this topic, in accordance with our study, shows that the game category, experience, and age contribute to the fluctuation in speed between handball players [18,41,42]. In general, the TS is mainly determined by BMI in all age groups, followed by height and arm span. For U12, the main predictive variable of TS is BMI, for U14 groups height, followed by BMI, arm span, and weight, showing the last two variables lower correlations. For U16 players, in order to establish the relation TS-anthropometry, the most influential variable is arm span. The greatest anthropometric determination of TS for U18 players is BMI, followed by arm span and height, exhibiting the last two variables a moderate relationship. In senior category, TS has a significant correlation with BMI.

Regarding the relation for each variables (Table 2) a large number of studies dealing with the relationship between TS and anthropometric [20,25,42], founding a positive effect between fat-free body mass and TS in experienced handball players and found relationship between TS and height in novice handball players. Nevertheless, the previous studies agree that the anthropometric variables are related to TS but, at the same time, the most determining anthropometric variable does not coincide in most of them. The results agree with those of [43] showed in elite players a significantly higher TS in all type of throw (standing throws and vertical jump throws), body height was significantly related to standing throws vertical jump throws only for senior athletes. Likewise, Zapartidis et al. [44] did not find any relationship with BMI, but a moderate correlation with hand length, arm span and body height was found, which was also the case in our study. In the intergroup analysis, the greatest deviation occurs in the comparison between U18-U16 groups. AT these ages, only weight and BMI show a most likely evolution in relation to TS. This might be due to the mismatches that occur at this stage of biological maturation. This leads us to think that anthropometric variables are more related to TS when we isolate the action from the competitive context. Nevertheless, other studies do not concur on the relationship between TS and BMI in handball players of similar category and level.

While interpreting the findings of the present study, some limitations need to be considered. First, the previous training experience was not considered, discarding, consequently, the likely contribution to the TS. Furthermore, the present protocol was performed by amateur handball players, thus, outcomes in elite handball players is unknown.

5. Conclusions

The conclusions of this study are BMI, arm span and height are proved to be good predictors of TS in amateur male handball players. However, further studies need to be undertaken in this area in order to reach a greater consensus among researchers, especially to unify what would be the anthropometric variable that mostly influences on TS in handball. The findings reported here make sport scientists and coaches clearly distinguish the different variables influencing on TS at different ages and, therefore, they facilitate their work not only on throwing improvement, but also on the return-to-play process. Hence, given that the anthropometric parameters analyzed here are easy to assess, these might be evaluated by coaches systematically over the sport career of the players allowing to know, from a practical standpoint, their evolution and the influence of body morphology on throwing speed.

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Comparisons of Accelerometer Variables Training Monotony and Strain of Starters and Non-Starters: A Full-Season Study in Professional Soccer Players

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Abstract: The purpose of this study was two-fold: (1) to describe weekly average values for training monotony (TM) and training strain (TS) and their variations across the full soccer season, based on the number of accelerations and decelerations; (2) to analyze the differences between starter and non-starter players on weekly average TM and TS values for the pre-season and three in-season periods. In total, 21 professional soccer players were evaluated over 48 weeks during the full-season. The TM and TS were calculated based on the number of accelerations and decelerations at zone 1, zone 2 and zone 3, respectively. The results revealed that starters presented higher values compared to non-starters throughout the full season for all variables analyzed (all, $p < 0.05$). Generally, there were higher values in the pre-season. Specifically, accelerations at zones 1, 2 and 3 revealed moderate to very large significance of the starters compared to non-starters over the full-season. Decelerations at zone 1, 2 and 3 presented moderate to nearly optimally significant greater weekly averages for starters compared to non-starters during the full season. In conclusion, the TM and TS values were higher for starters compared to non-starters through the full-season, which confirms that the training session does not provide a sufficient load to non-starter soccer players during the full-season.

Keywords: acceleration; deceleration; in-season; non-starters; pre-season; soccer; starters; training monotony; training strain

1. Introduction

In many sports, a full season is divided into phases that include the off-season, pre-season and in-season. The main phases are pre-season and in-season. Usually, pre-season improves the physical fitness of the players, while in-season promotes the maintenance of the capacities developed during pre-season [1,2].

In soccer science, there are several studies that focus on the maintenance of physical fitness during an entire competitive season [3] in order to assist coaches in training periodization and performance optimization, so as to avoid and/or reduce critical periods of decreased fitness [4]. In addition to the knowledge about the overall running demands of training sessions and matches, it is important to

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understand intense periods and the actions that occur (i.e., sprints, repeated sprints, accelerations and decelerations), as they have a substantial influence on the biomechanical and cardiometabolic demands experienced by players. The evidence indicates that an increasingly greater number of accelerations and decelerations is performed at higher standards, and this needs to be a consideration when designing training plans [5–10].

Moreover, in soccer there are differences in the first team squad because only 11 players can participate in a competitive match, and usually this is the day of the week with higher load [11]. This is a major aspect that determines different week loading patterns, depending on the regularity of a player starting a match or not. In this way, discrepancies in physical loads between players could lead to differences in important components of soccer-specific fitness, which may subsequently be presented on match day when players not accustomed to competitive match loads are required to complete the habitual physical loads performed by regular starting players. The challenge of maintaining squad physical fitness throughout the season is also technically difficult, given both organisational and traditional training practices inherent to professional soccer [12].

To better understand the differences between starter and non-starter soccer players, and to accomplish better training periodization and performance optimization strategies, training load should be monitored. For instance, quantifying external training loads has been extensively used and well discussed in sports, such as in soccer [13]. Through global positioning systems (GPS), there are different variables that can be assessed, such as total distance, different threshold speed distances covered, and acceleration and deceleration.

High-intensity activities (e.g., sprints, accelerations or decelerations) occur during decisive moments of soccer, such as contests for the ball, offensive or defensive actions, and goal-scoring opportunities [14,15], and may affect the match result. Therefore, coaches and researchers are constantly looking for better and more effective training methods to both improve and optimize the maximum acceleration capability of professional soccer players during linear sprinting and upon changes of direction speed. During the initial phases of sprinting, the maximum acceleration rate occurs when athletes increase their velocity [6,16,17].

However, soccer has also been reported to have a greater frequency of high and very high intensity decelerations compared to accelerations. Importantly, the damaging consequences of frequent and intense decelerations imply that specific loading strategies, to protect players from negative deceleration outcomes, may be advisable [9]. Intense accelerations and decelerations could make players particularly vulnerable to neuromuscular fatigue, and consequently to an exacerbated risk of incurring injury. Although accelerations and decelerations have substantial influence on external mechanical work [9,18], there are some discussions about the metric qualities of these variables, because they do not always provide valuable insights that give practical guidelines for training [8].

Thus, some studies provided more information when focusing on training monotony (TM: mean of training load during the seven days of the week divided by the standard deviation of the training load of the seven days) and training strain (TS: multiplication of accumulated weekly load by the TM) workload indices [19–24]. The knowledge of the variations in the load within and between weeks, and these variations' relationships with the load distribution, is very useful to understand the impact of training strategies imposed by coaches and the physiological adaptations of the players [25].

There are few analyses that include workload indices, comparisons between starters and non-starters and different phases of the season simultaneously. In addition, to the authors' knowledge, there is no exploration in the literature regarding workload indices produced through the metrics of acceleration and/or deceleration. Such information would be very practical, with a theoretical value for coaches and researchers, as it may help coaches with regard to the variations in acceleration and deceleration throughout the numerous training sessions over pre-season and in-season periods.

Therefore, the purpose of this study was two-fold: (1) to describe a weekly average for TM and TS values and their variations across the full season based on number of accelerations and decelerations;

(2) to analyze the differences between starter and non-starter players on weekly average TM and TS values, based on number of accelerations and decelerations for the pre-season and in-season periods.

2. Materials and Methods

2.1. Experimental Approach to the Problem

The study included a full season of studying a professional football team for 48 weeks in the Persian Gulf Premier League and knockout tournament in the 2018–2019 year. The 48 weeks of the full season were divided into four periods (pre-season, W1 to W5; early-season, W6 to W19; mid-season, W20 to W34; and end-season, W35 to W48) to analyze the differences between starter and non-starters player on their weekly averages. Table 1 presents training, match and total time sessions for the different periods of the season.

Table 1. Training, match and total time sessions measured separately during the periods of the season.

Variables	Pre-Season	Early-Season	Mid-Season	End-Season
Weeks (*n*)	5	14	15	14
Training Sessions (*n*)	27	64	57	52
Matches (*n*)	1	15	15	13
Total Time * (min)	1805.4 ± 602.7	4636.7 ± 1314.2	4014.0 ± 1418.3	3670.6 ± 1353.2

* Total Time = The average of the total duration for every week + the whole weeks of that phase.

This study monitored all the players' speed activities (including training and competitions) throughout the season. The two aims of this study were as follows: (i) To describe mean/standard deviation (SD) weekly averages for TM and TS and their variations across the full season based on number of accelerations in zones 1 (AccZ1), 2 (AccZ2) and 3 (AccZ3), and the number of decelerations in zones 1 (DecZ1), 2 (DecZ2) and 3 (DecZ3). (ii) To analyze the differences between starter and non-starter players for the full season and during 4 periods of the season (pre-, early-, mid- and end-season) on weekly average TMAccZ1, TMAccZ2 and TMAccZ3, weekly average TSAccZ1, TSAccZ2 and TSAccZ3, weekly average TMDecZ1, TMDecZ2 and TMDecZ3, and weekly average TSDecZ1, TSDecZ2 and TSDecZ3.

2.2. Participants

In total, 21 professional soccer players (age, 28.3 ± 3.8 years; height, 181.2 ± 7.1 cm; body mass, 74.5 ± 7.7 kg; BMI, 22.6 ± 1.0 kg/m^2) of one team competing in the Iranian Premier League were evaluated during 48 weeks of the full season. The inclusion criteria for the participants were as follows: (i) At least three training sessions per week. The exclusion criteria were as follows: (i) The lack of player information for two weeks in a row caused it to be excluded. (ii) To match the information in terms of physical activity, goalkeepers were excluded from the study.

The criteria to define starters and non-starters were assessed week by week according to a player's attendance time at the match and training. Participants were divided into two groups, starters ($n = 10$) and non-starters ($n = 11$), considering the total playing time during the competition match of every week. To be considered as a starter, the player needed to complete at least 60 min of play during the competition.

Prior to the study, the club's official license and head coach were obtained for research and it was done by the club coaches. Prior to commencing the study, we also received the approval of the research ethics committee from University of Isfahan. All players were informed of the purpose of the study, then signed the informed consent and also followed the Helsinki Declaration.

2.3. Monitoring External Load

2.3.1. GPS Receiver Specifications

Full information on players' training sessions and matches were collected by GPSports systems Pty Ltd. (Model: SPI High Performance Unit, Canberra, Australia). This GPS model's features include the following—15 Hz position GPS, distance and speed measurement; accelerometer: 100 Hz, 16 G Tri-Axial-Track impacts, accelerations and decelerations as well as data source body load (BL); Mag: 50 Hz, Tri-Axial; dimensions: smallest device on the market (74 mm × 42 mm × 16 mm); robustness; SPI high performance unit based on Mining/Industrial Strength Electronics design; water resistance and data transmission: infra-red and weighs 56 g. Previously, it has been shown that the GPS unit, which was assayed as having a very high accuracy, showed validity and inter-unit reliability [26]. The data collected in terms of weather were in suitable GPS satellite conditions.

2.3.2. Data Collection

In each training session, the GPS device was placed vertically in the belt bag. Then, before starting the warm-up, we made sure that the green and red lights are on for GPS tracking and heart-rate tracking, respectively. At the end of each training session, the GPS unit left the place. Then the entered the dock station for the device and the eventually to transfer data to automatically entered the computer by the AMS updated software. All data full season was set and collected by Default Zone in the SPI IQ Absolutes. The following variables were collected and analyzed: Duration (DR); Accelerations Zone1 (<2 m/s^2) (AccZ1); Accelerations Zone2 (2 to 4 m/s^2) (AccZ2); Accelerations Zone3 (>4 m/s^2) (AccZ3); Decelerations Zone1 (<-2 m/s^2) (DecZ1); Decelerations Zone2 (-2 to -4 m/s^2) (DecZ2); Decelerations Zone3 (>-4 m/s^2) (DecZ3) [27].

2.3.3. Calculate Training Load

In this study, the weekly acute load (wAL) for each variable was determined for the total sessions, which was maintained per week. The following variables were obtained: (i) wAL, the accumulated daily number of variables during 1 week; (ii) weekly training monotony (wTM), the relation of wAL to SD during 1 week; (iii) weekly training strain (wTS), the multiplication of wAL by wTM. For other variables calculated by form, the weekly averages of all zone accelerations and decelerations for the in-season periods were used.

2.4. Statistical Analysis

Statistical procedures and computations were conducted using SPSS (version 25.0; IBM SPSS Inc., Chicago, IL, USA). Data are presented as mean and SD. Shapiro–Wilk and Levene's tests were applied to check the normality and homogeneity of the data, respectively. Then, inferential tests were executed. Independent samples T-test were applied to analyze between group differences in all dependent derived GPS variables for the different periods of the season. Hedge's g effect size (95% confidence interval) was also calculated. The Hopkins' thresholds for effect size statistics were used, as follows: ≤ 0.2, trivial; >0.2, small; >0.6, moderate; >1.2, large; >2.0, very large; and >4.0, nearly perfect [28]. Differences were considered significant for $p \leq 0.05$.

3. Results

Figure 1 shows an overall vision of the weekly average TM and TS variations, based on the number of accelerations (TM_{AccZ1} and TS_{AccZ1}, respectively) and decelerations (TM_{DecZ1} and TS_{DecZ1}, respectively) in the zone 1 data, across the full-season and its different periods (pre-season, early-season, mid-season and end-season) for starter and non-starter players. Overall, the highest TM_{AccZ1} and TS_{AccZ1} occurred in week 1 for both starters and non-starters. The lowest TM_{AccZ1} happened in week 30 and week 46 for starters and non-starters, respectively, while both groups presented the lowest

TS_{AccZ1} in week 29 (Figure 1A). Starters experienced the highest TM_{DecZ1} in week 27 and non-starters in week 12, while the lowest TM_{DecZ1} occurred in week 29 and week 46 for starters and non-starters, respectively. Furthermore, both groups presented the highest TS_{DecZ1} in week 2, and the lowest TS_{DecZ1} in week 29 (Figure 1B).

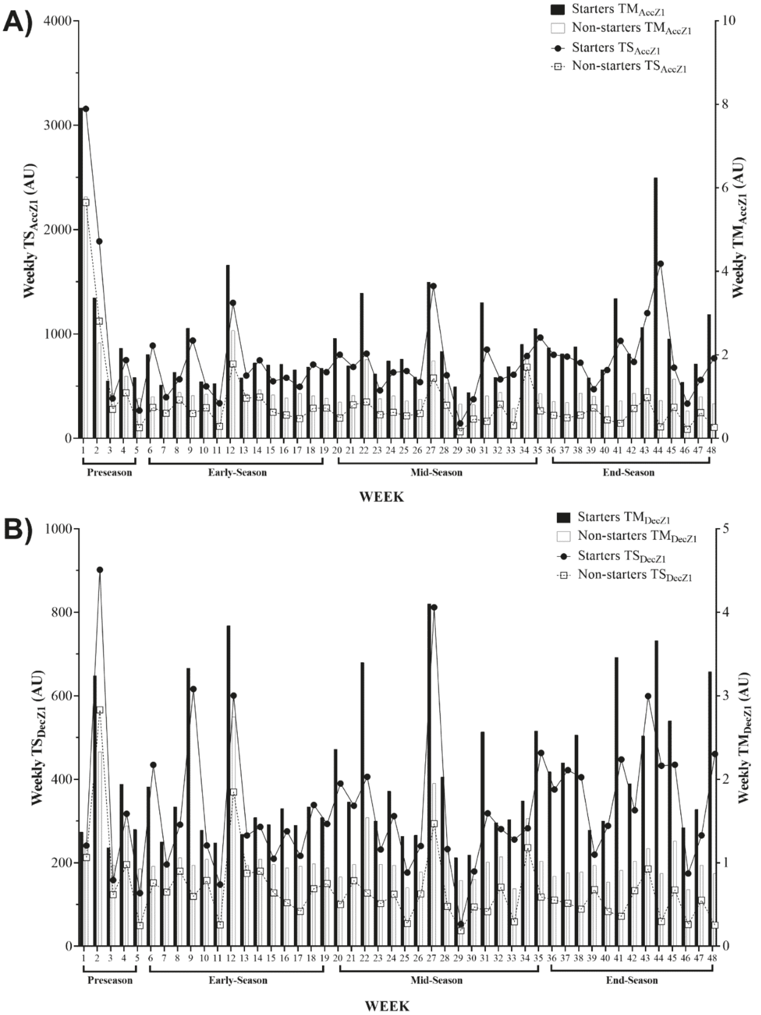

Figure 1. Descriptive statistics of weekly average for training monotony and training strain and their variations across the full season based on (**A**) number of accelerations in zone 1 (<2 m·s^{-2}) and (**B**) number of decelerations in zone 1 (>-2 m·s^{-2}). AU, arbitrary units; TM_{AccZ1}, weekly training monotony based on number of accelerations in zone 1 (<2 m·s^{-2}); TS_{AccZ1}, weekly training strain based on number of accelerations in zone 1 (<2 m·s^{-2}); TM_{DecZ1}, weekly training monotony based on number of decelerations in zone 1 (>-2 m·s^{-2}); TS_{DecZ1}, weekly training strain based on number of decelerations in zone 1 (>-2 m·s^{-2}).

Figure 2 illustrates an overall vision of the weekly average training monotony (TM) and training strain (TS) variations, based on the number of accelerations (TM_{AccZ2} and TS_{AccZ2}) and decelerations (TM_{DecZ2} and TS_{DecZ2}) in the zone 2 data, across the full season and its different periods for starter and non-starter players. Overall, the starters and non-starters presented the highest TM_{AccZ2} and TS_{AccZ2} values in weeks 12 and 2, respectively. The lowest TM_{AccZ2} happened in week 30 and week 46 for starters and non-starters, respectively. Coincidently, both groups experienced the lowest TS_{AccZ2} in week 29 (Figure 2A). Furthermore, starters presented the highest TM_{DecZ2} in week 12 and the lowest TM_{DecZ2} in week 25, while the highest and the lowest TM_{DecZ2} values were observed in week 34 and week 11 for non-starters, respectively. Coincidently, the highest and the lowest TS_{DecZ2} values arose in weeks 2 and 29, respectively, for both groups (Figure 2B).

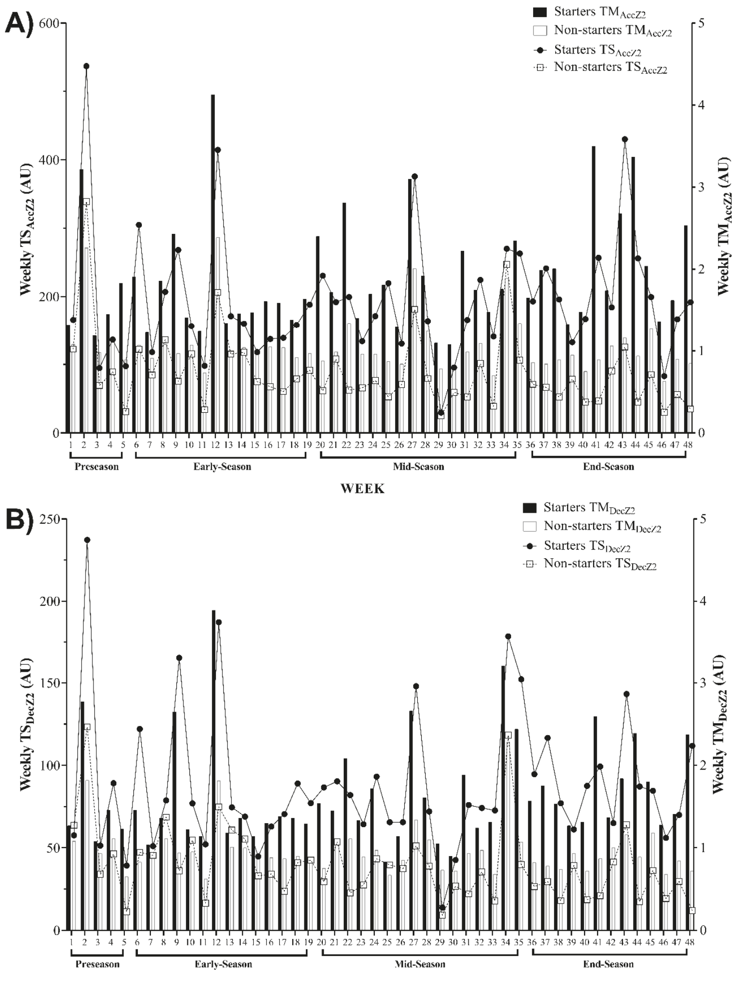

Figure 2. Descriptive statistics of weekly average for training monotony (TM) and training strain (TS) and their variations across the full season based on (**A**) number of accelerations in zone 2 (2 to 4 $m \cdot s^{-2}$) and (**B**) number of decelerations in zone 2 (−2 to −4 $m \cdot s^{-2}$). AU, arbitrary units; TM_{AccZ2}, weekly training monotony based on number of accelerations in zone 2 (2 to 4 $m \cdot s^{-2}$); TS_{AccZ2}, weekly training strain based on number of accelerations in zone 2 (2 to 4 $m \cdot s^{-2}$); TM_{DecZ2}, weekly training monotony based on number of decelerations in zone 2 (−2 to −4 $m \cdot s^{-2}$); TS_{DecZ2}, weekly training strain based on number of decelerations in zone 2 (−2 to −4 $m \cdot s^{-2}$).

Figure 3 displays an overall vision of the weekly average TM and TS variations, based on the number of accelerations (TM_{AccZ3} and TS_{AccZ3}) and decelerations (TM_{DecZ3} and TS_{DecZ3}) in the zone 3 data, across the full season and its different periods for starter and non-starter players. Overall, the highest TM_{AccZ3} values occurred in weeks 29 and 12, for starters and non-starters, respectively. Starters presented the lowest TM_{AccZ3} in week 30, while non-starters showed it in week 11. Coincidently, the highest TS_{AccZ3} values were observed in week 34 for both groups. However, starters presented the lowest TS_{AccZ3} in week 30 and non-starters showed it in week 5 (Figure 3A). Besides, non-starters showed the highest TM_{DecZ3} in week 27, while starters presented it in week 34. The lowest TM_{DecZ3} values occurred in week 30 and week 33 for starters and non-starters, respectively. Coincidently, both groups presented the highest TS_{DecZ3} in week 6, while the lowest TS_{DecZ3} was observed in week 29 for starters and week 48 for non-starters (Figure 3B).

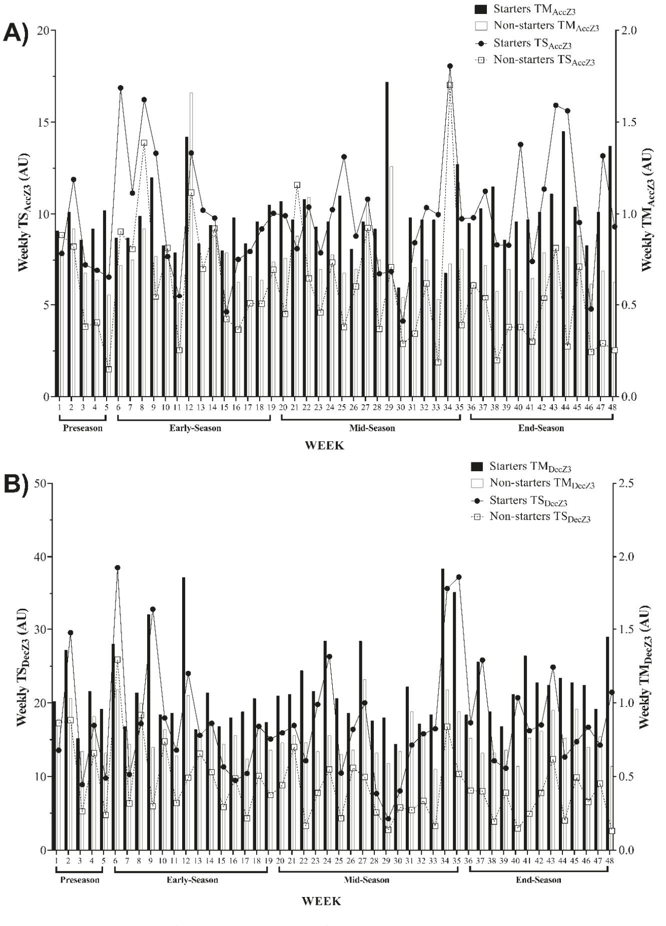

Figure 3. Descriptive statistics of weekly average for training monotony (TM) and training strain (TS) and their variations across the full season based on (**A**) number of accelerations in zone 3 (>4 m·s^{-2}) and (**B**) number of decelerations in zone 3 (<−4 m·s^{-2}). AU, arbitrary units; TM_{AccZ3}, weekly training monotony based on number of accelerations in zone 3 (>4 m·s^{-2}); TS_{AccZ3}, weekly training strain based on number of accelerations in zone 3 (>4 m·s^{-2}); TM_{DecZ3}, weekly training monotony based on number of decelerations in zone 3 (<−4 m·s^{-2}); TS_{DecZ3}, weekly training strain based on number of decelerations in zone 3 (<−4 m·s^{-2}).

Table 2 shows the between-group comparisons for weekly average TM_{AccZ1}, TS_{AccZ1}, TM_{AccZ2}, TS_{AccZ2}, TM_{AccZ3} and TS_{AccZ3} for the different periods of the season. Coincidently, the results revealed the moderately to very significantly greater weekly average TM_{AccZ1}, TS_{AccZ1}, TM_{AccZ2}, TS_{AccZ2}, TM_{AccZ3} and TS_{AccZ3} values of starters compared to non-starters during the pre-season (TM_{AccZ1}: $p = 0.015$, $g = -1.11$; TS_{AccZ1}: $p = 0.013$, $g = -1.15$; TM_{AccZ2}: $p < 0.001$, $g = 1.80$; TS_{AccZ2}: $p = 0.001$, $g = -1.62$; TM_{AccZ3}: $p < 0.001$, $g = -2.03$; and TS_{AccZ3}: $p = 0.008$, $g = -1.24$), early-season (TM_{AccZ1}: $p < 0.001$, $g = -2.67$; TS_{AccZ1}: $p < 0.001$, $g = -2.87$; TM_{AccZ2}: $p < 0.001$, $g = -2.43$; TS_{AccZ2}: $p < 0.001$, $g = 2.07$; TM_{AccZ3}: $p = 0.015$, $g = -1.12$; and TS_{AccZ3}: $p = 0.024$, $g = -1.03$), mid-season (TM_{AccZ1}: $p < 0.001$, $g = -2.86$; TS_{AccZ1}: $p < 0.001$, $g = -2.99$; TM_{AccZ2}: $p < 0.001$, $g = -2.70$; TS_{AccZ2}: $p < 0.001$, $g = -2.65$; TM_{AccZ3}: $p = 0.005$, $g = -1.33$; and TS_{AccZ3}: $p = 0.001$, $g = -1.72$) and end-season (TM_{AccZ1}: $p < 0.001$, $g = -2.62$; TS_{AccZ1}: $p < 0.001$, $g = -2.82$; TM_{AccZ2}: $p < 0.001$, $g = -2.92$; TS_{AccZ2}: $p < 0.001$, $g = -3.54$; TM_{AccZ3}: $p < 0.001$, $g = -2.82$; and TS_{AccZ3}: $p < 0.001$, $g = -3.29$).

Table 2. Differences between starters and non-starters in terms of training monotony and training strain based on acceleration-derived GPS variables in the full season and its different periods.

TLP	Season Period	Group		%Difference (Non-Starters–Starters)	p	Hedge's g (95% CI) (Non-Starters–Starters)
		Starters	Non-Starters			
TM_{AccZ1} (AU)	Pre-season	3.25 (0.62)	2.18 (1.14)	−41.0 (−60.6 to −11.8)	**0.015**	−1.11 (−2.03 to −0.19)
	Early-Season	1.87 (0.36)	1.13 (0.13)	−39.0 (−47.6 to −29.0)	**<0.001**	−2.67 (−3.85 to −1.49)
	Mid-Season	2.12 (0.37)	1.15 (0.27)	−46.1 (−55.1 to −35.3)	**<0.001**	−2.86 (−4.07 to −1.64)
	End-Season	2.48 (0.79)	0.98 (0.13)	−58.8 (−68.4 to −46.2)	**<0.001**	−2.62 (−3.79 to −1.45)
TS_{AccZ1} (AU)	Pre-season	1288.97 (265.15)	765.44 (547.51)	−56.7 (−78.0 to −15.1)	**0.013**	−1.15 (−2.07 to −0.23)
	Early-Season	659.98 (158.04)	306.50 (63.24)	−53.4 (−62.6 to −42.0)	**<0.001**	−2.87 (−4.09 to −1.65)
	Mid-Season	683.62 (153.10)	282.55 (101.83)	−59.9 (−69.2 to −47.7)	**<0.001**	−2.99 (−4.24 to −1.75)
	End-Season	793.44 (281.32)	216.63 (47.49)	−71.4 (−79.2 to −60.7)	**<0.001**	−2.82 (−4.02 to −1.61)
TM_{AccZ2} (AU)	Pre-season	1.82 (0.26)	1.19 (0.39)	−37.1 (−50.9 to −19.5)	**<0.001**	−1.80 (−2.81 to −0.78)
	Early-Season	1.76 (0.36)	1.09 (0.12)	−37.4 (−46.6 to −26.6)	**<0.001**	−2.43 (−3.56 to −1.30)
	Mid-Season	1.87 (0.27)	1.11 (0.27)	−41.5 (−50.6 to −30.8)	**<0.001**	−2.70 (−3.88 to −1.51)
	End-Season	2.10 (0.55)	0.93 (0.10)	−54.4 (−63.3 to −43.2)	**<0.001**	−2.92 (−4.15 to −1.69)
TS_{AccZ2} (AU)	Pre-season	209.71 (38.04)	112.24 (71.12)	−58.0 (−76.1 to −26.0)	**0.001**	−1.62 (−2.60 to −0.63)
	Early-Season	187.65 (55.12)	97.81 (23.62)	−47.4 (−59.6 to −31.5)	**<0.001**	−2.07 (−3.13 to −1.01)
	Mid-Season	188.62 (41.45)	87.19 (31.90)	−55.5 (−66.1 to −41.6)	**<0.001**	−2.65 (−3.82 to −1.48)
	End-Season	207.53 (54.59)	64.75 (12.88)	−68.3 (−75.1 to −59.7)	**<0.001**	−3.54 (−4.91 to −2.17)
TM_{AccZ3} (AU)	Pre-season	0.94 (0.10)	0.70 (0.13)	−26.5 (−36.0 to −15.7)	**<0.001**	−2.03 (−3.09 to −0.98)
	Early-Season	0.95 (0.14)	0.80 (0.11)	−15.4 (−25.5 to −4.0)	**0.015**	−1.12 (−2.05 to −0.20)
	Mid-Season	0.98 (0.09)	0.78 (0.18)	−21.8 (−32.4 to −9.5)	**0.005**	−1.33 (−2.28 to −0.39)
	End-Season	1.05 (0.14)	0.70 (0.09)	−33.1 (−40.7 to −24.5)	**<0.001**	−2.82 (−4.03 to −1.61)
TS_{AccZ3} (AU)	Pre-season	8.09 (2.40)	4.86 (2.59)	−46.8 (−65.6 to −17.6)	**0.008**	−1.24 (−2.18 to −0.31)
	Early-Season	10.17 (3.14)	7.24 (2.31)	−29.7 (−47.6 to −5.7)	**0.024**	−1.03 (−1.94 to −0.12)
	Mid-Season	9.65 (1.60)	6.12 (2.25)	−39.5 (−53.2 to −21.9)	**0.001**	−1.72 (−2.72 to −0.72)
	End-Season	10.61 (2.31)	4.35 (1.23)	−59.9 (−68.7 to −48.7)	**<0.001**	−3.29 (−4.61 to −1.98)

Abbreviations: TLP, training load parameters; AU, arbitrary units; TM_{AccZ1}, weekly average training monotony based on number of accelerations in zone 1 ($<2\ m\cdot s^{-2}$); TS_{AccZ1}, weekly average training strain based on number of accelerations in zone 1 ($<2\ m\cdot s^{-2}$); TM_{AccZ2}, weekly average training monotony based on number of accelerations in zone 2 (2 to 4 $m\cdot s^{-2}$); TS_{AccZ2}, weekly average training strain based on number of accelerations in zone 2 (2 to 4 $m\cdot s^{-2}$); TM_{AccZ3}, weekly average training monotony based on number of accelerations in zone 3 ($>4\ m\cdot s^{-2}$); TS_{AccZ3}, weekly average training strain based on number of accelerations in zone 3 ($>4\ m\cdot s^{-2}$); p, p-value at alpha level 0.05; Hedge's g (95% CI), Hedge's g effect size magnitude with 95% confidence interval. Significant differences ($p \leq 0.05$) are highlighted in bold.

Table 3 shows the between-group comparisons for weekly average TM_{DecZ1}, TS_{DecZ1}, TM_{DecZ2}, TS_{DecZ2}, TM_{DecZ3} and TS_{DecZ3} values for the different periods of the season. Similar to the outcomes obtained for parameters based on accelerations, moderate to nearly perfect significantly greater weekly average TM_{DecZ1}, TS_{DecZ1}, TM_{DecZ2}, TS_{DecZ2}, TM_{DecZ3} and TS_{DecZ3} values were derived from the starters compared to non-starters during the pre-season (TM_{AccZ1}: $p = 0.003$, $g = -1.43$; TS_{AccZ1}: $p = 0.002$, $g = -1.52$; TM_{AccZ2}: $p < 0.001$, $g = -1.78$; TS_{AccZ2}: $p = 0.002$, $g = -1.55$; TM_{AccZ3}: $p = 0.003$, $g = -1.48$; and TS_{AccZ3}: $p = 0.048$, $g = -0.89$), early-season (TM_{AccZ1}: $p < 0.001$, $g = -2.72$; TS_{AccZ1}: $p < 0.001$, $g = -2.75$; TM_{AccZ2}: $p < 0.001$, $g = -2.84$; TS_{AccZ2}: $p < 0.001$, $g = -2.35$; TM_{AccZ3}: $p < 0.001$, $g = -2.48$; and TS_{AccZ3}: $p < 0.001$, $g = -1.84$), mid-season (TM_{AccZ1}: $p < 0.001$, $g = -3.63$; TS_{AccZ1}: $p < 0.001$, $g = -3.53$; TM_{AccZ2}: $p < 0.001$, $g = -2.95$; TS_{AccZ2}: $p < 0.001$, $g = -2.85$; TM_{AccZ3}: $p < 0.001$, $g = -2.29$; and TS_{AccZ3}: $p < 0.001$, $g = -2.20$) and end-season (TM_{AccZ1}: $p < 0.001$, $g = -2.85$; TS_{AccZ1}: $p < 0.001$, $g = -3.21$; TM_{AccZ2}: $p < 0.001$, $g = -3.37$; TS_{AccZ2}: $p < 0.001$, $g = -4.56$; TM_{AccZ3}: $p < 0.001$, $g = -2.98$; and TS_{AccZ3}: $p < 0.001$, $g = -3.33$).

Table 3. Differences between starters and non-starters in terms of training monotony and training strain based on deceleration-derived GPS variables in the full-season and its different periods.

TLP	Season Period	Group		%Difference	*p*	Cohen's *d* (95% CI)
		Starters	Non-Starters			
TM_{DecZ1} (AU)	Pre-season	1.82 (0.19)	1.31 (0.44)	−32.3 (−48.1 to −11.7)	**0.003**	−1.43 (−2.39 to −0.47)
	Early-Season	1.80 (0.33)	1.09 (0.16)	−39.3 (−48.2 to −29.0)	**<0.001**	−2.72 (−3.91 to −1.53)
	Mid-Season	1.98 (0.27)	1.06 (0.22)	−46.9 (−54.6 to −38.0)	**<0.001**	−3.63 (−5.02 to −2.24)
	End-Season	2.33 (0.67)	0.94 (0.12)	−58.2 (−67.3 to −46.5)	**<0.001**	−2.85 (−4.06 to −1.63)
TS_{DecZ1} (AU)	Pre-season	349.37 (42.58)	208.15 (116.22)	−52.0 (−72.0 to −17.8)	**0.002**	−1.52 (−2.49 to −0.55)
	Early-Season	315.25 (74.37)	151.32 (35.13)	−52.1 (−62.3 to −39.2)	**<0.001**	−2.75 (−3.95 to −1.56)
	Mid-Season	310.75 (62.22)	122.72 (38.47)	−61.6 (−69.9 to −50.9)	**<0.001**	−3.53 (−4.90 to −2.16)
	End-Season	373.32 (114.88)	103.09 (22.17)	−71.5 (−78.5 to −62.3)	**<0.001**	−3.21 (−4.51 to −1.92)
TM_{DecZ2} (AU)	Pre-season	1.56 (0.19)	1.07 (0.32)	−34.1 (−47.7 to −17.1)	**<0.001**	−1.78 (−2.79 to −0.77)
	Early-Season	1.56 (0.26)	0.97 (0.11)	−37.2 (−45.5 to −27.7)	**<0.001**	−2.84 (−4.06 to −1.63)
	Mid-Season	1.65 (0.24)	1.01 (0.17)	−38.9 (−47.0 to −29.5)	**<0.001**	−2.95 (−4.19 to −1.72)
	End-Season	1.73 (0.33)	0.88 (0.12)	−48.8 (−56.7 to −39.5)	**<0.001**	−3.37 (−4.70 to −2.04)
TS_{DecZ2} (AU)	Pre-season	94.91 (24.53)	50.88 (29.47)	−54.9 (−72.8 to −25.2)	**0.002**	−1.55 (−2.53 to −0.58)
	Early-Season	87.25 (20.56)	45.25 (13.33)	−48.9 (−60.9 to −33.3)	**<0.001**	−2.35 (−3.47 to −1.24)
	Mid-Season	86.08 (18.99)	38.33 (12.96)	−56.9 (−67.1 to −43.5)	**<0.001**	−2.85 (−4.06 to −1.63)
	End-Season	89.15 (28.96)	28.96 (6.29)	−67.6 (−73.7 to −60.1)	**<0.001**	−4.56 (−6.18 to −2.94)
TM_{DecZ3} (AU)	Pre-season	1.03 (0.11)	0.80 (0.18)	−23.9 (−35.8 to −9.7)	**0.003**	−1.48 (−2.44 to −0.51)
	Early-Season	1.08 (0.09)	0.81 (0.12)	−25.4 (−32.8 to −17.2)	**<0.001**	−2.48 (−3.61 to −1.34)
	Mid-Season	1.14 (0.19)	0.78 (0.11)	−31.4 (−40.4 to −21.1)	**<0.001**	−2.29 (−3.39 to −1.19)
	End-Season	1.11 (0.16)	0.74 (0.07)	−32.7 (−39.8 to −24.7)	**<0.001**	−2.98 (−4.23 to −1.74)
TS_{DecZ3} (AU)	Pre-season	15.76 (4.63)	10.77 (5.99)	−40.0 (−61.9 to −5.6)	**0.048**	−0.89 (−1.79 to 0.01)
	Early-Season	17.88 (3.47)	10.64 (4.03)	−43.4 (−57.5 to −24.8)	**<0.001**	−1.84 (−2.86 to −0.82)
	Mid-Season	17.36 (5.33)	7.98 (2.54)	−54.3 (−66.0 to −38.5)	**<0.001**	−2.20 (−3.28 to −1.11)
	End-Season	17.38 (4.22)	6.77 (1.30)	−60.7 (−68.4 to −51.0)	**<0.001**	−3.33 (−4.66 to −2.01)

Abbreviations: TLP, training load parameters; AU, arbitrary units; TM_{DecZ1}, weekly average training monotony based on number of decelerations in zone 1 ($> -2\ m{\cdot}s^{-2}$); TS_{DecZ1}, weekly average training strain based on number of deceleration in zone 1 ($> -2\ m{\cdot}s^{-2}$); TM_{DecZ2}, weekly average training monotony based on number of decelerations in zone 2 (-2 to $-4\ m{\cdot}s^{-2}$); TS_{AccZ2}, weekly average training strain based on number of accelerations in zone 2 (2 to $4\ m{\cdot}s^{-2}$); TM_{DecZ3}, weekly average training monotony based on number of decelerations in zone 3 ($< -4\ m{\cdot}s^{-2}$); TS_{DecZ3}, weekly average training strain based on number of decelerations in zone 3 ($< -4\ m{\cdot}s^{-2}$); *p*, *p*-value at alpha level 0.05; Hedge's *g* (95% CI), Hedge's *g* effect size magnitude with 95% confidence interval. Significant differences ($p \leq 0.05$) are highlighted in bold.

4. Discussion

The aims of this study were as follows: (1) to describe TM and TS and their variations across four periods of the season, based on the number of accelerations and decelerations; (2) to analyze the differences between starter and non-starter players in terms of TM and TS based on the number of accelerations and decelerations across four periods of the season. The first aim was accomplished and can be observed in Figures 1–3. Moreover, as expected, a major finding revealed a meaningful variation in the workload indices of starters and non-starters.

Regarding the variations described in Figures 1–3, there are some coincident findings that should be highlighted. The highest TM_{AccZ1} and TS_{AccZ1} occurred in week 1 for both starters and non-starters. These results were expected for the first week of training sessions (pre-season), whereat a possible higher training load was applied. Although it was not a purpose of this study to compare different periods of the season, the results are in line with some studies [19,20,29], which means that the exercise training program, early in the pre-season, focused on improving physical condition through a higher training load [30].

Then, a relevant variation occurred in the second week, wherein the TS_{DecZ1} and TS_{AccZ2} values were revealed to be the highest through the full-season. On week 6, the highest TS_{DecZ3} occurred for both starters and non-starters. A "w-shape" remained until week 12, when the highest TM_{AccZ2} occurred for starters and non-starters, and the highest TM_{DecZ2} for starters and the highest TM_{AccZ3} for non-starter occurred. Moreover, a "w-shape" remained until week 27, whereat the starters experienced the highest TM_{DecZ1} and non-starters showed the highest TM_{DecZ3}. Then, on week 29, the lowest TS_{AccZ1} and the lowest TS_{DecZ1} occurred for starters and non-starters. The lowest TM_{DecZ1} also occurred for starters in the same week. Then, the lowest TS_{DecZ2} and TS_{AccZ2} for both starters and non-starters, and the lowest TS_{DecZ3} for starters, occurred in week 29 for all. On week 29, the lowest TM_{AccZ3} occurred, and on week 30 the lowest TM_{AccZ1} and TM_{DecZ3} occurred for starters. In this week, TM and TS showed a higher tendency towards lower loads for non-starter players, which could be associated with the end of the season and the importance given to starter players when compared to non-starter players.

While for the beginning of the season (pre-season) it is easy to explain the results via the similarities between starters and non-starters in the weeks with higher TM and TS, it is not clear why there is an overall "w-shape" through the season. There are some contextual variables, such as match location, match result, quality of the opponent, tactic system and exercise training program applied, which could explain the data. Contextual factors, such as tactical formation, strength of opposition and match stoppages, may influence overall workloads during matches, and consequently have an impact on the previous or next training sessions. The evidence indicates that players competing in some match formations (3–5–2) could cover more total distance and perform higher-speed running, as well as performing more accelerations/decelerations compared to other formations [31].

In fact, few studies used this approach of calculating TM and TS [19–21,23]. Lazarus et al. [23] found that TM and TS revealed trivial effects on Australian soccer training performance. The same authors showed that the variations in those indices were difficult to understand, as they were in the present study. Delecroix et al. [21] showed that a regular workload is an injury-protective factor, while high TS is a risk factor when it is sustained for four weeks. As mentioned before, our study presented a "w-shape" that could have possible negative effects on the players, but injuries were not analyzed. In opposition to the studies of Clemente et al. [19,20], where TM showed a tendency to decrease as the weeks progressed, the present study did not present the same pattern. Indeed, there were variations throughout the full season. However, it is important to highlight that the present study used acceleration and deceleration to calculate TM and TS, and the previous studies mentioned [19–21,23] used session rate of perceived exertion (s-RPE).

Although all comparisons between starters and non-starters in the various acceleration and deceleration thresholds are statistically different, the objective for this team's pre-season training may have been to establish a chronic load, which was reduced in the early-season and in other periods throughout the competitive season. It is likely that this reduction in strain in some periods of the season was a deliberate attempt to reduce training volume, provide adequate recovery and maintain fitness and freshness. There are several contextual factors that could also influence this reduction in training load (training strain) during some portions of the season (e.g., congested match schedule, playoffs, and increased injury rate).

With respect to the second aim of the study, it is important to acknowledge that the soccer game has developed in the last few years. Players have more tactical responsibilities whilst in and out of possession and during ball possession transitions [32]. With such roles, players must be able to perform frequent intense acceleration and deceleration actions. High-intensity accelerations and decelerations are two very important metrics of external load. Both make distinctive and disparate internal physiological and mechanical loading demands on players [33]. On one hand, a higher metabolic cost emerges with acceleration [34]. On the other hand, a higher mechanical load manifests with decelerations [7] through the high impact peaks, loading rates [35] and possibly higher damage on soft-tissue structures [36]. This is why the frequency of accelerations and decelerations is associated with reductions in neuromuscular performance after the matches [37]. Even with the non-positive effects presented, elite players can perform a higher number of accelerations and decelerations than the lower-level players [38]. This statement can help to understand the differences between starters and non-starters in the present study. Overall, starters presented significatively higher values of TM and TS through the four periods of the season. This finding reinforces that the training load applied to non-starter players was not enough to produce more adaptations and to ensure players evolved as the weeks progressed. Coaches and their staff need to adjust their exercise training programs in order to develop and to apply similar loads to non-starter players.

Although Anderson et al. [12] reported that in the English Premier League, non-starters performed significantly less running (14.4–19.8 km/h), high speed running (19.9–25.1 km/h) and sprinting (>25.2 km/h) than starter players, in the present study, the analysis of movements of high demand and neuromuscular wear, such as accelerations and decelerations, showed significant differences between both groups. The results are indicators that monitoring training load must be carried out while considering the different metrics available to coaches and technical teams.

Some limitations should be addressed. The small sample size regarding number of players and teams analyzed constitute a limitation in the present study, but these issues are frequent in longitudinal studies over a full season in professional contexts, as reported by Clemente et al. [19]. Furthermore, differences in player positions were not analyzed, and this could influence the data analysis. There could also possibly exist different results if they were analyzed. For instance, the study of Clemente et al. [19] found small-to-moderate effect size differences for the number of sprints in acute load, TM and TS through different external load metrics. Moreover, the present study does not consider individual differences in acceleration and deceleration capacities, which can result in different results [5].

It is relevant to mention that when accelerometers are worn on the upper body, as they were in the present study, the crania–caudal axis of the accelerometer will likely only be close to equivalent with the global vertical axis when standing up-right or performing movements in the vertical plane. Any deviation from the assumed vertical orientation of the device may influence the accelerometer’s accuracy.

Finally, as reported in the Clemente et al. [19] study, internal load, s-RPE, was not used and usually this variable is used to calculate training monotony and training strain which was not the purpose of the present study. Finally, this study did not consider the results of the match that may affect the collective behavior and, naturally, the demands imposed on players. Further research should analyze the impact of the matches as well as the competitive level of the team in analyses of workload.

Despite the limitations mentioned, this study was one of the first to analyze the variations in TM and TS between periods of the season, as well as between starters and non-starters through the acceleration and deceleration metrics.

This study provides further knowledge regarding the variation profiling of acceleration and deceleration metrics during an entire soccer season. As it has been reported, a high frequency of rapid decelerations leaves players vulnerable to muscle damage and to chronic fatigue, which can lead to reductions in the performance of activities such as sprinting and changing direction [39]. Understanding how specific training sessions, match-play activities and contextual factors (e.g., formation model, play away or at home, opponent level) may influence player fatigue and recovery profiles is significantly relevant to practitioners/coaches.

The evident unpredictability of loads associated with decelerating rapidly also has important implications for the management of loads throughout the season; as suggested in Harper et al.'s [36] study, exercise training sessions should include specific exercises for offensive linesmen, which target the development of the neuromuscular capabilities required to produce and attenuate the high forces associated with decelerating rapidly or the braking forces during emergent and unpredictable situations.

Status differences should also be taken into account when planning and prescribing training loads across a full season.

5. Conclusions

Soccer involves a higher frequency and number of accelerations and decelerations, so training activities and match requirements must be managed throughout the microcycles by controlling the monotony and strain of the training load. This study gives new insights concerning the variation profiling of TS and TM, calculated through the accelerations and decelerations during the full season. It shows that there are significant differences between starters and non-starters in the four different periods analyzed during the full-season. Furthermore, there are some physiological adaptations that do not occur when players do not participate in matches. They correspond to the higher loads that are not reached on training sessions. Considering this information and the variability of the TM and TS presented, it is important for coaches, practitioners and scientists to monitor the demands imposed on their own group of players in order to better periodize and plan training sessions, and impose the proper load on starter and non-starter players throughout the full-season.

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Article

Power, Muscle, and Take-Off Asymmetry in Young Soccer Players

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Abstract: (1) Background: The objective of the study was to check the relationship between laterality, amount of muscle mass (MM), and selected strength parameters on lower extremities and assessment of asymmetry like a result of training. (2) Methods: The screened sample consisted of soccer players (n = 65, age = 16.0 ± 1.2 years). The legs were assessed for MM, height of reflection on a force plate, and power over 30 s Wingate anaerobic test (WAnT). The relationships between the individual parameters and age dependence were assessed using a correlation analysis. The differences between the dominant and non-dominant leg were assessed using the t-test. (3) Results: A relationship between the jump height and the mean 30 s power in WAnT ($r = 0.375$, $p < 0.01$) and between the amount of MM and the absolute power of the individual legs in WAnT (r = 0.695–0.832, $p < 0.01$) was proved. A relationship between the take-off force and the MM, or between the MM and the relative power during a velocity force load was not found. (4) Conclusions: The amount of MM in young soccer players does not affect take-off force or strength power in WAnT. The more specific the movement is, the lower the effect on the achieved power output of the concerned MM. Differences in the performance between the dominant and non-dominant leg decrease with duration of the training.

Keywords: asymmetry; soccer; strength; youth; muscles

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1. Introduction

Lateralization that developed during human evolution has an internal and external background. It is especially manifested in the preference for one upper or lower limb in relation to motor skills and it influences the execution of the movement as well as the achieved power output [1,2]. About 90% of the population prefer their upper right limb for both working and physical activities [3,4]. Only 25–45% of people prefer their lower right limb for realization, for example jumping [3]. The preference of the lower limb might be influenced by the need for higher cerebral activation compared to upper limb movement [5]. The distal position of the lower limb muscles may also play a role [6]. Laterality is also influenced by various factors of the human body (genetics) and the environment (e.g., birth stress, hormonal activity) that may affect its form, even in the early postnatal period [7]. Structural asymmetry is considerably higher in men than in women [8].

Laterality plays an important role in a lot of sports that significantly use one of the limbs during exercise (ice hockey, tennis, etc.) including soccer. There is a relationship and transfer between the laterality of the upper and lower limbs [9]. Considering the ever-increasing pace of the game, players who are able to play with both legs have an advantage [10,11]. Therefore, players who use both legs are more useful in the game and they are much more valuable for the team than players with one leg preference [12]. According to some studies, the ability of players to play with both legs increases considerably with the increasing level of players and the time of performed intense training [13]. Additionally, the differences in the engagement and effectiveness of the dominant and non-dominant leg in ice-hockey have been studied [14]. In soccer, there are studies with similar topics [15] that did not register any strength differences between the preferred and non-preferred lower limb in adult female soccer players. The occurrence of bilateral knee flexor asymmetries at higher angle speeds was an important finding. It was found that there is at least one force asymmetry in 50% of players (bilateral knee flexor). In addition, an obvious leg preference in mobilization and stabilization tasks was found both in soccer players and in those who do not play soccer [16]. Among elite soccer players lower limb preferences can differ according to playing position [17].

Walking and running as a part of soccer performance are basic physical activities; they have a bipedal character and thus do not promote the development of differences between the limbs. The morphology of the limbs is affected by the duration of which the individual performs the procedure with only one limb. This time in soccer is negligible compared to some other sports (tennis, javelin throw, hockey, etc.). Currently, basically the entire content of the training leads to even development of the preferred and non-preferred lower limb in soccer players [18]. When comparing the level of difference in soccer players at various performance levels, insignificant differences between the one-foot jump distance and between the speed of repeated one-foot jumps were found [19]. The higher the level of the athletes (including soccer players), the lower their preference for their dominant limb in specific skills [10]. Physical development during adolescence influences the level of players [20] and the improved physical performance may minimize the scope of asymmetry and thus improve injury prevention [2]. The pursuit of a movement and structural balance is important in sports from a medical perspective as well, as some asymmetries may increase the risk of injury [21].

With the exception of some internal organs, man is symmetrical due to development. Asymmetry is tolerable, to some extent the individual compensates for it. If it exceeds the tolerable limit, the probability of injury increases significantly. Therefore, there are reasons to support the symmetrical development of the individual in the vast majority of sports. With asymmetrical movement, imbalances arise. They are based on an asymmetry in the amount of muscle mass, with some muscles shortening and some muscles weakening. In the event of a difference in the amount of muscle mass (MM) between the limbs, one limb may be overloaded, resulting in greater fatigue that may increase the risk of tissue damage and injury [21,22].

In trained athletes with good speed predispositions, the force in the execution of a physical activity based on take-off may be a more important factor than speed [23]. The motor performance of legs assessed by the Bosco Jump Test and Wingate anaerobic test (WAnT) is influenced by the maturity level of the assessed individuals, namely leg muscle development [24]. Both tests (the two-foot Bosco test and WAnT) correlate with increasing age [25]. The magnitude of the force executed by the striated skeletal muscle usually depends on the cross-section of the muscle [26,27]. This is used in sports where training is aimed to increase the muscle cross-section and where maximal hypertrophy is desirable [27–29]. However, there are sports where hypertrophy is not the goal, such as tennis, but where, from the point of view of laterality, one-sided specific training is reflected in the volume and quality of muscle mass [30]. The force should always be assessed in a specific manifestation. There is no dependence between the amount of muscle mass (MM) and the physical manifestation in the entire scope of the executed load intensity in athletes where a skill element is dominant in the execution of the physical activity. The volume of MM is only a necessary, not a sufficient condition for the physical activity, and the magnitude of the force is only a condition to some extent [28,31,32].

The basic objective in soccer training is to achieve a specific physical skill, while maximal muscle cross-section or maximal hypertrophy are not the objective. This means achieving a cross-section of the concerned muscles that ensures the execution of the required physical activity, which is optimal, not the maximal increase in the muscle cross-section. In this case, nervous coordination-adaptation is dominant [31]. Unlike other sports such as tennis [30], the training load of soccer players does not contain such an amount of specific load of the dominant limb, but there is an effort to evenly engage both limbs [33]. Movement skills in soccer performance are essential. Neuromuscular adaptation in sports where it plays a dominant role (in sports that are more demanding on coordination—skill-based), requires the force training to focus specifically on cultivating crucial physical skills [34]. Jump is one of the most frequently occurring game acts of a soccer player. Therefore, strength training in soccer is also aimed at while achieving the highest strength performance—jump height [35,36]. There is a minimal muscle hypertrophy in the specifically focused strength training [27,32,37–39]. The jump height and its changes depend on gender, age, and performance increases with age [40]. Soccer training focuses on cultivating specific physical skills; it influences the preferred physical skills, and the development of fitness is not primary. The development of "general" physical skills has to reach a level that is essential for the execution of specific soccer performance [31]. In general, it is not true that a higher level of force and speed potential leads to higher specific soccer performance. There are also different requirements for players at different positions [41]. The objective of this study was to determine the connection between laterality, amount of MM, speed-force performance, and training duration (the age of players) in top-level adolescent soccer players, and also to determine whether laterality (limb preference) affects the amount of MM. One of the goals was also to assess asymmetry as a result of training. This could be important for muscle morphology and also in order to prevent muscle disabilities and thus for injury prevention and the selection of training methods.

This study will verify whether laterality affects the morphological (MM) and functional (strength) parameters of young soccer players.

2. Materials and Methods

2.1. Subjects

The screened sample consisted of young players of the highest national league club, members of the teams U16–U19 category ($n = 65$, age = 16.0 ± 1.2 years, body height = 179.0 ± 6.5 cm, body mass = 71.0 ± 8.9 kg). Concerning the playing positions, the following players were assessed: eight goalkeepers, 15 defenders, 19 midfielders, and 23 attackers. To be included in the set of participants the following criteria must be fulfilled: active players in national sports level, age 15–18 years, and good health throughout last 2 months, without injuries throughout last 6 months.

All participants had been playing soccer since the age of 10; their average training load ranged from 12 to 16 h per week. The testing took place in the Laboratory of Load Diagnostics at DPSS FE FEU at the beginning of the competition period. Participants were not injured or rehabilitating from injury at time of testing.

2.2. Measures and Design

The dominant and non-dominant leg and hand were set, date of birthday was determined, as well as their player position. Players marked their preferred lower limb for kicking and jumping (confirmed by the coach) and their preferred hand for writing. The laboratory evaluation started by body composition assessment. Five minutes after that, take-off was measured. WAnT was used about 5 min after the jump test.

The body composition, including the amount of MM of individual legs, was measured by way of a Tanita BC 418 MA (Tanita Corp., Tokyo, Japan), and data were assessed by firm's software. All participants were measured in the same time period (3–5 p.m.), before training, at least 3 h after lunch, without caffeine, for at least 1 h without drinking. The water intake was controlled during at 24 h before the evaluation.

The take-off from the right and left leg was then measured on a take-off board (Lode, Groningen, The Netherlands), which consists of a digital timer (maximum response time 10 ms) connected to a resistive platform. The flight time of the subject during the jump was thus measured. Take-off was performed from a squat position (knee angle at 90%), hands on hips. This design is standardized for take-off from both legs [17]. The test–retest (the take-off from the right and left leg) analysis revealed a high level of reliability between the two testing sessions ($r = 0.907$).

The strength parameters were evaluated on an Excalibur sport bicycle ergometer (Lode, Groningen, The Netherlands). A 5-min warm-up on the bicycle was followed by a 30 s all-out test. The test was used to determine the maximum relative power in 1 s and 30 s in each leg.

The goal of present study was to assess the relationship, influence of laterality on preference of the lower limb, the amount of MM, jumping abilities, and strength abilities in top level youth soccer players. The size of the difference in amount of MM between the left and right lower limb and the differences in the motor performance between the dominant and non-dominant leg was determined. The relationship between muscles mass on each lower limb, the level of jumping force, and WAnT performance was investigated as well as differences between the preferred and non-preferred lower limb. The differences between players of different ages, positions, and preferred lower limbs were also investigated.

2.3. Statistical Analysis

The data are represented as the average and the standard deviation (SD), unless otherwise indicated. The measured data were not modified. Shapiro–Wilk test was used for normality calculation, and data showed normal distribution. Dependence of the amount of MM, take-off skills, and force skills at WAnT were assessed using a correlation analysis (Pearson's correlation coefficient). Linear regressions were calculated between one-legged jump and WAnT performance (difference of values between individual limbs). When determining the difference in muscle mass between the individual limbs and its relationship to age, the difference in muscle mass was determined as a percentage. When evaluating the relationship between jump height and power in WAnT, the difference between the right and left limbs was always evaluated by setting the value for left lower limb at 100%. The value measured on the right lower limb was related to this value. Significance was set at the $p < 0.05$ level. The critical value of Pearson's correlation coefficient for a one-tailed test with 65 variables at the level of $p = 0.05$ is 0.244; at the level of $p = 0.01$, it is 0.318. The differences in the groups of players by leg preference in the individual parameters and in the individual players were assessed using the t-test at the level of significance of $p < 0.05$. Graphically, the differences between the dominant and non-dominant leg in the individual players from the aspect of the amount of MM, jump height, and power at two WAnT intensities (1 s and 30 s) was expressed. The differences were also assessed with regard to the age of the players, or the duration of their athletic career. Data processing was performed in Microsoft Excel (Microsoft, Redmond, WA, USA) and Statistica 12 (TIBCO Software Inc., Palo Alto, CA, USA).

2.4. Ethical Approval

All participants, or parents in case of minors, signed an informed consent form. The research was carried out with consent of the Ethics Committee, Faculty of Education, University of South Bohemia, Ref. No.: 002/2018. All procedures performed in the study were in accordance with the ethical standards of the institutional research committee and with the Helsinki declaration.

3. Results

Figure 1 shows the ratio in the upper and lower limb preferences. There is expressed laterality of players by which hand they write and which one is the preferred leg for kicking and for jumping in terms of playing soccer. The set of participants has a prevalence of individuals with a dominant right hand (for writing) and dominant right leg (for kicking) and dominant left leg (for take-off) (see Figure 1). As Figure 1 shows, 90% of the players with right hand preference prefer the right leg for kicking and 27% prefer the right leg for take-off. In total, 46% of players with left hand preference prefer the left leg for kicking and 54% prefer the left leg for take-off. Thus, there is a difference in lower limb preference between right-handed and left-handed players.

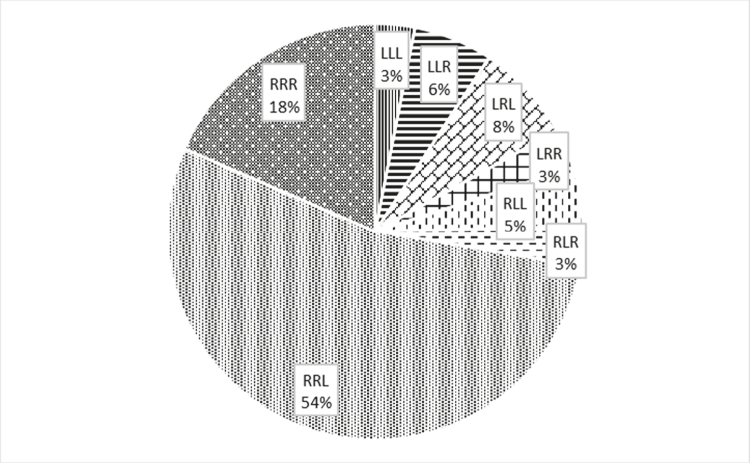

Figure 1. Percentage of representation of players by the preferred upper limb (writing), preferred lower limb (kicking) and take-off lower limb. 1st letter: which hand they use (L—left, R—right), 2nd letter: which leg they use for kicking, 3rd letter: which leg they use for take-off.

Table 1 presents the basic somatic, take-off parameters of the tested players and results during WAnT. The players show a higher volume of MM on the right leg than on the left ($p < 0.01$), regardless of their leg preference. There are no significant differences in the monitored parameters (amount of MM, jump height, engaging legs in WAnT) among the groups of players according to the leg preference for kicking and for take-off.

Table 1. Measured values of the monitored participants by lower limb preference for kicking and by lower limb preference for take-off.

Parameters	Left Kicking	Right Kicking	Left Take-Off	Right Take-Off
Number of players (*n*)	11	54	45	20
Height (cm)	179.4 ± 7.9	178.9 ± 6.2	179.7 ± 6.7	177.4 ± 5.7
Body mass (kg)	69.3 ± 7.5	71.3 ± 9.1	71.1 ± 9.0	70.5 ± 8.6
Age (years)	16.5 ± 1.2	15.9 ± 1.1	15.9 ± 1.2	16.1 ± 1.1
MM right leg (kg)	10.09 ± 1.10	10.56 ± 1.26	10.52 ± 1.18	10.40 ± 1.38
MM left leg (kg)	9.86 ± 1.02	10.13 ± 1.22	10.10 ± 1.16	10.04 ± 1.27
Jump height right leg (m)	0.19 ± 0.04	0.19 ± 0.03	0.19 ± 0.03	0.18 ± 0.03
Jump height left leg (m)	0.18 ± 0.04	0.20 ± 0.03	0.20 ± 0.03	0.19 ± 0.03
1 s power of right leg (W)	1470.9 ± 161.8	1502.7 ± 221.8	1498.8 ± 221.7	1494.0 ± 192.7
1 s power of left leg (W)	1435.5 ± 133.2	1429.1 ± 224.4	1434.8 ± 225.2	1419.9 ± 177.3
30 s power of right leg (W)	1095.1 ± 121.4	1124.3 ± 156.2	1120.8 ± 157.9	1116.2 ± 135.0
30 s power of left leg (W)	1019.9 ± 94.4	1053.3 ± 143.6	1047.9 ± 136.5	1047.2 ± 138.5

Note: Differences in means of all followed variables are not statistically significant ($p > 0.05$).

Figure 2 shows the distribution of players by their positions and preferred leg; 11 of them (two players on the left, eight in the center, and one on the right) are able to use both legs in the game comparably, according to the trainer's assessment. It can be observed that the most represented profile was the right leg. Nobody from the attackers and goalkeepers prefers the left leg for kicking. Among defenders there are 32% of players with preferred left leg and among midfielders 24% of players.

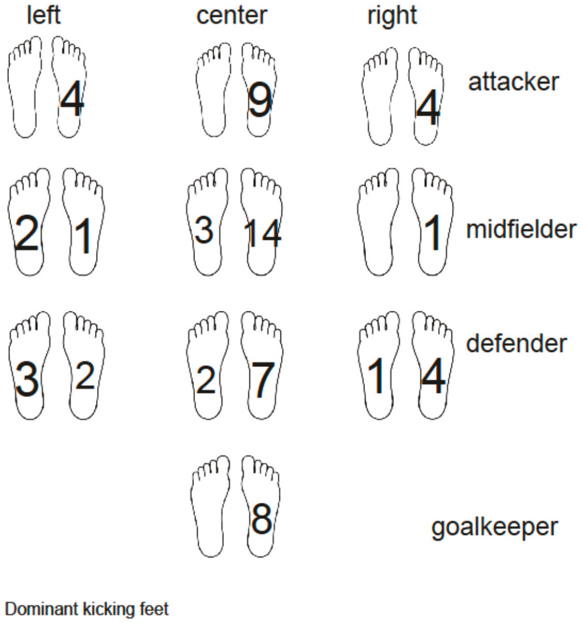

Figure 2. Dominant kicking leg—number of players by the position.

Table 2 presents relationship between several pairs of parameters (amount of MM, WAnT performance, and jump height—on each lower limb).

Table 2. Relationship between the individual variables.

Parameters	Correlation Coefficient	Significance
Difference R and L leg: jump height and power at 1 s WAnT	0.277	$p < 0.025$
Difference R and L leg: jump height and power at 30 s WAnT	0.375	$p < 0.01$
MM R leg and power at 30 s WAnT R leg	0.832	$p < 0.001$
MM L leg and power at 30 s WAnT L leg	0.811	$p < 0.001$
MM R leg and power at 1 s WAnT R leg	0.753	$p < 0.001$
MM L leg and power at 1 s WAnT L leg	0.695	$p < 0.001$
Difference R and L leg: MM and absolute power at 30 s WAnT	0.022	$p > 0.50$
Difference R and L leg: MM and relative power at 30 s WAnT	0.002	$p > 0.50$
Difference R and L leg: MM and absolute power at 1 s WAnT	0.082	$p > 0.50$
Difference R and L leg: MM and relative power at 1 s WAnT	0.035	$p > 0.50$
Difference R and L leg: MM and jump height	0.063	$p > 0.50$

Figure 3 and Table 2 present the relationship between the 30 s WAnT results and the jump height from the aspect of differences in the power outputs between the individual legs. A statistically significant dependence between the test results was determined ($p < 0.01$; $r = 0.375$).

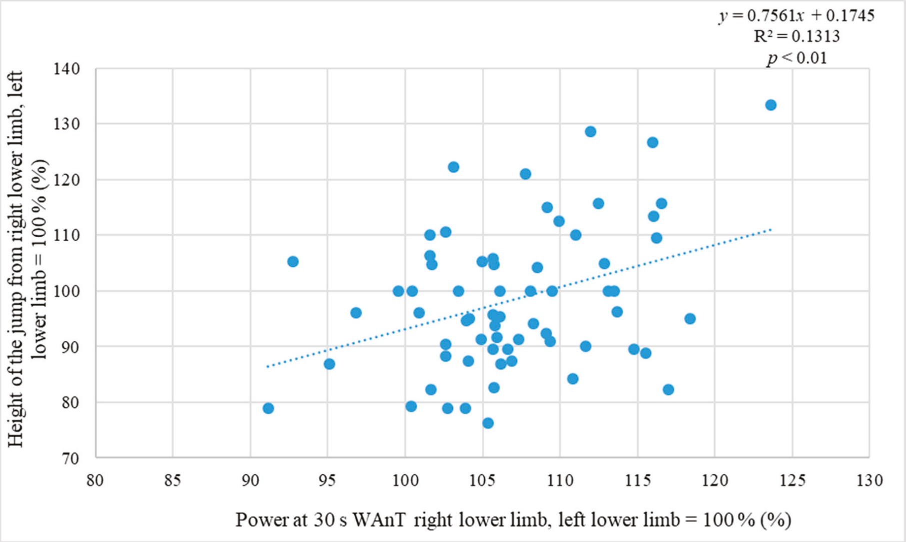

Figure 3. Relation of power at 30 s Wingate anaerobic test (WAnT) and jump height.

Figure 4 presents an insignificant dependence (p = 0.26; r = 0.164) of the differences in power outputs of the individual legs on the age.

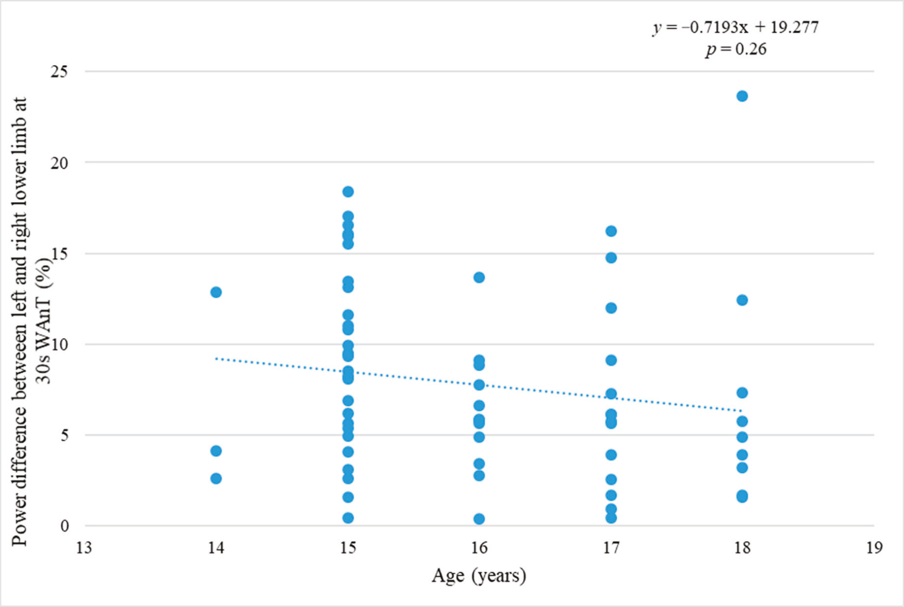

Figure 4. Relation of age and the power difference of individual legs at 30 s WAnT.

Figure 5 states the difference in the percentage amount of MM in the individual legs depending on the age. No dependence or trend was confirmed. No change in the differences of amount MM between the individual legs in the set of participants was registered.

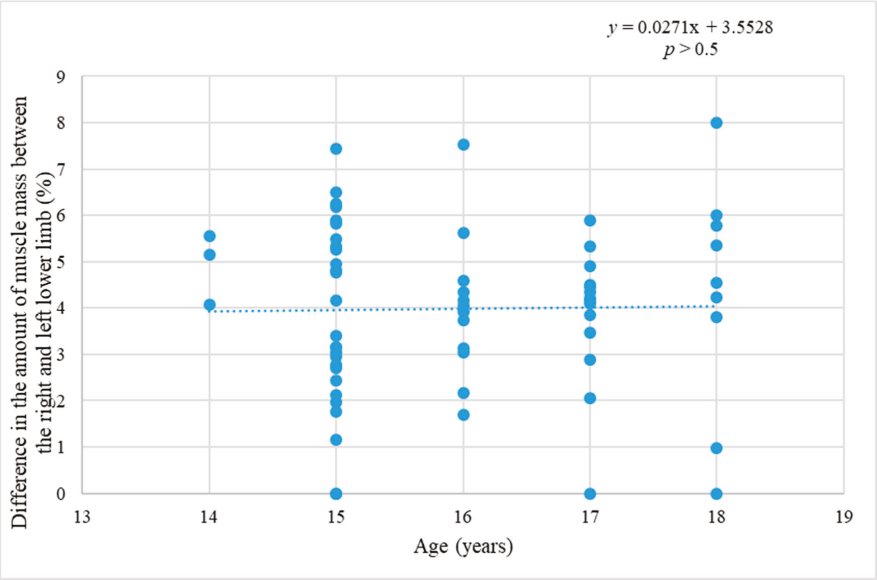

Figure 5. The relation of % difference in the amount of muscle mass (MM) in the individual legs and age.

Figure 6 shows the change in amount of MM during adolescence. The dependence of amount of MM in the legs on age is significant ($p < 0.01$; $r = 0.399$), and the amount of MM grows with age during adolescence.

The right leg was completely dominant in all monitored parameters in more than one-third of players. The distribution of the monitored variances was similar when the players were distributed by the preferred kicking leg. The opposite case, i.e., the left leg being better in all monitored indicators than the right leg, did not occur in our set, not even among the players who prefer their left leg both for kicking and take-off. On the contrary, two of those players had a completely dominant right leg. Furthermore, the results indicate that some players show a power imbalance in the monitored parameters (the largest difference in the power output of the individual legs was 33%), while the differences between the measured indicators for the right and left leg were low in others (at least 0%). The difference in the amount of MM between the left and right leg was 3.81% ± 1.68%; it was 7.07% ± 4.29% in 30 s WAnT, and 10.79% ± 7.85% in the one-foot jump.

No significant differences were demonstrated in the amount of MM, jump height, and power in WAnT between players with a different take-off leg ($p = 0.82$), or with a different preferred leg during the game ($p = 0.85$) or according to the preferred hand. It is therefore obvious that as far as laterality is concerned, there are no significant differences in the amount of MM, one-foot jump height, and power in WAnT between the players with left and right take-off legs.

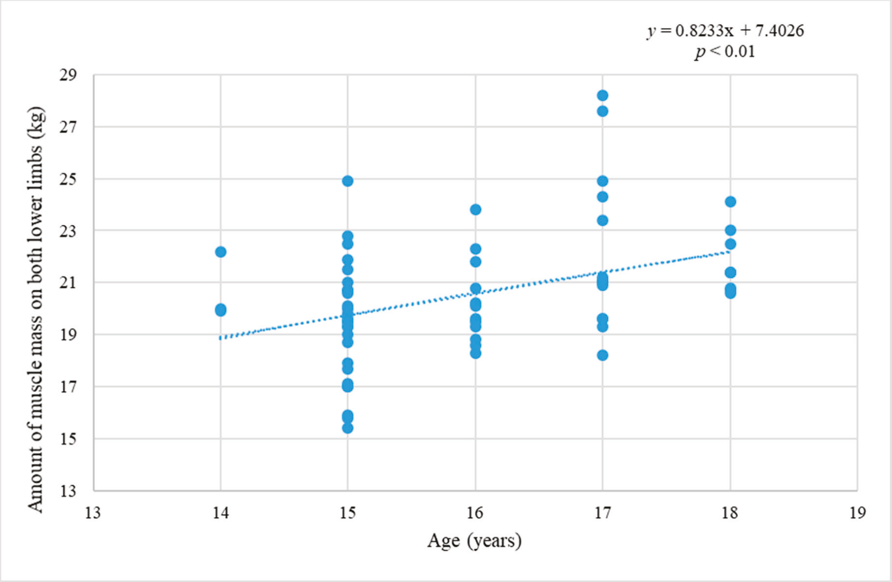

Figure 6. The relationship between the amount of MM in the both legs and age.

4. Discussion

The most relevant results found the fact that laterality does not significantly affect the morphology and performance of soccer players. In the observed group of adolescents, there are no significant differences in the amount of MM, jump height, and power in WAnT between the groups of players with left and right leg preference for kicking and take-off. It was confirmed by the insignificant values of correlation coefficients. There are no significant differences among the position groups of players as well. The analysis of the game shows that the preferred foot of soccer players is unilaterally loaded only about 2% or less of the total playing time [42]. Thus, youth soccer training does not affect laterality. Neuromuscular coordination affects performance in terms of laterality [31].

The study did not find any relationship between the lower limb strength at WAnT and the amount of MM. The muscle strength and the amount of MM had no relationship to the dominance of the lower limb (take-off leg, kicking leg). No significant differences were registered in the take-off from the dominant and non-dominant leg, which is consistent with the published results [43].

It was also determined that the amount of MM increases considerably with age (by about 15.5% between the ages of 14 and 18), it is natural biological development, maturation. In this research the difference in the amount of MM between the dominant and non-dominant lower limb decreases insignificantly as age increases (by about 0.1% between the ages of 14 and 18). The difference between the dominant and non-dominant lower limb at maximal power in WAnT decreases by about 3% in the course of the monitored time period, which is significantly more than in the amount of MM. That is likely the consequence of the prevailing training locomotion which is specific for bipedal character. This suggests that the choice of training methods in the monitored players contributes to the symmetrical development of the body. This should help prevent asymmetries and reduce the likelihood of injury.

Another cause could be the higher effect of learning at a younger age and gradual loading of the training effect over the course of time [44]. These authors also confirmed a relationship between the intensity of conditioning training and improvement in physical skills. Balanced training, which puts an even load on the dominant and non-dominant limbs, may contribute to reducing potential differences in the engagement of limbs when executing a physical performance and to the development of required physical skills [45].

In case of one lower limb, power in WAnT is significantly influenced by the amount of MM. It was confirmed on the right lower limb and on the left one as well on both lower extremities—dominated and non-dominated or preferred or non-preferred. A significant relationship between the amount of MM and the absolute force power in the individual lower limbs was found. On the contrary, a relationship between amount of MM and the relative strength performance (converted to 1 kg weight of individual) related to the weight body mass of the individual lower limbs was not found. However, the differences in the power outcome in WAnT between the right and left lower limbs do not correspond to the differences in the amount of muscle mass, as well as the differences in jumps between the right and left lower limbs do not correspond to the differences in the amount of muscle mass. Thus, no general relationship between the amount of MM and muscle power was confirmed. This indicates the likely effect of the skill component.

The effect of laterality on the execution of strength performance is the subject of studies at various departments, as it may have a considerable influence on physical activity executed using only one limb. There are also other studies that deal with the topic of determining the preferred and non-preferred lower limb in soccer players and the differences in their composition and strength dispositions; for example, a relationship between the results of physiological tests and soccer performance was found [36]. Some studies deal with the relationship between the amount of MM and strength dispositions [26,31], others deal with relationships between the amount of MM and jump height [35]. The specificity of the training stimulus and its effect on strength development was additionally confirmed [37]. Significant differences in muscle activation between the dominant and non-dominant limb have not been confirmed neither in athletes nor non-athletes [34]. There are only a few studies that deal with the issue of the relationship between the lower limb amount of MM and speed-force performance, such as jump, in adolescents [40,46]. However, they are based on different methodology, take-off from both legs [40] or repeated jumps [46], but with similar results.

Considering the fact that the first step of measures to increase strength preconditions is to increase the cross-sections of the concerned muscles, MM hypertrophy, our study concentrated on an assessment of the relationship between the amount of MM and speed force of lower limbs, as well as the take-off force in adolescent soccer players.

Our study set included players with a dominant left limb (17%) and a dominant right limb (83%), comparable to published data on soccer players [47]. The ratio of players according to foot preference is similar for individual positions, except for attackers and goalkeepers. Due to the lack of players with a preferred left lower limb, these players are missing at some positions (left wing). This fact may influence the possibility of using tactical versions of the game. The take-off leg of the players is 70% left and 30% right, which is also consistent with published studies [3,47]. Most players (71%) have a different take-off leg and preferred leg in a specific performance—kicking. This might be caused by inherent dispositions for take-off, motion control and morphology of the concerned muscles (muscle fibers [3]), for limb preference [47], development of skills, and the essence of basic physical activity in soccer—locomotion with both legs. It has been reported that most right-handed individuals prefer the right lower limb for manipulation (kick, smoothing sand) and the left lower limb for posture securing [9]. The opposite tendency is recorded in left-handed individuals. In the case of right-handers, the results were confirmed in our study as well, but not for left-handers.

The determined significant relationship between the one-foot jump and 1 s power output of the same leg at WAnT means that the strength performance of the legs can be assessed in different ways. In practice, it implies options in the assessment of lower limb strength capacity in soccer players, both in jump and WAnT. However, due to the required equipment, WAnT is not usually available in field conditions. That corresponds to the already published conclusions [36] that have confirmed a close relationship between the maximum force (1 s WAnT) and jump height. The same was confirmed in volleyball players [25], while this dependence is closer in adults than in adolescents. It confirms the relationship between explosive force and take-off. Even closer dependence in the jump height difference between the dominant and non-dominant leg when executing a one-foot jump using individual legs and the difference in the power of the individual legs at 30 s WAnT was confirmed. A similar study was performed on healthy men and women between the ages of 17 and 20 who did not participate in any regular sports [48].

The limitations of our study include number of relatively homogeneous participants, the narrow age range of participants, different training history of players, and different capability of participants to learn new movement especially during the take-off from the non-dominant leg. However, the screened sample includes all soccer players from this region who fulfilled set conditions.

It shows that the amount of MM in adolescent soccer players is only a necessary, albeit insufficient, condition for strength performance, when it is assessed using movements that are difficult with respect to coordination [31,32,34]. The more general the movement is, or the more the individual is adapted to the specific physical activity, the closer the relationship between the amount of MM of the concerned muscle groups and the speed-force performance. This means that the amount of MM plays a significantly greater role in the execution of speed-force power in movements that the individual has adapted to than in physical activities with a specific character that are trained in a considerably shorter time period than basic physical activities [26]. The practical implications of the aforesaid are that it is essential to adjust the currently used conditioning methods in sports, the performance of which includes take-off and speed force.

5. Conclusions

This study confirmed a relationship between the take-off force and the explosive force of a single limb, as well as between the take-off force and the speed force of the limbs. There is a relationship between the amount of MM and the absolute power at WAnT. It was also confirmed that there is no relationship between take-off force and the amount of MM, or between the amount of MM and relative power at WAnT. That is an important factor when selecting conditioning methods. The laterality does not affect the morphology and performance of soccer players. The differences between the lower limbs decrease during the athletic career with the use of a sufficient and balanced load that respects individuality. Compensatory exercises are important for harmonious development, especially in adolescence.

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Repeated Sprint Ability Demands in U16 to U19 Highly Trained Handball Players Concerning Playing Position

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Abstract: The aim of the study was to determine anaerobic capacity and characterize changes in repeated sprint ability (RSA) within youth elite handball players. For this study, 142 male athletes (17.1 ± 0.9 years) were recruited from a handball sports high school and performed the RSA test on a cycle ergometer, including five 6 s all-out efforts separated by 24 s passive breaks. Maximal (P_{max}) and mean (P_{mean}) power, highest (W_{max}), and total work (W_{tot}) as well as power (P_{dec}) and work (W_{dec}) decrement were measured. Significant differences in RSA were noted in relation to age (greater values of P_{max}, P_{mean}, W_{tot}, W_{dec}, and P_{dec} in U19 than U17 as well as greater values of P_{max}, W_{tot}, W_{max}, W_{dec}, and P_{dec} in U19 than U16 ($p < 0.05$)) and playing position (wing players had greater W_{tot} than pivot, 269 vs. 243 (J/kg) ($p < 0.05$), and wing players differed significantly in absolute and relative power from athletes of other positions). RSA depends on playing position and age in groups of youth handball players and the RSA test can be helpful in the selection of athletes for a playing position. The article introduces normative values for elite youth handball players, empowering coaches in the evaluation of anaerobic abilities and selection.

Keywords: youth handball players' characteristics; RSA test; anaerobic performance; playing position characteristics

1. Introduction

The repeated sprint ability (RSA) test is widely applied in team and racket sports. Handball, soccer, basketball, and tennis players are expected to generate in intervals high values of muscle power (sprints) in order to respond to specific playing situations, alternated by periods of low physical activity [1,2]. Girard et al. (2011) noted that the time dedicated to sprint in team sports accounts for 1 to 4% of the effective playtime. However, the ability to develop high values of power and to maintain it during several subsequent actions in a game can be crucial for success [3].

Within the RSA test maximum values of variables defining the ability to repeat sprints are measured. With regard to running tests this accounts for the time needed to cover the distance and, in the case of tests performed on a cycle ergometer, the maximum power. The fatigue index is measured as the percentage speed decrease in the subsequent part of the running distance and the percentage decrease in power or work in repeated trials performed on a cycle ergometer [3].

In studies carried out on elite youth handball players by Ingebrigtsen et al. (2013) [4], a difference related to the age and experience of subjects was found in results achieved in running RSA tests conducted on U18 and U16 players. On the other hand, Buchheit et al. (2010) [5] evaluated the impact of training on sprint abilities measured in RSA tests in 14 young handball players. That observation confirmed that this ability is trainable in youth, and specifically for handball. The dependence between the physiological profile of handball players and their playing position as well as their sport level has been examined [6]. Authors reached the conclusion that a dependence between body composition, physical performance abilities, and playing position of handball players from the 1st and 2nd German League can be found [6]. Another interesting issue related to repeated sprint ability is the differences in results between wings (W), pivot (P), goalkeepers (G), and back (B) players. Previous research conducted on handball players investigated the anthropometric profile and physiological tests of 181 female youth players. The results showed that wings had better performance than all other players in the broad jump, 30 m sprint, and VO_2max [7]. In the other study, conducted on 53 elite female handball players, only the 30 m sprint test was a factor that determined differences between playing positions [8]. The playing position is also related to shot-specific muscle strength and power as well as injury incidents in male players [9,10]. Moreover, papers describing the impact of cortisol and testosterone on performance in team sports [11] and theirs responses to training regardless of playing position in handball suggest that G have a greater hormonal reactivity than other players [12]. Differences in RSA resulting from playing positions have been observed in research conducted in other team sports. The research conducted on 120 soccer players showed differences in the sprint time between defenders, midfielders, and forwards [13]. Moreover, research performed on 110 professional basketball players led to the conclusion that the running jumps have discriminative validity in differentiating playing positions in basketball [14]. From this brief literature overview, it is clear that the playing position has an impact on performance in handball and other team sports. Evidently, little is known about the validity of RSA test results and their applicability in differentiating between playing positions in youth male handball players.

The complexity of handball preparation, as well as the importance of RSA test results for practice, was presented in the previous mentioned publications. Those findings led us to investigate the dynamics of changes in the measured RSA variables in U16 to U19 groups. To date, the dynamics of changes in RSA have not been investigated in such broad age groups of youth handball players. The monitoring of athletes from different youth age groups seems to be crucial to determine the predictive utility of the applied test, and the understanding of the factors that contribute to handball performance. One of the aims of preseason training is to improve RSA and for this reason the normative values could help to optimize training loads. Therefore, the aim of the study was to determine changes in repeated sprint ability between players from identified age groups (U16, U17, U18, and U19) and various playing positions.

2. Materials and Methods

2.1. Participants

For this study, 142 male handball players with training experience of more than 3 years at the age of 17.1 ± 0.9 years (9 in the age of 15–15.9 years (U16), 60 in the age of 16–16.9 years (U17), 39 in the age of 17–17.9 years (U18), and 34 in the age of 18–18.9 years (U19)) were recruited from handball sport high schools. Players were selected to the study by coaches, which affected the numbers in the chosen age groups. The athletes participated voluntarily and were informed about the right to withdraw at every stage of the research. All participants provided written consent for participation, and in the case of underage players, such consent was received from their guardians. The research protocol was approved by the ethics commission at the Institute of Sport–National Research Institute in Warsaw, Poland (KEBN-17-32-KB), in compliance with the Declaration of Helsinki.

2.2. Procedures

Although the RSA tests in handball players have so far been conducted within running trials [15–17], in the presented study the cycle ergometry test was used. The cycle ergometry RSA test is more reliable than the running test and is focused on the physiological aspects of lower limb power and speed/force features. It also allowed us to evaluate other aspects of the RSA than running tests, which was described in publications of the other authors [2,18,19]. The method used to determine total work and the decrement (%) in power and work have been described previously [20]. The cycling protocol provides both a valid and reliable test of RSA [21] with coefficient of variation 3.7% in recreationally active female students [20]. Moreover, cycle ergometry tests have often been used before in order to determine anaerobic capacity in handball players [17,22–24] as well in the RSA test [1,25,26].

In order to determine the repeated sprint ability, the RSA test was conducted on the cycle ergometer Monark 874E. The ambient temperature for testing sessions ranged from 18 to 22 °C and tests were performed at the same time of day, between 10.00 AM and 1.00 PM for all subjects. Players were instructed not to perform intense exercise on the day before a test and to consume their last meal at least 2 h before the scheduled test time. The RSA test was composed of five 6 s intervals of maximal effort alternated with 24 s of passive rest. During the test, the athletes were instructed to reach the greatest possible cadence of weight-bearing pedaling (friction weight accounted for 7.5% of the body mass) in each interval. Following a 5 min warm up (about 70 W) with two 3 s sprints between, each athlete was allowed a 5 min recovery before performing the test. All sprints were performed from a stopped position and passive recovery was utilized between sprints. Five seconds before starting the next sprint, the athletes were asked to keep a ready position and wait for the start.

The maximal power and work values were calculated from the best 6 s interval. An absolute (total kJ and W) and relative (J/kg and W/kg) work and power score was calculated along with their respective fatigue index (% of decrement over repeated efforts). The equations for the fatigue index calculation were as previously described by Orysiak et al. (2018) [27].

2.3. Decrement of Work and Power

Decrement of work
$W_{dec} = 100 - (W_{tot} \cdot (W_{max} \cdot 5)^{-1} \cdot 100)$
W_{dec}—decrement of work, W_{tot}—total work, W_{max}—highest 6 s work.
Decrement of power
$P_{dec} = 100 - (P_{min} \cdot P_{max}{}^{-1} \cdot 100)$
P_{dec}—decrement of power, P_{min}—lowest 6 s power, P_{max}—highest 6 s power.

2.4. Statistical Analysis

All results were presented as mean and standard deviation. Prior to the statistical analysis, tests for normality (Kolmogorov–Smirnov and Shapiro–Wilk) and a test for the homogeneity of variance (Levene’s) were carried out on all variables. In order to determine the differences in RSA variables between age groups and playing position, the Kruskal–Wallis test and Bonferroni post hoc test for multiple comparisons were applied. The level of significance was set at $p < 0.05$. All calculations were performed with STATISTICA software (v. 12.0, StatSoft, TIBCO Software Inc., Palo Alto, CA, USA).

3. Results

In Table 1, changes in RSA test variables in U16, U17, U18, and U19 age categories are presented. The Kruskal–Wallis test did not show any significant differences in height, P_{max}, W_{tot}, and W_{max} relative values between the examined groups. Significant differences in the remaining variables (P_{max}, P_{mean}, $P_{mean/kg}$, W_{tot}, W_{abs}, P_{dec}, and W_{dec}) were found. As a result of multiple comparison tests, significant differences of the abovementioned variables were determined with regard to the respective age groups (Table 1).

Table 1. Repeated sprint ability (RSA) test results with regard to age groups.

	Unit	Age Groups				p
		U16 (n = 9)	**U17 (n = 60)**	**U18 (n = 39)**	**U19 (n = 34)**	
Height	cm	191 ± 3.48	188 ± 5.97	189 ± 6.37	190 ± 6.31	0.397
Body mass	kg	82.0 ± 8.55	81.6 ± 9.36	84.0 ± 8.90	86.6 ± 9.70 †	0.041
P_{max}	W/kg	11.0 ± 0.47	11.2 ± 0.81	11.5 ± 0.81	11.9 ± 0.78	0.421
	W	899 ± 77.7	906 ± 91.6	966 ± 91.0†	1024 ± 114 *,†	<0.001
P_{mean}	W/kg	10.6 ± 0.48	10.7 ± 0.69	10.9 ± 0.65	11.1 ± 0.59	0.017
	W	864 ± 69.5	867 ± 85.4	914 ± 88.8	959 ± 107 †	0.002
W_{tot}	J/kg	256 ± 16.7	256 ± 22.7	262 ± 18.5	275 ± 21.0	0.394
	kJ	21.0 ± 2.81	20.8 ± 2.44	21.9 ± 2.04	23,8 ± 3.00 *,†	<0.001
W_{max}	J/kg	52.9 ± 3.79	53.4 ± 4.92	55.3 ± 4.60	58.8 ± 5.08	0.594
	kJ	4.34 ± 0.61	4.34 ± 0.52	4.63 ± 0.48	5.09 ± 0.71 *,†,‡	<0.001
W_{dec}	%	3.34 ± 1.48	4.31 ± 1.89	5.15 ± 2.36	6.34 ± 3.41 *,†	0.002
P_{dec}	%	7.53 ± 4.15	9.14 ± 4.18	11.2 ± 4.28	12.8 ± 3.41 *,†	0.002

U16—age 15–15.9, U17—age 16–16.9, U18—age 17–17.9, U19—age 18–18.9. P_{max}—highest value of power in 5 trials, P_{mean}—mean value of highest value of power in each trial, W_{tot}—total work in 5 test trials, W_{max}—highest value of work in 5 trials, P_{dec}—power decrement, W_{dec}—work decrement. *—significantly different from U16; †—significantly different from U17; ‡—significantly different from U18.

When comparing players of different positions, regardless of U16 to U19 categories, it was observed that only age and W_{dec} were not significant indicators differentiating players from the different playing position (Table 2).

Table 2. Repeated sprint ability (RSA) test normative values with regard to playing position.

	Unit	Playing Position				p
		B (n = 62)	**G (n = 22)**	**P (n = 15)**	**W (n = 43)**	
Age	years	17.2 ± 0.93	17.3 ± 0.94	16.8 ± 0.83	17.1 ± 0.86	0.282
Height	cm	191 ± 5.47	191 ± 3.51	194 ± 6.51	184 ± 3.97	<0.001
Body mass	kg	83.5 ± 5.50	87.5 ± 6.42	99.6 ± 9.51	75.7 ± 6.29	<0.001
P_{max}	W/kg	11.5 ± 0.73	11.1 ± 0.62	10.6 ± 1.02	11.8 ± 0.73	0.001
	W	957 ± 87.1	971 ± 108	1051 ± 143	896 ± 89.1	0.001
P_{mean}	W/kg	10.8 ± 0.56	10.6 ± 0.48	10.1 ± 0.93	11.2 ± 0.52	<0.001
	W	904 ± 74.8	929 ± 94.3	1007 ± 131	847 ± 79.7	<0.001
W_{tot}	J/kg	263 ± 19.4	259 ± 15.7	243 ± 32.4	269 ± 20.7	0.002
	kJ	22.0 ± 2.22	22.6 ± 2.29	24.2 ± 4.11	20.4 ± 2.35	<0.001
W_{max}	J/kg	55.5 ± 4.73	53.8 ± 3.87	51.5 ± 7.17	56.7 ± 5.18	0.041
	kJ	4.64 ± 0.53	4.71 ± 0.54	5.14 ± 0.95	4.30 ± 0.54	0.006
W_{dec}	%	5.16 ± 2.75	3.89 ± 2.02	5.56 ± 2.77	5.03 ± 2.4	0.101
P_{dec}	%	11.2 ± 4.58	8.71 ± 4.02	8.00 ± 4.45	11.2 ± 4.53	0.009

B—backs, G—goalkeepers, P—pivots, W—wings. P_{max}—highest value of power in 5 trials, P_{mean}—mean value of highest value of power in each trial, W_{tot}—total work in 5 test trials, W_{max}—highest value of work in 5 trials, P_{dec}—power decrement, W_{dec}—work decrement.

The absolute power values P_{max}, P_{mean} were significantly lower ($p < 0.05$) in W players than in the other groups. On the other hand, relative values of P_{max}, P_{mean} were the highest in W in comparison to B, G, and P athletes ($p < 0.05$). Relative P_{max} and P_{mean} were also significantly lower in the P compared to B group ($p < 0.05$) (Figure 1).

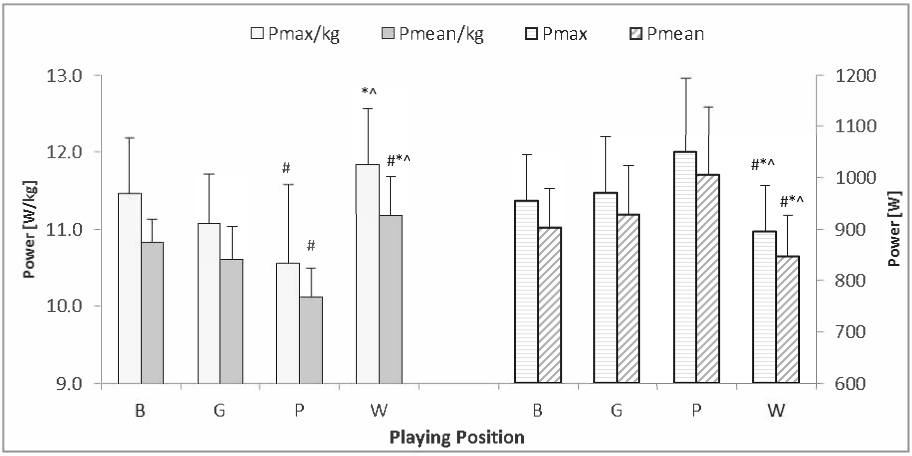

Figure 1. Differences in absolute maximal power (P_{max}) and mean power (P_{mean}) as well as relative maximal power ($P_{max/kg}$) and mean power ($P_{mean/kg}$) in the RSA test for athletes of various playing positions. B—backs, G—goalkeepers, P—pivots, W—wings, #—significantly different from B, *—significantly different from G, ^—significantly different from P.

A similar relationship to that presented in Figure 1 can be found in W_{max} and W_{tot} values. The W players had significantly lower absolute values of those variables than B, G, and P players ($p < 0.05$). However, the relative values of W_{max} and W_{tot} were higher in the W and B groups than in P ($p < 0.05$) (Figure 2).

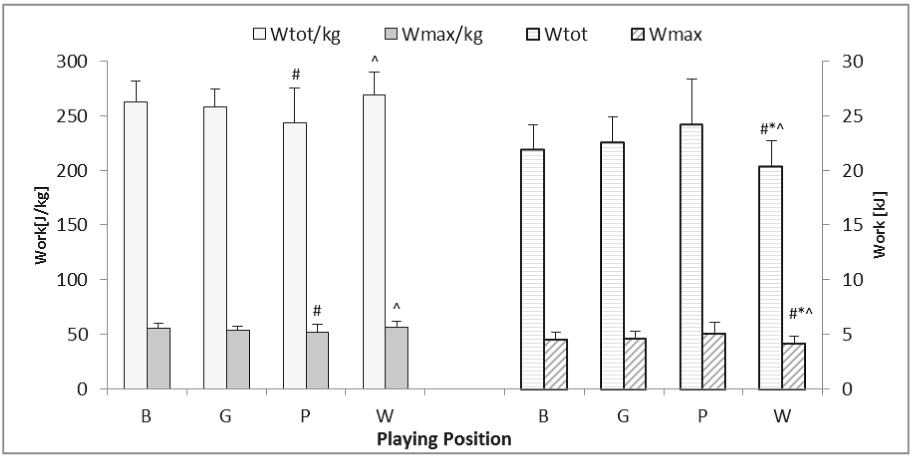

Figure 2. Differences in absolute maximal work (W_{max}) and total work (W_{tot}) as well as relative maximal work ($W_{max/kg}$) and total work ($W_{tot/kg}$) in the RSA test for athletes of various playing positions. B—backs, G—goalkeepers, P—pivots, W—wings, #—significantly different from B, *—significantly different from G, ^—significantly different from P.

Significantly lower body mass and height were observed in wings in comparison to other players ($p < 0.001$ for all positions). On the other hand, pivots were characterized by significantly higher body mass in comparison to backs ($p < 0.001$) (Figure 3).

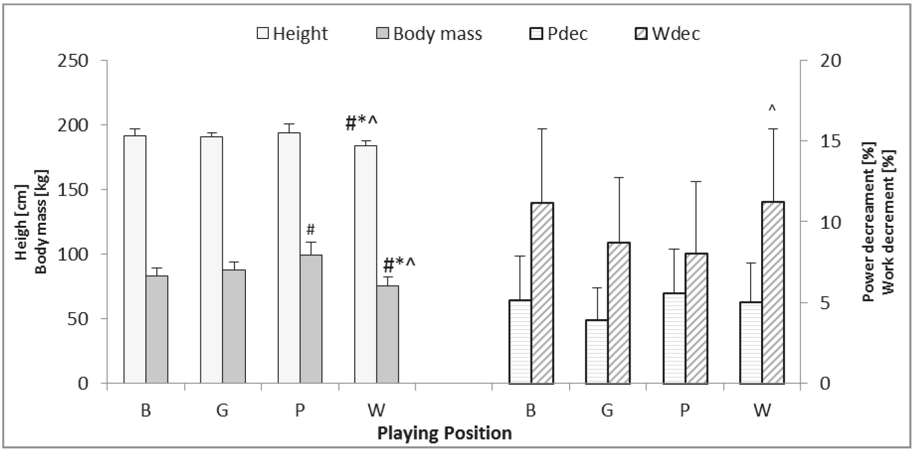

Figure 3. Differences in height, body mass, work decrement (W_{dec}), and power decrement (P_{dec}) in the RSA test for athletes of various playing positions. B—backs, G—goalkeepers, P—pivots, W—wings, #—significantly different from B, *—significantly different from G, ^—significantly different from P.

Only wings achieved significantly higher values of the W_{dec} indicator in respective test trials in comparison to pivot players ($p < 0.05$) (Figure 3). In other cases, no significant differences were noted with regard to fatigue variables in the RSA test (P_{dec} and W_{dec}) (Figure 3).

4. Discussion

The main observation resulting from this research is that the values of the RSA test variables are determined by the age and playing position. The dynamics of changes in RSA variables in age categories U16 to U19 are presented. The study introduces normative values for elite youth handball players, empowering coaches in the evaluation of repeated sprint abilities and the process of selection. Significant differences between the U19 group and the younger categories in absolute values of P_{max} ($p < 0.001$), P_{mean} ($p = 0.002$), W_{tot} ($p < 0.001$), W_{max} ($p < 0.001$), P_{dec} ($p = 0.002$), and W_{dec} ($p = 0.002$) were noted (Table 1). In this study, significant differences in power and work for the majority of the measured variables were observed in players of the U19 category when compared to the U16 category (Table 1). It is highly probable that the observed changes may be related to maturity status and the physical development of the players at age 15 to 19 years. Similar observations of significant changes in maximal power with the increasing sport experience were found in a work conducted on 197 handball players [24]. The publication showed that the cadet elite players (17.3 ± 0.6 years of age) obtained significantly lower maximal power in comparison to junior elite players' (18.6 ± 0.9 years of age) maximal power [24]. As opposed to the studies of the abovementioned author, no significant differences between groups of similar age were noted in the showed data (Table 1). The authors of this publication assume that the differences in results may have been affected by the training experience and the maturity of athletes. Regarding the sports level, the investigated players were previously selected for a handball sports school.

On the other hand, conclusions similar to the ones presented in the study were reached in the research regarding handball players in groups U14 and U16 whose age did not have any significant impact on physical performance level [28]. However, despite the fact that no significant differences in changes of $P_{max/kg}$ ($p = 0.421$) due to age were demonstrated, a tendency to increase with age can be noted in the case of this variable (Table 1). We should also consider training impact on power. In a publication by Maroto-Izquierdo et al. (2020), the authors concluded that six weeks of pneumatic or flywheel training resulted in increases in shoulder strength and power and throwing speed [29].

Presented results also showed significant differences in the absolute values of the W_{max} variable in U19 players in comparison to other groups. That may suggest that W_{max} can have a diagnostic value in the development of repeated sprint ability in youth handball players (Table 1). The use of the W_{max} variable measured in the RSA test was not previously described in the literature, but can be an area for a further investigation.

In the described study, the anthropometric characteristics (height and body mass) differentiated W players from B, G, and P (Figure 3). However, P players had significantly greater body mass than B. It may suggest that particular playing positions require appropriate motor abilities and are determined by the dimensions of the body. A previous publication showed significantly higher values of height and body mass in backs and pivots among teams taking part in the World Seniors Championships [30]. In another work, conducted on Italian handball players, significant differences in body composition of wings and goalkeepers in comparison to athletes playing in other playing positions were observed [31]. The results achieved in this study, and by mentioned authors, may imply that the assignment of playing position should be determined by the player's anthropometric characteristics.

The players anthropometric characteristics also had an impact on the physiological characteristics shown in Table 2. Wing players achieved the highest scores of relative values of the work and power test, but the absolute values were the lowest (Figures 1 and 2). However, no significant differences of the P_{dec} and W_{dec} values were found between groups. In addition, results showed the highest absolute values of P_{max}, P_{mean}, W_{tot}, and W_{max} in P players. Differences between wings and other players were also observed in Greek adult handball players [23]. The study of Nikolaidis et al., similarly to the results achieved in this research, showed significant differences of absolute P_{max} and P_{mean} in adult players, where the pivot players had the highest values, and wings the lowest. On the other hand, no significant differences were found in the adolescents [23]. With regard to relative values, similarly to the presented findings, adult wing players achieved the highest values of the examined anaerobic performance variables in comparison to other players. Similar dependencies of playing position related to the predictors of repeated sprint ability were found in elite female handball players [7,8]. Those findings may suggest that to monitor development of W players, focus should be on relative, and in P players on absolute, RSA values.

This study is not exempt of limitations. Firstly, the division into the age and playing position groups caused an unequal number of athletes. It was related to the Polish school system and the number of athletes on the chosen position in the team, and we had no impact on that. Secondly, we used the cycle ergometer rather than running RSA tests, which is most common in team sports testing. On the other hand, the main value of this study is that the chosen test allowed us to measure mechanical variables as power and work in large groups of athletes with high reliability.

The strength of this work is that the results indicate the relationship between age, handball playing position, and specific characteristics of anaerobic performance and anthropometric features. These differences should therefore be considered in the process of team selection and youth development. The wings are characterized by low height and body mass in comparison to other players, which result in the highest values of relative power and work.

5. Conclusions

The conclusion drawn from the performed analysis is that age and playing position have a significant impact on physical fitness in handball. This is evidenced by significantly higher RSA test results in players from the U19 group in comparison to other groups. The study confirms the impact of the playing position on the results achieved in the RSA test. Wing players achieved the best relative scores, whereas pivots achieved the best absolute results predicting repeated sprint ability.

Based on the test results, mean values of physiological and anthropometrical variables were established in relation to age and playing position groups. These values may become of practical use for handball coaches in the ongoing control of the athlete's power–speed preparation in U16, U17, U18, U19 groups as well as assignment to the playing positions.

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Effects of Match-Related Contextual Factors on Weekly Load Responses in Professional Brazilian Soccer Players

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Abstract: This study aimed to quantify the weekly training load distributions according to match location, opponent standard, and match outcome in professional soccer players. Rate-of-perceived-exertion-based training load (sRPE) and distance- and accelerometry-based measures were monitored daily during 52 training sessions and 11 matches performed by 23 players. Athletes who played ≥ 60 min during non-congested weeks were considered for data analysis. The training days close to away matches (e.g., one day before the match = MD-1) presented greater sRPE, distance-based volume measures, and mechanical work (player load) compared to the training days close to home matches (p = 0.001–0.002; effect size (ES) = medium−large). The most distant days of the home matches (e.g., five days before the match = MD-5) presented higher internal and external loads than before away matches (p = 0.002–0.003, ES = medium). Higher sRPE, distance-based volume measures, and mechanical work were found during the middle of the week (e.g., three days before the match, MD-3) before playing against bottom vs. medium-ranking teams (p = 0.001–0.01, ES = small−medium). These metrics were lower in MD-5 before matches against bottom vs. medium-ranking opponents (p = 0.001, ES = medium). Higher values of all external load measures were observed during the training session before winning matches (MD-1) compared to a draw or loss (p < 0.001–0.001, ES = medium−large). In conclusion, the training load distribution throughout the week varied considerably according to match-contextual factors.

Keywords: football; load monitoring; situational variables; GPS; sports science

1. Introduction

The training load (TL) has been described as the input variable that is manipulated to elicit the desired training response to warrant peak performance in competitions [1,2]. Also, TL monitoring can be employed using two dimensions [3]: (i) external TL, which is defined as the physical work prescribed or foreseen in the training plan (e.g., distance- and accelerometry-based measures); (ii) internal TL, the psychophysiological response to cope with the requirements elicited by the external TL (e.g., oxygen consumption during exercise or the rating of perceived exertion). Therefore, well-implemented monitoring cycles of players, including both external and internal TL measures, help coaches and sports scientists to understand and optimize the training process [3].

The current literature is vast and has allowed characterization of the general demands of soccer training and match-play, using a myriad of variables that potentially affect weekly TL responses [4–6]. The latter notably include wellness indicators [7], match players' participation i.e., starters and non-starters [8], congested fixture [9], constraint tasks [10,11], coach behavior and practice structure [12], and training style of the coach [13]. Also, various studies have suggested that match-related contextual factors are important factors that influence the measurement of soccer performance [14,15]. For instance, professional soccer players cover a longer total distance under high-intensity running, perform a higher number of acceleration/deceleration intervals, and reach higher peak speed when playing home matches [14], playing against a stronger opponent [16,17] or winning the match [18].

However, few studies have explored the effects of these match contextual factors on TL. Young French professional soccer players (U19) perceived a higher weekly training load after a defeat or a draw compared to a win and when preparing to play against medium-level than against bottom- or top-level opponents [19]. A recent study on the top Spanish League (LaLiga) also found a higher training volume before and after playing against a top-ranked opponent and after losing a match. Moreover, the volume of high-intensity training seemed to decrease before and after playing against a top-ranked opponent and to increase after a home game (or when preparing for an away game) [20]. Furthermore, Curtis, Huggins [21] found higher values of external TL after lost matches compared to won matches.

In fact, these studies have provided important insights mainly for French, Spanish, and National Collegiate Athletic Association (NCAA) soccer players, though the effects of match-related contextual factors in other countries are still unknown. In addition, information on these effects for each day of the week using the match as a reference (e.g., one, two, three, four, or five days before the match) is important for coaches and practitioners for a deep understanding of the weekly session distribution and workload responses considering the match-contextual factors [8,22]. Thus, the aim of this study was to quantify the weekly internal and external TL distributions according to match location (home, away), opponent standard (bottom, medium, top-ranking teams), and match outcome (loss, draw, win) in outfield professional Brazilian soccer players.

2. Materials and Methods

2.1. Design

The present study was conducted under nonexperimental conditions in which the research problem was embedded [19]. The players' internal and external TLs were monitored during training sessions and matches for 26 weeks over the 2019 season of the Brazilian National 2nd Division League (from June to November; 119 training sessions and 33 matches). To prevent confounding factors that influence the results and to understand more accurately the effects of match-contextual factors on weekly load responses, we considered only athletes who played ≥ 60 min [23] during non-congested weeks for data analysis i.e., when the reference team had only one match during the week [24,25]).

Thus, we analyzed 52 training sessions and 11 matches performed by 23 players during a 15-week observation. Three match-contextual variables were considered, as previously described [19,20]: (i) match location: home ($n = 339$ individual observations) and away ($n = 156$ individual observations); (ii) opponent standard: top—first to sixth in the current rankings ($n = 0$ individual observations), medium—7th to 14th ($n = 311$ individual observations), bottom—15th to 20th ($n = 184$ individual observations), and (iii) match outcome: loss ($n = 170$ individual observations), draw ($n = 243$ individual observations), and win ($n = 82$ individual observations). Curiously, the non-congested weeks analyzed did not feature matches against top-ranked teams. The training days before the match were considered in order to analyze the weekly load distribution throughout the week according to match-contextual factors: (i) five days before the match (MD-5); (ii) four days before the match (MD-4); (iii) three days before the match (MD-3); (iv) two days before the match (MD-2); (v) one day before the match (MD-1).

2.2. Participants

Twenty-three male outfield professional soccer players were monitored on a daily basis (four central defenders; five external defenders; six central midfielders; five external midfielders; three forwards; age 27 ± 4 years; height 179 ± 7 cm; body mass 79 ± 8 kg; professional experience 7 ± 4 years). The number of individual observations was also recorded ($n = 495$). The study was approved by the local Human Research Ethics Committee (School of Physical Education and Sport of Ribeirão Preto, University of São Paulo; protocol no. 61884716.9.0000.5659).

2.3. Internal Training Load

The players were previously familiarized with the use of Borgs' scale (CR10) aiming to increase the accuracy of the answers during the data collection period. Players were asked to answer "How was your workout?" approximately thirty min after the end of the training sessions or matches. The CR10 scores were provided individually, avoiding hearing the teammate's answers. Internal TL (rate-of-perceived-exertion-based training load (sRPE)) was determined by multiplying the duration of the training session or match (in minutes) by the CR10 score [26]. The individual internal TL was computed daily considering the match as a reference. The sRPE is considered a valid indicator of internal TL in soccer training and match-play [27].

2.4. External Training Load

The distance- and accelerometry-based measures were recorded in real-time during the training sessions and matches using a wearable 10-Hz global position system (GPS) integrated with a 400-Hz Tri-Axial accelerometer and 10-Hz Tri-Axial magnetometer (Playertek, Catapult Innovations, Australia). The devices were fitted to the upper back of each player using adjustable harnesses and were activated 15 min before the data collection, in accordance with the manufacturer's instructions to optimize the acquisition of satellite signals. The players used the same device throughout the season to avoid inter-unit error [28]. The following metrics were obtained: (i) total distance covered (TD, m); (ii) total distance covered under low to moderate-intensity running (LMIR, $\leq 18\ \text{m}\cdot\text{h}^{-1}$, m); (iii) total distance covered under high-intensity running (HIR, $>18\ \text{km}\cdot\text{h}^{-1}$, m); (iv) total distance covered under high-intensity acceleration (Acc, $\geq 2\ \text{m}\cdot\text{s}^{-2}$, m); (v) total distance covered under high-intensity deceleration (Dec, $\leq -2\ \text{m}\cdot\text{s}^{-2}$, m); (vi) Player Load (expressed as the square root of the sum of the squared instantaneous rate of change in acceleration in each of the three vectors—X, Y, and Z axes [29]) divided by 100; arbitrary units (AU)). The speed and accelerometry thresholds used are similar to those reported in previous studies [30,31].

2.5. Statistical Analysis

The Kolmogorov–Smirnov test revealed that TL data were not normally distributed ($p < 0.05$). Thus, the data are described by the median (interquartile range). The effects of match-contextual factors for each day during the weekly load distributions were assessed using the Mann–Whitney test (Match location and Opponent standard) or Kruskal–Wallis test (Match outcome). For these analyses, the significance level was set at $p < 0.05$. To establish the paired differences among the match outcomes, the Mann–Whitney test was applied with the significance level corrected to $p < 0.017$ (i.e., 0.05 divided by the number of comparisons). Additionally, effect sizes (ES) were calculated for pairwise comparisons ($ES = z\cdot\sqrt{n}$) and classified as negligible (<0.1), small (0.1–0.29), medium (0.3–0.49), and large (>0.5). The statistical package reported the appropriate "z" value, and the "n" refers to the sample size [32]. All data were processed using IBM SPSS Statistics 22.0 (Armonk, New York, NY, USA).

3. Results

3.1. Match Location

Figure 1 shows the weekly external TL parameters, and Figure 2 demonstrates the weekly internal load values according to match location. No significant differences were observed during the match day in home vs. away games, both for external ($p > 0.38$; ES = 0.02 (negligible) to 0.09 (negligible)) and internal loads ($p = 0.97$; ES = 0.00 (negligible)).

The TD ($p = 0.002$; ES = −0.38 (medium)), LMIR ($p = 0.002$; ES = −0.38 (medium)), Acc ($p = 0.039$; ES = −0.21 (small)), Dec ($p = 0.031$; ES = −0.22 (small)), Player load ($p = 0.001$; ES = −0.42 (medium)), and sRPE ($p = 0.001$; ES = −0.54 (large)) were higher in MD-1 during weeks before playing away than home matches. In contrast, with the exception of sRPE, these metrics demonstrated reduced values in MD-5 during the weeks before playing in away vs. home matches (TD: $p = 0.002$, ES = 0.45 (medium); LMIR: $p = 0.002$, ES = 0.45 (medium); Acc: $p = 0.010$, ES = 0.38 (medium); Dec: $p = 0.032$, ES = 0.32 (medium); Player load: $p = 0.005$, ES = 0.41 (medium)).

For MD-4, we observed higher values of TD ($p = 0.026$; ES = 0.25 (small)), LMIR ($p = 0.035$; ES = 0.24 (small)), HIR ($p = 0.019$; ES = 0.23 (small)), Acc ($p = 0.006$; ES = 0.31 (small)), Player load ($p = 0.035$; ES = 0.24 (small)), and sRPE ($p = 0.020$; ES = 0.26 (small)) during the weeks before playing home compared to away matches. Also, for MD-3, we found higher values of HIR ($p = 0.038$; ES = 0.22 (small)) during the weeks before playing home vs. away matches; the opposite pattern was noted for LMIR and Player Load ($p > 0.36$; ES < −0.22 (small)).

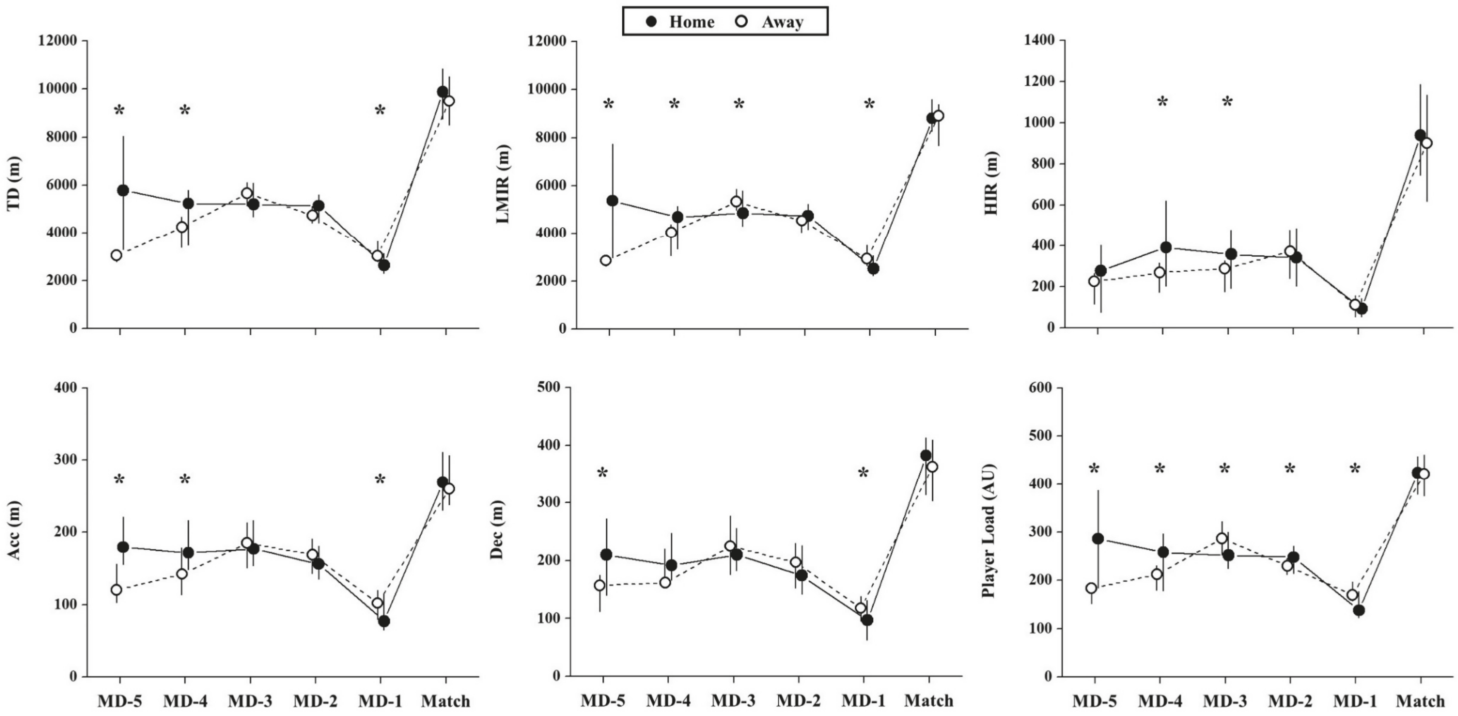

Figure 1. Effects of match location on weekly external load parameters. TD: total distance covered; LMIR: total distance covered under low to moderate-intensity running (≤18 m·h^{-1}, m); HIR: total distance covered under high-intensity running (>18 km·h^{-1}); Acc: total distance covered under high-intensity acceleration (≥2 m·s^{-2}); Dec: total distance covered under high-intensity deceleration (≤−2 m·s^{-2}); MD-5 = five days before the match; MD-4 = four days before the match; MD-3 = three days before the match; MD-2 = two days before the match; MD-1 = one day before the match. *: Significant differences between days before playing home vs. away ($p < 0.05$).

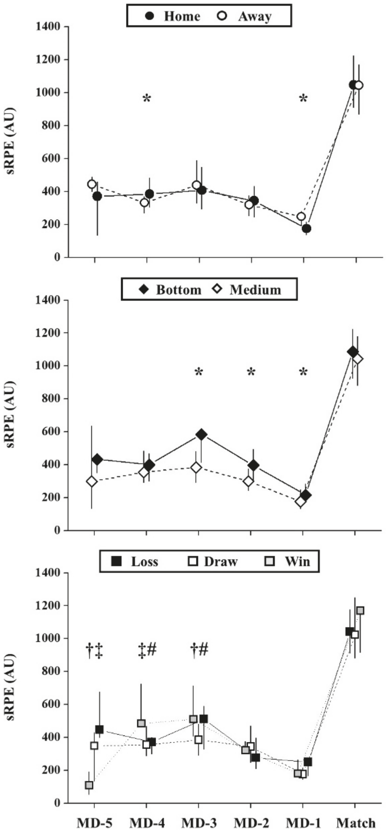

Figure 2. Effects of contextual factors on weekly internal load parameter (sRPE). *: Significant differences between home vs. away or bottom- vs. medium-ranking opponents ($p < 0.05$). #: Significant differences between days before win vs. draw matches ($p < 0.017$); ‡: Significant differences between days before win vs. loss ($p < 0.017$); MD-5 = five days before the match; MD-4 = four days before the match; MD-3 = three days before the match; MD-2 = two days before the match; MD-1 = one day before the match. †: Significant differences between days before loss vs. draw ($p < 0.017$).

3.2. Opponent Standard

The external (Figure 3) and internal TL parameters (Figure 2) were not different during the match day between bottom- and medium-ranking opponents ($p > 0.17$; ES = 0.01 (negligible) to 0.05 (negligible)).

The HIR values were higher on MD-1 and MD-3 before playing against medium- than bottom-ranked opponents ($p = 0.003$ to 0.008; ES = 0.27 to −0.32 (small to medium)). Also, TD ($p = 0.013$; ES = 0.38 (medium)), LMIR ($p = 0.010$; ES = 0.39 (medium)), and Player load ($p = 0.011$; ES = 0.38 (medium)) presented greater values on MD-5 in the weeks before playing against medium- compared to bottom-ranked opponents. In contrast, on MD-3, the TD (p = 0.014; ES = −0.26 (small)), LMIR ($p = 0.001$; ES = −0.34 (medium)), and Player load ($p = 0.001$; ES = −0.36 (medium)) presented greater values before playing against bottom– vs. medium-ranking teams. Also, the internal load was higher during the weeks before playing against bottom- vs. medium-ranked opponents on MD-1 ($p = 0.001$; ES = 0.43 (medium)), MD-2 ($p = 0.001$; ES = 0.41 (medium)), and MD-3 ($p = 0.001$; ES = 0.46 (medium)).

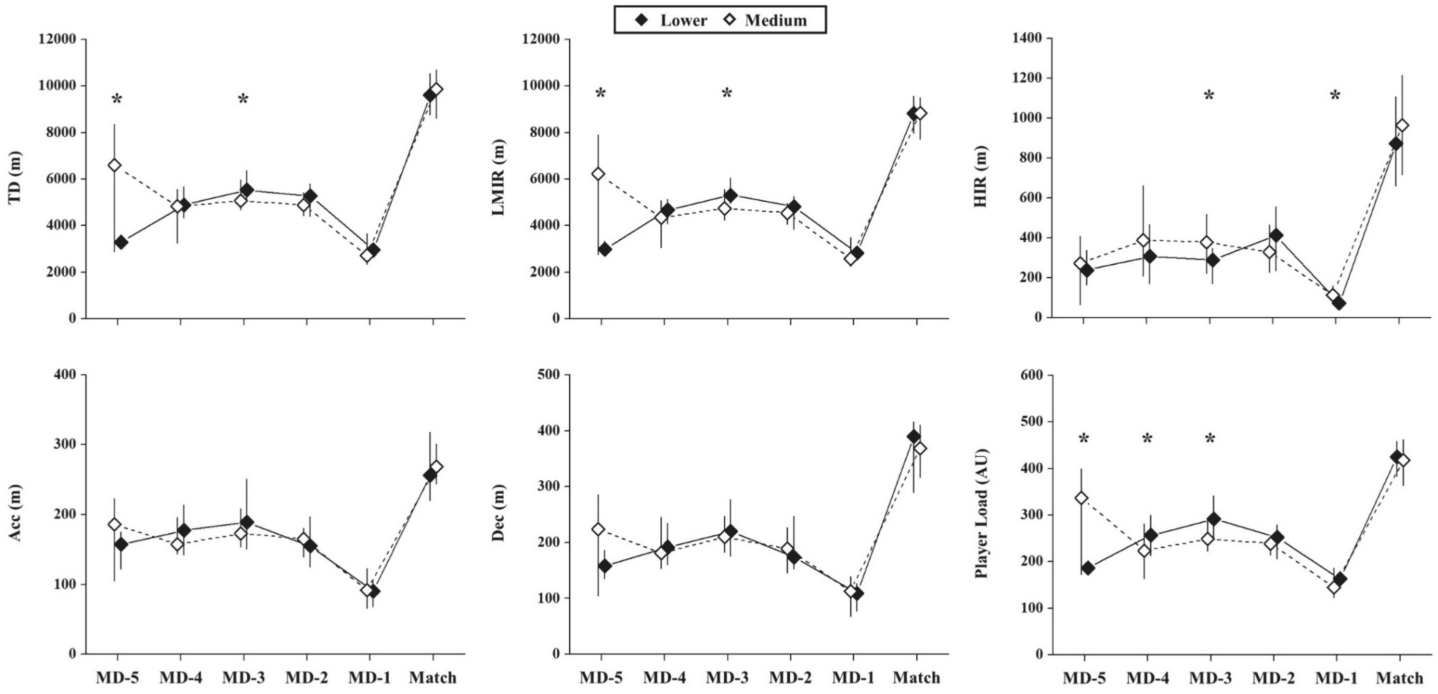

Figure 3. Effects of opponent standard on weekly external load parameters. TD: total distance covered; LMIR: total distance covered under low- to moderate-intensity running (≤18 m·h^{-1}, m); HIR: total distance covered under high-intensity running (> 18 km·h^{-1}); Acc: total distance covered under high-intensity acceleration (≥2 m·s^{-2}); Dec: total distance covered under high-intensity deceleration (≤−2 m·s^{-2}); MD-5 = five days before the match; MD-4 = four days before the match; MD-3 = three days before the match; MD-2 = two days before the match; MD-1 = one day before the match. *: Significant differences between days before playing against bottom vs. medium-ranking teams ($p < 0.05$).

3.3. Match Outcome

On the match day, no significant differences were observed when comparing match outcomes ($p >$ 0.179), both for external (Figure 4) and internal TL (Figure 2).

However, the MD-1 before winning the matches presented higher values than draws for all external load variables ($p < 0.001$; ES = 0.49 (medium) to 0.68 (large)) and higher than a loss for HIR (p = 0.001; ES = 0.46 (medium)) and Dec (p = 0.003; ES = 0.41 (medium)). Also, the MD-1 before losing the matches presented higher values than draws for Acc (p = 0.001; ES = 0.41 (medium)), Dec (p = 0.002; ES = 0.35 (medium)), and Player load (p = 0.001; ES = 0.51 (large)).

The MD-2 before losing the matches presented lower values than draws for TD (p = 0.001; ES = −0.51 (large)), LMIR (p = 0.001; ES = −0.55 (large)), and Player load (p = 0.001; ES = −0.38 (medium)) and lower values than wins for TD (p = 0.002; ES = −0.47 (medium)), LMIR (p = 0.002; ES = −0.46 (medium)), and Acc (p = 0.007; ES = −0.40 (medium)). Differently, the MD-3 before losing the matches presented higher values than draws for TD (p = 0.001; ES = 0.46 (medium)), LMIR (p = 0.001; ES = 0.42 (medium)), Acc (p = 0.001; ES = 0.39 (medium)), Dec (p = 0.001; ES = 0.44 (medium)), and Player load (p = 0.001; ES = 0.52 (large)). Also, the MD-3 before winning the matches presented higher values than draws for TD, (p = 0.001; ES = 0.56 (large)), LMIR (p = 0.001; ES = 0.56 (large)), HIR (p = 0.013; ES = 0.34 (medium)), Acc (p = 0.012; ES = 0.34 (medium)), and Player load (p = 0.001; ES = 0.56 (large)).

The MD-5 before winning the matches presented lower values than draws for all external load parameters ($p < 0.001$; ES = −0.69 (large) to 0.74 (large)) and lower than a loss for TD (p = 0.003; ES = −0.60 (large)), LMIR (p = 0.006; ES = −0.56 (large)), Acc (p = 0.001; ES = −0.65 (large)), Dec (p = 0.001; ES = −0.68 (large)), and Player load (p = 0.005; ES = −0.57 (large)). Also, the MD-5 before losing the matches presented lower values than draws for HIR (p = 0.001; ES = −0.71 (large)) and Acc (p = 0.004; ES = −0.46 (medium)).

Concerning the sRPE, the MD-5 before losing the matches presented higher values than draws (p = 0.001; ES = 0.49 (medium)) and wins (p = 0.001; ES = 0.53 (large)). The internal load on MD-3 was higher before winning the matches than draws (p = 0.004; ES = 0.39 (medium)) and higher for draws vs. losses on MD-4 (p = 0.008; ES = 0.36 (medium)). In addition, the MD-3 was higher before losing the matches compared to draws (p = 0.007; ES = 0.30 (medium).

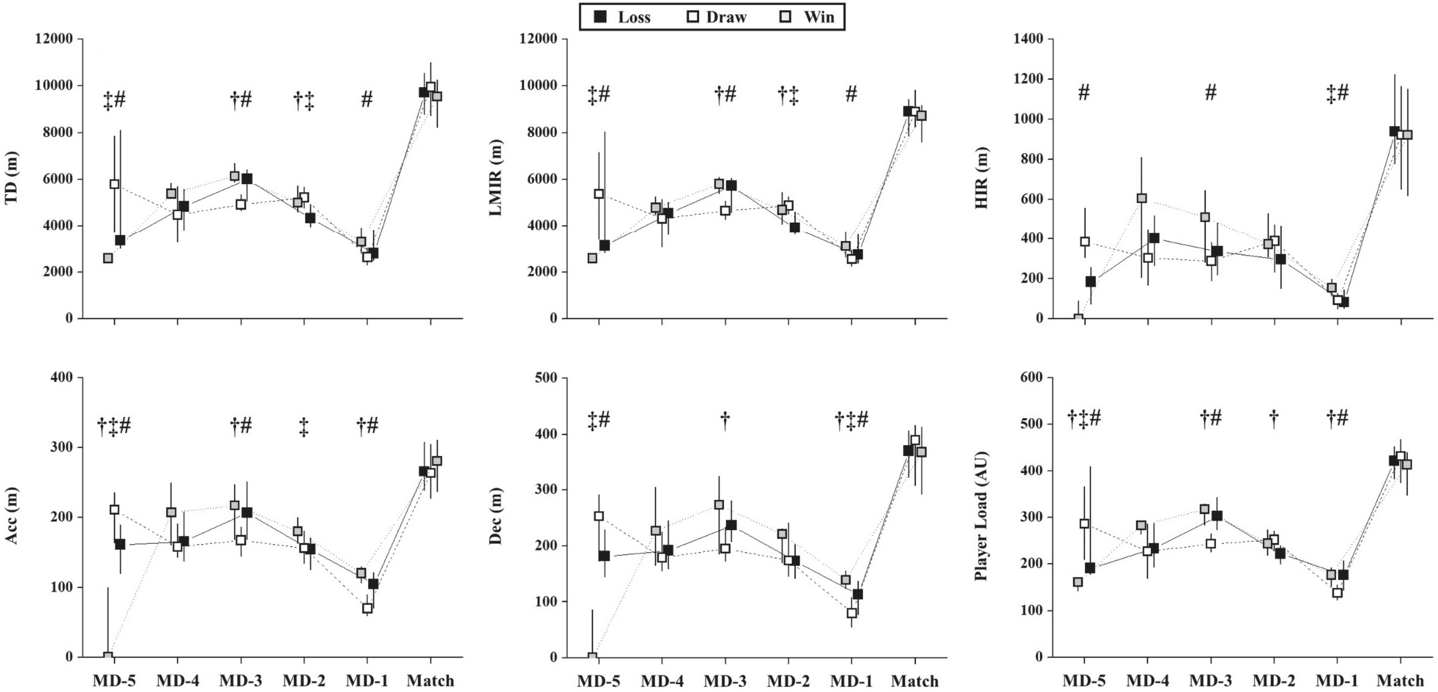

Figure 4. Weekly external load parameters according to match outcome (before a win, draw, and loss). TD: total distance covered; LMIR: total distance covered under low- to moderate-intensity running (≤ 18 m·h^{-1}, m); HIR: total distance covered under high-intensity running (>18 km·h^{-1}); Acc: total distance covered under high-intensity acceleration (≥ 2 m·s^{-2}); Dec: total distance covered under high-intensity deceleration (≤ -2 m·s^{-2}) #: Significant differences between days before win vs. draw ($p < 0.017$); ‡: Significant differences between days before win vs. loss ($p < 0.017$); MD-5 = five days before the match; MD-4 = four days before the match; MD-3 = three days before the match; MD-2 = two days before the match; MD-1 = one day before the match. †: Significant differences between days before loss vs. draw ($p < 0.017$).

4. Discussion

To the authors' knowledge, this is the first study to investigate the weekly load responses according to contextual factors in professional soccer, considering the match as a reference and the training days throughout the week. Concerning the match day, internal and external loads were not influenced by match location, opponent standard, and match outcome. In general, during the training session close to the away matches or against bottom-ranking opponents (e.g., MD-1, MD-3), we observed higher values of internal and external loads compared to these days before home matches or against medium-ranking opponents. However, on the most distant sessions of the away matches or against bottom-ranking opponents (e.g., MD-5), we found reduced values of the internal and external load than these same days before home matches or against medium-ranking opponents. Curiously, we found higher values of all external load measures during the training session before winning matches (i.e., MD-1) compared to a draw or loss. On the other hand, in general, internal and external load metrics presented higher values in the other training sessions (e.g., MD-2, MD-4, MD-5) before losing or draw matches compared with winning matches.

Previous studies found higher external load values when teams competed in home vs. away, against strong vs. weak opponents, and won vs. loss during match days of the Brazilian National 3rd and 4th Division Leagues [16,18]. Also, another investigation has shown that greater distances were covered in total and high-intensity activities ($\geq$19.8 km$\cdot$h^{-1}) in lower (English Championship and League 1) compared to higher standard divisions (English Premier League) [33]. In contrast, we did not observe an influence of match-contextual factors on internal and external loads during the Brazilian National 2nd Division League. It is difficult to fully explain the discrepancies between studies, but most likely they are linked to the elite/sub-elite team composition of the lower divisions compared to the full-team elite standard in upper divisions [33]. Also, additional factors related to the complexity of soccer match play could contribute and impact load parameters, such as physical capacity [34], technical level [35], playing formation [36,37], and environment [38]. Furthermore, each competition may present its own idiosyncrasies, suggesting that data generalization should be done with caution.

Here, the TL distribution throughout the week varied considerably according to match-contextual factors. Training days close to away matches (e.g., MD-1) presented greater internal and external loads compared to home matches, mainly for sRPE, distance-based volume measures (TD, LMIR), and mechanical work (player load) (medium to large effect sizes). It is possible that one day before away matches, the coaches increase the volume of tactical preparation (e.g., match-specific situation), increasing the distance-based volume measures, and mechanical work. On the other hand, the most distant days of the home matches (e.g., MD-5) presented higher internal and external loads compared with away matches. Rago, Rebelo [20] investigated the sum of the weekly load and found reduced values of Acc and Dec when preparing for away matches, possibly due to the coaches' prescribed workload or players' pacing strategy affected by the forthcoming travel. Considering that soccer teams usually alternate home and away matches, these responses could be hypothetically explained by the possibility of improving recovery strategies after home matches (i.e., no travel) and consequently increasing the TL. Further studies are warranted to clarify these aspects.

Regarding the opponent standard, we verified greater distances covered in HIR during training sessions close to matches (e.g., MD-1) against medium- vs. bottom-ranking teams; however, with a small effect-size. The MD-5 also showed these differences for TD, LMIR, and Player Load (medium effect sizes). However, in the middle of the week (i.e., MD-3), higher sRPE, distance-based volume measures (TD, LMIR), and mechanical work (player load) were found against bottom- vs. medium-ranking teams (medium effect sizes). This seems to be a good practice because the higher predicted level of difficulty of a match requires lower training stress and higher recovery on the days leading up to the match [39]. Curiously, the non-congested weeks analyzed did not feature matches against top-ranking teams, considered as a limitation of this study. A previous study on the top Spanish League (LaLiga) also found greater values of distance-based metrics before playing against bottom- vs. medium-ranking opponents [20]. It is possible that the coaches increased TL mainly during the middle of the weeks against bottom-ranking teams to maintain their physical fitness [39]. In contrast, in the weeks against medium-ranking opponents, coaches usually adopt tactical training strategies, which possibly decreases TL. Coaches and practitioners should be cautious with the spikes promoted by daily TL, which may increase fatigue [40] and hamper technical performance during a match [41].

Collectively, it is difficult to draw inferences about the cause–effect between match outcome and changes in weekly load distribution. However, this study provides important insights for coaches and practitioners when planning training sessions to consider this match-contextual variable. We found higher values of all external load measures during the training session before winning matches (i.e., MD-1) compared to a draw or loss. However, in general, internal and external load metrics presented higher values in the other training sessions (e.g., MD-2, MD-4, MD-5) before losing or draw matches than before winning. Our findings complement previous studies on U19, professional, and collegiate players that competed in France [19], Spain [20], and EUA [21], respectively.

The study contains some limitations that we should acknowledge. The major limitations were the load monitoring in a single club, the lack of objective quantification of exercise intensity in response to the activity performed by the players (e.g., heart rate), and other training/match performance indicators (i.e., technical actions, collective dynamics, and tactical behavior). Therefore, further studies investigating the effects of match-contextual factors on objective weekly load responses, technical-tactical aspects, and players' fatigue/readiness state should be conducted across multiple teams and seasons, considering the game model for training sessions and matches in elite Brazilian soccer (e.g., 1st division; interviewing the coaches according to the training and match ideas over the seasons). Also, curiously, the non-congested weeks analyzed did not feature matches against top-ranked teams, and this should be considered a limitation. Notwithstanding, this study analyzed only starter players that competed for most of the match (i.e., >60 min). Further studies should investigate these effects during congested weeks and in substitute players.

5. Conclusions

We verified that match-day TL was not influenced by match location, opponent standard, and match outcome. The training days close to away matches (e.g., MD-1) presented higher internal and external loads compared to home matches. In contrast, the most distant days of the home matches (e.g., MD-5) presented higher internal and external loads than away matches. Also, greater internal load, distance-based volume measures (TD, LMIR), and mechanical work (player load) were found during the middle of the week (e.g., MD-3) before playing against bottom- vs. medium-ranking teams; however, these metrics were lower in MD-5 before playing against bottom- vs. medium-ranking opponents. Regarding the match outcome, curiously, we found higher values of all external load measures during the training session before winning matches (i.e., MD-1) compared to a draw or loss. Finally, internal load presented greater values before losing the matches than draws (MD-5, MD-3) and winning (MD-5) and higher values before winning vs. drawing (MD-4, MD-3) and losing the match (MD-4).

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Review

Effects of Strength vs. Plyometric Training Programs on Vertical Jumping, Linear Sprint and Change of Direction Speed Performance in Female Soccer Players: A Systematic Review and Meta-Analysis

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Abstract: The main purpose of this systematic review and meta-analysis was to compare the effects of strength training (ST) and plyometric training (PT) on vertical jump, linear sprint and change of direction (COD) performance in female soccer players. A systematic search of the PubMed, Web of Science, Google Scholar and SportDiscus databases revealed 12 studies satisfying the inclusion criteria. The inverse-variance random-effects model for meta-analyses was used. Effect sizes (ES) were represented by the standardized mean difference and presented alongside 95% confidence intervals (CI). The magnitude of the main effect was small to moderate (vertical jump (ES 0.53 (95% CI—0.11, 0.95), Z = 2.47 (p = 0.01); linear sprint (ES −0.66 (95% CI—2.03, −0.21), Z = 2.20 (p = 0.03); COD (ES −0.36 (95% CI—0.68, −0.03), Z = 2.17 (p = 0.03)). Subgroup analyses were performed (i.e., ST and PT duration, frequency, session duration and total number of sessions), revealing no significant subgroup differences (p = 0.12–0.88). In conclusion, PT provides better benefits than ST to improve vertical jump, linear sprint and COD performance in female soccer players. However, significant limitations in the current literature prevent assured PT and ST prescription recommendations being made.

Keywords: training interventions; fitness assessment; strength and conditioning; football; female

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1. Introduction

Women's soccer has increased in popularity and participation during the last decade [1]. Soccer is considered a contact sport and such impact has had consequences through both a greater skill level and physical demands throughout training and matches [2]. Some of the physical demands for female soccer players during matches have been reported, with total distances covered reaching 10 km, 1.7 km of which was completed at high speed (>18 km·h^{-1}) [3,4]. In addition, female players perform between 1350 and 1650 changes of activity, such as passing, tackling, trapping and dribbling [3,4]. Despite its growing popularity, female players are exposed to greater training volumes and competition demands than ever before and, therefore, a better understanding of female players' physical performance changes is needed to design appropriate training programs.

Female soccer players have been evaluated through a wide variety of physical tests (i.e., Abalakov test, 505 test, linear speed 40 m). These tests can be performed in the laboratory, which is more reliable, and on the soccer field, which is more popular among coaches and physical trainers due to the simplicity and lower cost [2].

Different intervention programs, such as neuromuscular training, plyometric training (PT), strength training (ST) or power training [5–8], have been performed to improve physical capacities. However, there are discrepancies about which are the best exercises to improve female soccer players' performance due to the lack of studies.

Plyometrics consists of the rapid stretching of a muscle (eccentric action) immediately followed by a concentric or shortening action of the same muscle and connective tissue [9]. This training method is used to increase strength and explosiveness [10] and it includes a diverse range of bilateral and unilateral jumps, bounds and hops [9]. Regarding female soccer players, PT improves jumping, single and repeated sprinting, changes in direction and kicking power, as well as endurance attributes [11]. Several reviews and meta-analyses related to PT programs have been published in soccer [12,13]. This program constitutes an efficient training solution to improve different power-related skills. However, this evidence has not been clarified in female soccer players, although it has increased the scientific value of PT regarding physical fitness enhancements [12,13]. Hence, more studies for this population are warranted.

Maximal strength is the maximum force or torque that can be exerted by skeletal muscles during movement [14]. An ST program can contribute to improved vertical jump performance, acceleration, leg strength, muscular power, increased joint awareness and overall proprioception [15]. However, intervention studies of ST regarding physical condition in female soccer players are lacking [7]. Despite this, several reviews and meta-analyses related to ST programs have been published in different populations and sports [16–19]. Nevertheless, the improvement caused by ST raises certain doubts, since the authors do not agree on which doses and exercises are recommended to improve the strength of the lower extremities. In relation to this, research is necessary to provide coaches and practitioners with more information to plan their ST programs.

To our knowledge, there have been no reviews conducted regarding the effects of ST on female soccer players, particularly on physical fitness. Given that PT appears serve as a skill solution to meet the demands of female soccer, an investigation comparing the effects of both programs in female soccer players is warranted. Therefore, the main purpose of this systematic review and meta-analysis was to compare the effects of ST and PT on jump ability, linear sprint and change of direction (COD) performance in female soccer players. A secondary aim was to establish clear guidelines for the prescription of both types of training in female soccer players.

2. Materials and Methods

2.1. Experimental Approach to the Problem

A systematic review and meta-analysis were conducted following the guidelines of the Cochrane Collaboration [20]. This meta-analytical review was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [21] and registered in the PROSPERO database with the number CRD42020219998.

2.2. Literature Search

The US National Library of Medicine (PubMed), Web of Science, Google Scholar and SportDiscus electronic databases from inception until 19 October 2020 were searched. Only English and Spanish language articles were considered. Using Boolean logic, we used the following search terms: (“female”) AND (“soccer” OR “football”) AND (“intervention” OR “training”) AND (“strength” OR “plyometric” OR “jump” OR “strength” OR “power” OR “change of direction” OR “side-step” OR “side-cutting” OR “sprint” OR “agility”). In selecting studies for inclusion, a review of all relevant article titles within was conducted before an examination of article abstracts and, then, full published articles. Only peer-reviewed articles were included in the meta-analysis. The search process is outlined in Figure 1. Following the formal systematic searches, additional hand searches were conducted.

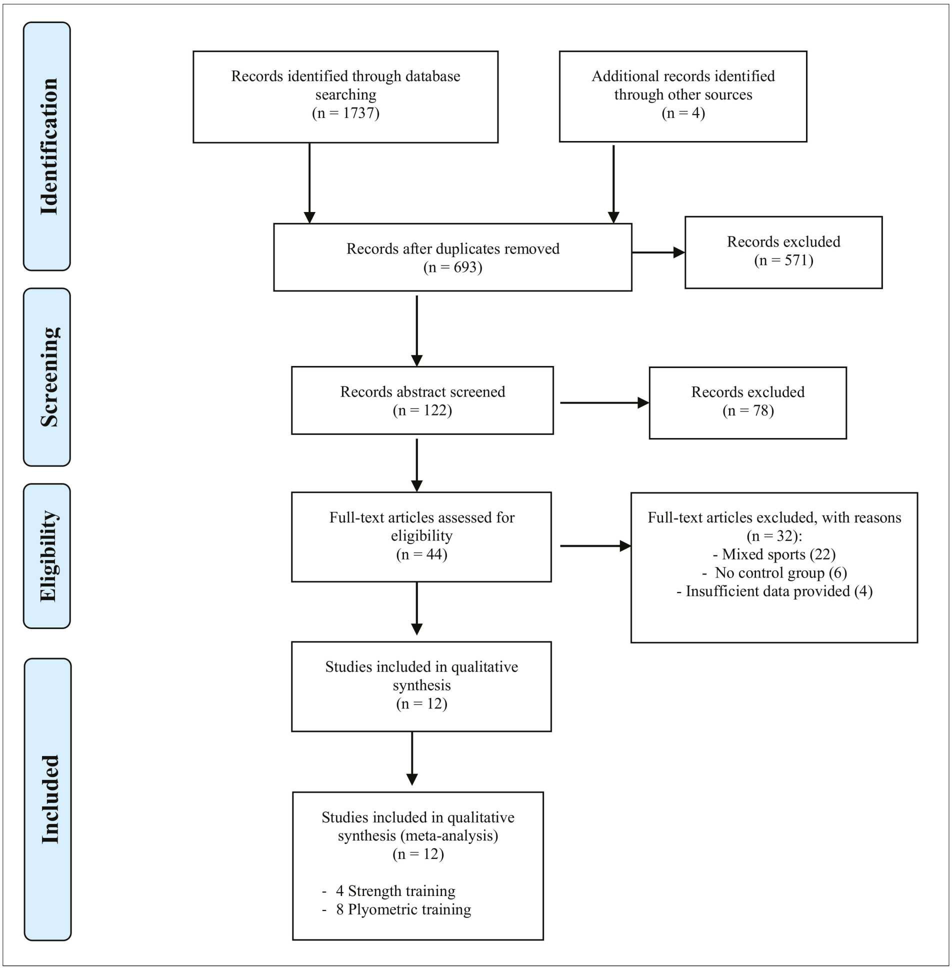


Figure 1. PRISMA flow chart for inclusion and exclusion of studies.

2.3. Procedures

In selecting studies for inclusion, a review of all relevant article titles was conducted before an examination of article abstracts and then full published articles. Two authors conducted the process independently. Potential discrepancies between the two reviewers about study conditions were resolved by consensus with a third author. Full-text articles excluded, with reasons, were recorded. Data were extracted from gathered articles by two authors independently, using a form created in Microsoft Excel (Microsoft Corporation, Redmond, WA, USA).

The extraction of data from gathered articles was undertaken by two reviewers.

The following criteria determined the eligibility of studies for inclusion in the review: cohorts of healthy female soccer players, with no restriction for age; strength and plyometric interventions must have been at least 2 weeks in duration and must have included a control group (CG) and group mean baseline and follow-up data outcome measures relating to vertical jump, linear sprint and COD performance. The study involved a randomized controlled trial or quasi-experimental design. Based on previous studies, we defined ST as "maximal strength and muscular hypertrophy to improve physical performance" [22] and

PT as "lower-body unilateral and bilateral bounds, jumps, and hops that use a pre-stretch or countermovement that incites usage of the stretch-shortening cycle" [23]. A measure of physical fitness was selected based on a logically defensible rationale [24,25], most often some form of countermovement jump (CMJ) without or with arms, linear sprint between 15 and 30 m, V-cut test, 505 test or Illinios Agility test.

2.4. Statistical Analyses

Meta-analytical comparisons were carried out in RevMan version 5.3 [26]. Included were 12 studies that comprised 13 individual experimental groups. Means and standard deviations for a measure of post-intervention performance within experimental group (pre- vs. posttest) and between groups (experimental vs. control group) were used to calculate an effect size (ES). Effect sizes were adjusted using Hedges' small sample size bias correction [27]. The inverse-variance random-effects model for meta-analyses was used because it allocates a proportionate weight to trials based on the size of their individual standard errors [28] and facilitates analysis whilst accounting for heterogeneity across studies [29]. Effect sizes are represented by the standardized mean difference (Hedges' g) and are presented alongside 95% confidence intervals. The calculated ESs were interpreted using the conventions outlined for standardized mean difference by Hopkins et al. [30] (<0.2 = trivial; 0.2–0.6 = small, 0.6–1.2 = moderate, 1.2–2.0 = large, 2.0–4.0 = very large, >4.0 = extremely large).

In cases in which there was more than one intervention group in a given study, the control group was proportionately divided to facilitate comparison across all participants [31].

To gauge the degree of heterogeneity amongst the included studies, the I^2 statistic was referred to. This represents the proportion of effects that are due to heterogeneity as opposed to chance [21]. Low, moderate and high levels of heterogeneity correspond to I^2 values of 25%, 50% and 75%; however, these thresholds are considered tentative [32]. The χ^2 (chi square) statistic determines if any observed differences in results are compatible with chance alone. A low p value, or a large χ^2 statistic, relative to its degrees of freedom, provides evidence of heterogeneity of intervention effects beyond those attributed to chance [28].

The Physiotherapy Evidence Database (PEDro) scale was used to assess the risk of bias and methodological quality of eligible studies included in the meta-analysis. This scale evaluates internal study validity on a scale from 0 (high risk of bias) to 10 (low risk of bias) to each methodological item listed in Table 1. A score of ≥ 6 represents the threshold for studies with a low risk of bias [29].

2.5. Analysis of Moderator Variables

To assess the potential effects of moderator variables, subgroup analyses were performed. This method, which was preferred to meta-regression, is based on the documented limitations on the latter method when applied to small datasets with low samples and few predictor variables [33].

Using a random-effects model, potential sources of heterogeneity likely to influence the effects of training were selected a priori. The moderator variables of program duration (weeks), training frequency (sessions per week), total number of training sessions and session duration (minutes) were chosen based on the accepted influence of the FITT (frequency, intensity, type and time) principle on adaptations to exercise [34], as previously demonstrated in meta-analyses performed in female athletes participating in different training interventions [12,35]. Each variable was divided using a median split, except for mean total sessions, in which studies were allocated as groups with more than 16 sessions and groups with less than 16 sessions. Meta-analysis stratification by each of these factors was performed, with a p value of <0.05 considered as the threshold for statistical significance.

3. Results

3.1. Study Selection

A total of 1737 studies were found in the identification phase. After removing duplicates and adding additional records identified through other sources, 693 publications were retained for the article selection process. Title and abstract selection excluded 571 articles. The remaining 44 records were further examined using the specified inclusion/exclusion criteria, and 32 records were subsequently rejected. Finally, 12 studies were included in the systematic review and meta-analysis (Figure 1).

3.2. Methodological Quality

The selected studies were submitted to the PEDro methodological quality scale. Two studies obtained a score of 9/10 [36,37], one study obtained 8/10 [38], six obtained 7/10 [5,6,39–41], two obtained 5/10 [42,43], and two obtained 4/10 [44,45]. Table 1 displays the complete and detailed PEDro scale score of each study.

Table 1. The Physiotherapy Evidence Database (PEDro) scale ratings.

Studies	N°1	N°2	N°3	N°4	N°5	N°6	N°7	N°8	N°9	N°10	N°11	Total [1]
Lindblom et al., 2012 [39]	1	1	1	1	1	0	0	0	0	1	1	7
Ozbar et al., 2014 [42]	0	1	0	1	0	0	0	1	0	1	1	5
Pardos-Mainer et al., 2019 [5]	0	1	1	1	1	0	0	1	0	1	1	7
Pardos-Mainer et al., 2020 [6]	0	1	1	1	1	0	0	1	0	1	1	7
Pedersen et al., 2019 [38]	1	1	1	1	1	0	0	1	0	1	1	8
Ramirez-Campillo 2016 b [41]	0	1	1	1	1	1	1	1	0	1	1	7
Ramirez-Campillo 2016 a [36]	0	1	1	1	1	0	0	1	0	1	1	9
Ramirez-Campillo 2018 (1 session/wk.) [40]	1	1	1	1	0	0	1	0	0	1	1	7
Ramirez-Campillo 2018 (2 session/wk.) [40]	1	1	1	1	0	0	1	0	0	1	1	7
Rosas et al., 2018 [37]	0	1	1	1	1	1	1	1	0	1	1	9
Rubley et al., 2011 [44]	0	0	0	1	0	0	0	1	0	1	1	4
Sedano del Campo et al., 2009 [43]	0	1	0	1	0	0	0	1	0	1	1	5
Siegler et al., 2003 [45]	0	0	0	1	0	0	0	1	0	1	1	4

[1] The total number of points from a possible maximal of 10.

3.3. Study Characteristics

The characteristics of the participants and ST and PT programming parameters from the 12 studies incorporated in the meta-analysis are indicated in Tables 2 and 3.

3.4. Main Effect

3.4.1. Vertical Jump Performance

Twelve studies were included in this systematic review and meta-analysis. Vertical jump height was measured in centimeters. The performance of training programs was associated with a moderate and significant increase in vertical jump performance (ES 0.53 (95% CI—0.11, 0.95), Z = 2.47 ($p = 0.01$)). There was a significant level of between-study heterogeneity ($I^2 = 69\%$ ($p = 0.0001$)). Concerning the subgroup analyses, non-significant performance improvements were observed after ST (ES 0.24 (95% CI −0.14, 0.62), Z = 1.23 ($p = 0.22$)). A significant difference was observed for PT (ES 0.73 (95% CI—0.33, 1.13), Z = 3.48 ($p = 0.0005$)). No significant differences among subgroups were observed ($p = 0.07$). Within-mode ESs were small and moderate (ST: ES 0.24 (95% CI −0.14, 0.62), Z = 1.23 ($p = 0.22$); PT: ES 0.73 (95% CI—0.33, 1.13), Z = 3.60 ($p = 0.0003$)), respectively. No significant differences among subgroups were observed ($p = 0.08$). These results are displayed in Figure 2 (ST vs. PT) and Figure 3 (baseline vs. follow-up).

Table 2. Characteristics of study participants of strength training.

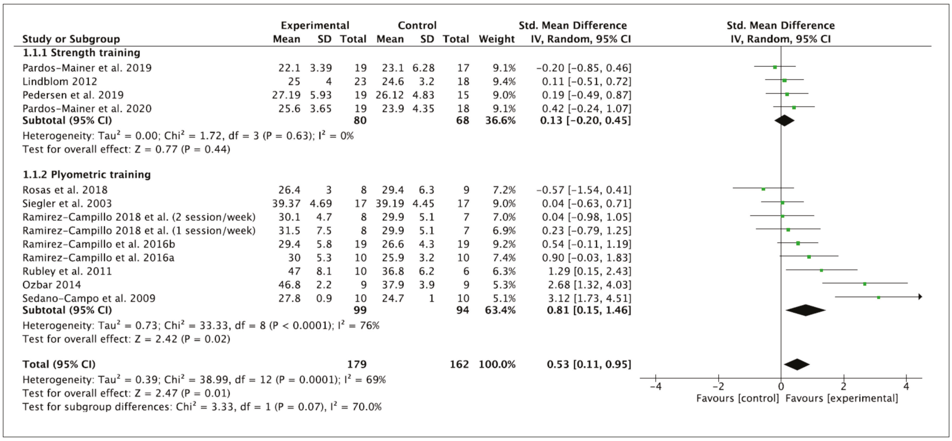
Study	Study Group	N	Age (Years)	BM (kg)	Height (cm)	SST	Wks	F	T	D	Exercise Type	Test	Response
Lindblom et al.	ST (FIFA 11+)	23	14.2 ± 0.7	53.9 ± 8.6	165 ± 6.5	Yes	11	2	22	15	One-legged knee squat, pelvic lift, two-legged knee squat, the bench, the lunge and jump/landing	CMJ 20-m linear sprint Illinois agility test	=CMJ =20-m linear sprint =Illinois agility test
	Control	18	14.2 ± 1.1	51.6 ± 7.4	164.2 ± 6.1								
Pardos-Mainer et al.	ST (FIFA 11+)	19	12.5 ± 0.4	51.2 ± 7.7	153.7 ± 6.9	Yes	10	2	20	20	Running, lower extremities' strength, balance, plyometric, agility and COD exercises	CMJ V-cut test	↑ CMJ ↓ V-cut test
	Control	17	13.1 ± 0.3	55.9 ± 8.2	160.8 ± 4.9								
Pardos-Mainer et al.	ST (CSPT)	19	16.2 ± 0.9	55.9 ± 5.5	159.8 ± 5.4	Yes	8	2	16	35	The diver, one-legged pelvic tilt, single leg box step-up, forward lunge, backward lunge, one-legged hip thrust, eccentric box drops, Russian belt posterior chain, Russian belt anterior chain, plank, lateral plank and lumbar bridge	CMJ 20-m linear sprint V-cut test	↑ CMJ ↑ 20-m linear sprint ↑ V-cut test
	Control	18	15.6 ± 0.9	54.1 ± 8.8	159.7 ± 4.9								
Pedersen et al.	ST	18	18 ± 3	62 ± 6	167 ± 6	Yes	5	2	10	NR	90°squat with load and Nordic hamstring exercises	CMJ 15-m linear sprint	=CMJ =15-m linear sprint
	Control	15	19 ± 2	63 ± 10	168 ± 5								

Note: BM: Body mass; CMJ; Countermovement jump; CSPT: Combined strength and power training; F: Frequency (per wk.); T: Total sessions; D: Mean session duration (min); NR: Non-reported; ST: Strength training; SST: Indicates if the participants had previous systematic experience with ST; FIFA: Federation international football association; COD: Change of direction.

Table 3. Characteristics of study participants of plyometric training.

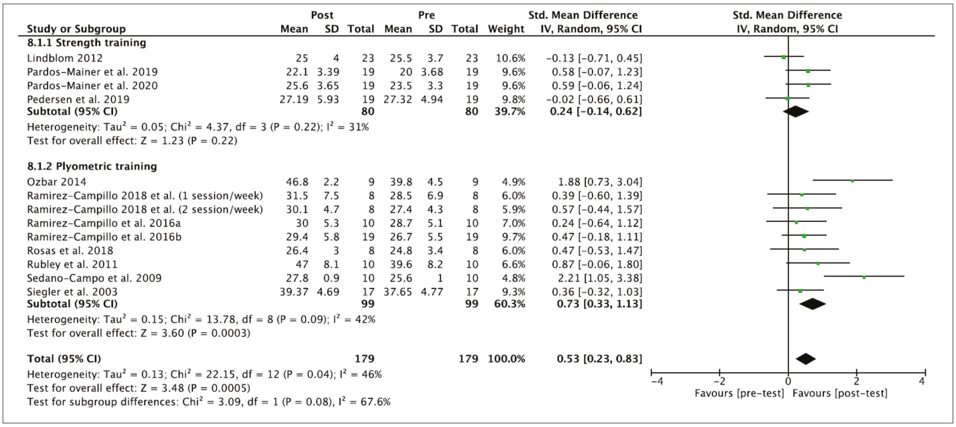
Study	Study Group	N	Age (years)	BM (kg)	Height (cm)	SPT	Wks	F	T	D	Exercise Type	Test	Response
Ozbar et al.	PT	9	18.3 ± 2.6	58.8 ±7.8	163.1 ± 5.3	Yes	1	8	8	30–40	Variety of plyometric exercises designed for the lower extremity (i.e., bilateral and unilateral DJs, CMJs and SLJ)	CMJ 20-m linear sprint	↑ CMJ ↑ 20-m linear sprint
	Control	9	18 ± 2	54.4 ± 6.1	159.4 ± 5.1								
Ramirez-Campillo 2016 a	PT	10	22.9 ± 2.1	56.8 ± 5.4	164 ± 9	No	2	6	12	NR		CMJ	↑ CMJ
	Control	10	22.5 ± 2.1	60.1 ± 7.5	161± 6								
Ramirez-Campillo 2016 b	PT	19	22.4 ±2.4	60.7 ± 9.3	161 ± 5	No	2	6	12	40		CMJ 30-m linear sprint COD speed test	↑ CMJ ↑ 30-m linear sprint ↑ COD speed test
	Control	19	20.5 ± 2.5	60.2 ± 9.3	159 ± 6								
Ramirez-Campillo 2018 (1 session/wk.)	PT	8	22.8 ± 4.3	54.9 ± 3.7	158 ± 3	No	1	8	8	6–20		CMJ 15-m linear sprint COD speed test	↑ CMJ ↑ 15-m linear sprint ↑ COD speed test
	Control	7	20.1 ± 1.8	55.3 ± 3.3	160.1 ± 5								
Ramirez-Campillo 2018 (2 session/wk.)	PT	8	21.4 ± 2.5	59.6 ± 8.5	157.6 ± 4.8	No	2	8	16	6–20		CMJ 15-m linear sprint COD speed test	↑ CMJ ↑ 15-m linear sprint ↑ COD speed test
	Control	7	20.1 ± 1.8	55.3 ± 3.3	160.1 ± 5								
Rosas et al.	PT	8	22.8 ± 2.1	61.1 ± 8.3	164 ± 8	No	2	6	12	NR		CMJ	↑ CMJ
	Control	9	24 ± 2.7	58.5 ± 7.2	132 ± 4								
Rubley et al.	PT	10	13.4 ± 0.5	50.8 ± 5.1	162.5 ± 5.6	No	1	12	12	NR		CMJA	↑ CMJA
	Control	6	NR	NR	NR								
Sedano- Campo et al.	PT	10	22.8 ± 2.1	58.5 ± 9.3	163 ± 7	Yes	3	12	36	46–60		CMJ	↑ CMJ
	Control	10	23 ± 3.2	56.9 ± 7.4	161.5 ± 5.4								
Siegler et al.	PT	17	16.5 ± 0.91	61.4 ± 9.43	167.4 ± 4.6	No	2 (1–3)	10	20	10–15		CMJA 20-m linear sprint	↑ CMJA ↑ 20-m linear sprint
	Control	17	16.2 ± 1.4	58 ± 7.23	166.7 ± 4.7								

BM: Body mass; DJ: Drop jump; CMJ; Countermovement jump; CMJA: CMJ with arm swing; NR: Non-reported; PT: Plyometric training; SPT: Indicates if the participants had previous systematic experience with PT; SLJ: Standing long jump.



Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.1.1 Strength training								
Pardos–Mainer et al. 2019	22.1	3.39	19	23.1	6.28	17	9.1%	−0.20 [−0.85, 0.46]
Lindblom 2012	25	4	23	24.6	3.2	18	9.4%	0.11 [−0.51, 0.72]
Pedersen et al. 2019	27.19	5.93	19	26.12	4.83	15	9.0%	0.19 [−0.49, 0.87]
Pardos–Mainer et al. 2020	25.6	3.65	19	23.9	4.35	18	9.1%	0.42 [−0.24, 1.07]
Subtotal (95% CI)			**80**			**68**	**36.6%**	**0.13 [−0.20, 0.45]**
Heterogeneity: Tau² = 0.00; Chi² = 1.72, df = 3 (P = 0.63); I² = 0%								
Test for overall effect: Z = 0.77 (P = 0.44)								
1.1.2 Plyometric training								
Rosas et al. 2018	26.4	3	8	29.4	6.3	9	7.2%	−0.57 [−1.54, 0.41]
Siegler et al. 2003	39.37	4.69	17	39.19	4.45	17	9.0%	0.04 [−0.63, 0.71]
Ramirez–Campillo 2018 et al. (2 session/week)	30.1	4.7	8	29.9	5.1	7	7.0%	0.04 [−0.98, 1.05]
Ramirez–Campillo 2018 et al. (1 session/week)	31.5	7.5	8	29.9	5.1	7	6.9%	0.23 [−0.79, 1.25]
Ramirez–Campillo et al. 2016b	29.4	5.8	19	26.6	4.3	19	9.2%	0.54 [−0.11, 1.19]
Ramirez–Campillo et al. 2016a	30	5.3	10	25.9	3.2	10	7.4%	0.90 [−0.03, 1.83]
Rubley et al. 2011	47	8.1	10	36.8	6.2	6	6.3%	1.29 [0.15, 2.43]
Ozbar 2014	46.8	2.2	9	37.9	3.9	9	5.3%	2.68 [1.32, 4.03]
Sedano–Campo et al. 2009	27.8	0.9	10	24.7	1	10	5.1%	3.12 [1.73, 4.51]
Subtotal (95% CI)			**99**			**94**	**63.4%**	**0.81 [0.15, 1.46]**
Heterogeneity: Tau² = 0.73; Chi² = 33.33, df = 8 (P < 0.0001); I² = 76%								
Test for overall effect: Z = 2.42 (P = 0.02)								
Total (95% CI)			**179**			**162**	**100.0%**	**0.53 [0.11, 0.95]**
Heterogeneity: Tau² = 0.39; Chi² = 38.99, df = 12 (P = 0.0001); I² = 69%								
Test for overall effect: Z = 2.47 (P = 0.01)								
Test for subgroup differences: Chi² = 3.33, df = 1 (P = 0.07), I² = 70.0%								

Figure 2. Forest plot of between-mode effect sizes with 95% confidence intervals (CIs) in vertical jump performance (cm). IV: inverse variance method; SD: standard deviation; Std: standardized.

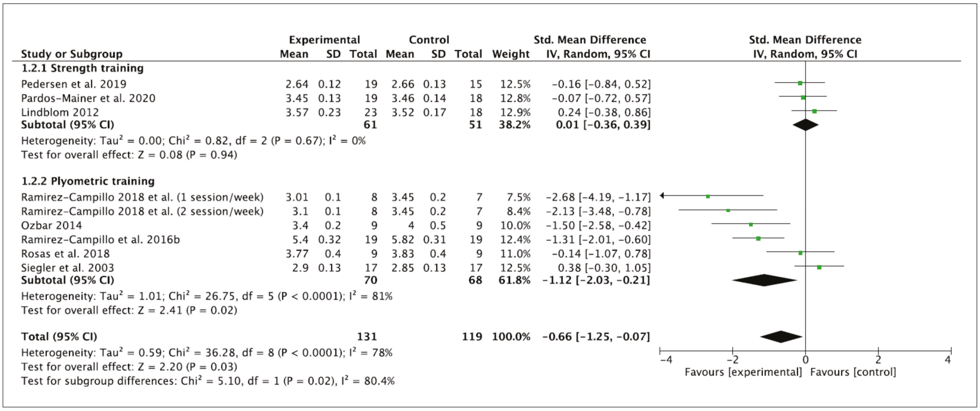


Study or Subgroup	Post Mean	Post SD	Post Total	Pre Mean	Pre SD	Pre Total	Weight	Std. Mean Difference IV, Random, 95% CI
8.1.1 Strength training								
Lindblom 2012	25	4	23	25.5	3.7	23	10.6%	−0.13 [−0.71, 0.45]
Pardos–Mainer et al. 2019	22.1	3.39	19	20	3.68	19	9.6%	0.58 [−0.07, 1.23]
Pardos–Mainer et al. 2020	25.6	3.65	19	23.5	3.3	19	9.6%	0.59 [−0.06, 1.24]
Pedersen et al. 2019	27.19	5.93	19	27.32	4.94	19	9.8%	−0.02 [−0.66, 0.61]
Subtotal (95% CI)			**80**			**80**	**39.7%**	**0.24 [−0.14, 0.62]**
Heterogeneity: Tau² = 0.05; Chi² = 4.37, df = 3 (P = 0.22); I² = 31%								
Test for overall effect: Z = 1.23 (P = 0.22)								
8.1.2 Plyometric training								
Ozbar 2014	46.8	2.2	9	39.8	4.5	9	4.9%	1.88 [0.73, 3.04]
Ramirez–Campillo 2018 et al. (1 session/week)	31.5	7.5	8	28.5	6.9	8	6.0%	0.39 [−0.60, 1.39]
Ramirez–Campillo 2018 et al. (2 session/week)	30.1	4.7	8	27.4	4.3	8	5.9%	0.57 [−0.44, 1.57]
Ramirez–Campillo et al. 2016a	30	5.3	10	28.7	5.1	10	7.0%	0.24 [−0.64, 1.12]
Ramirez–Campillo et al. 2016b	29.4	5.8	19	26.7	5.5	19	9.7%	0.47 [−0.18, 1.11]
Rosas et al. 2018	26.4	3	8	24.8	3.4	8	6.0%	0.47 [−0.53, 1.47]
Rubley et al. 2011	47	8.1	10	39.6	8.2	10	6.6%	0.87 [−0.06, 1.80]
Sedano–Campo et al. 2009	27.8	0.9	10	25.6	1	10	4.8%	2.21 [1.05, 3.38]
Siegler et al. 2003	39.37	4.69	17	37.65	4.77	17	9.3%	0.36 [−0.32, 1.03]
Subtotal (95% CI)			**99**			**99**	**60.3%**	**0.73 [0.33, 1.13]**
Heterogeneity: Tau² = 0.15; Chi² = 13.78, df = 8 (P = 0.09); I² = 42%								
Test for overall effect: Z = 3.60 (P = 0.0003)								
Total (95% CI)			**179**			**179**	**100.0%**	**0.53 [0.23, 0.83]**
Heterogeneity: Tau² = 0.13; Chi² = 22.15, df = 12 (P = 0.04); I² = 46%								
Test for overall effect: Z = 3.48 (P = 0.0005)								
Test for subgroup differences: Chi² = 3.09, df = 1 (P = 0.08), I² = 67.6%								

Figure 3. Forest plot of within-mode effect sizes with 95% confidence intervals (CIs) in vertical jump performance (cm). IV: inverse variance method; SD: standard deviation; Std: standardized.

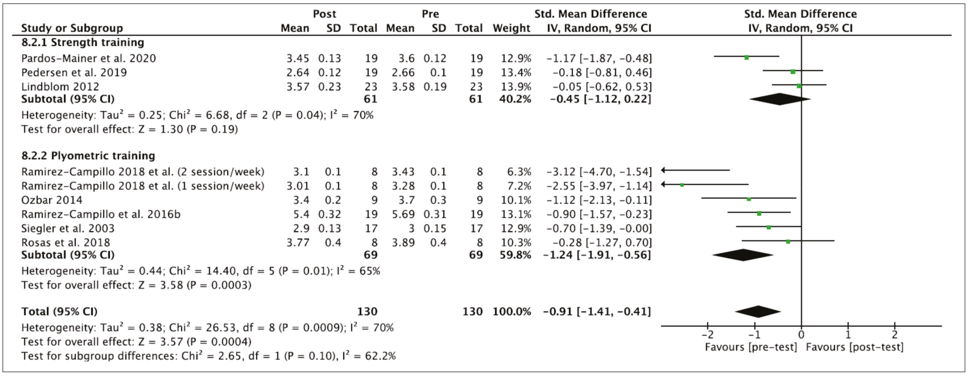
3.4.2. Linear Sprint Time

Nine effects were analyzed from 12 original studies. The linear sprint performance was measured in time (seconds). The performance of training programs was associated with a moderate and significant reduction in the time of linear sprint (ES −0.66 (95% CI −2.03, −0.21), Z = 2.20 (p = 0.03)). There was a significant level of between-study heterogeneity (I^2 = 78% (p = < 0.0001)). Concerning the subgroup analyses, non-significant performance improvements were observed after ST (ES 0.01 (95% CI −0.36, 0.39), Z = 0.08 (p = 0.94)). A significant difference was observed for PT (ES −1.12 (95% CI −2.03, 0.21), Z = 2.41 (p = 0.02)). Significant differences among subgroups were observed (p = 0.02). Within-mode ESs were small and large (ST: ES −0.45 (95% CI −1.12, 0.22), Z = 1.30 (p = 0.19); PT: ES −1.24 (95% CI −1.91, 0.56), Z = 3.58 (p = 0.0003)), respectively. No significant differences among subgroups were observed (p = 0.10). These results are displayed in Figure 4 (ST vs. PT) and Figure 5 (baseline vs. follow-up).



Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.2.1 Strength training								
Pedersen et al. 2019	2.64	0.12	19	2.66	0.13	15	12.5%	−0.16 [−0.84, 0.52]
Pardos-Mainer et al. 2020	3.45	0.13	19	3.46	0.14	18	12.8%	−0.07 [−0.72, 0.57]
Lindblom 2012	3.57	0.23	23	3.52	0.17	18	12.9%	0.24 [−0.38, 0.86]
Subtotal (95% CI)			**61**			**51**	**38.2%**	**0.01 [−0.36, 0.39]**
Heterogeneity: Tau² = 0.00; Chi² = 0.82, df = 2 (P = 0.67); I² = 0%								
Test for overall effect: Z = 0.08 (P = 0.94)								
1.2.2 Plyometric training								
Ramirez-Campillo 2018 et al. (1 session/week)	3.01	0.1	8	3.45	0.2	7	7.5%	−2.68 [−4.19, −1.17]
Ramirez-Campillo 2018 et al. (2 session/week)	3.1	0.1	8	3.45	0.2	7	8.4%	−2.13 [−3.48, −0.78]
Ozbar 2014	3.4	0.2	9	4	0.5	9	10.0%	−1.50 [−2.58, −0.42]
Ramirez-Campillo et al. 2016b	5.4	0.32	19	5.82	0.31	19	12.4%	−1.31 [−2.01, −0.60]
Rosas et al. 2018	3.77	0.4	9	3.83	0.4	9	11.0%	−0.14 [−1.07, 0.78]
Siegler et al. 2003	2.9	0.13	17	2.85	0.13	17	12.5%	0.38 [−0.30, 1.05]
Subtotal (95% CI)			**70**			**68**	**61.8%**	**−1.12 [−2.03, −0.21]**
Heterogeneity: Tau² = 1.01; Chi² = 26.75, df = 5 (P < 0.0001); I² = 81%								
Test for overall effect: Z = 2.41 (P = 0.02)								
Total (95% CI)			**131**			**119**	**100.0%**	**−0.66 [−1.25, −0.07]**
Heterogeneity: Tau² = 0.59; Chi² = 36.28, df = 8 (P < 0.0001); I² = 78%								
Test for overall effect: Z = 2.20 (P = 0.03)								
Test for subgroup differences: Chi² = 5.10, df = 1 (P = 0.02), I² = 80.4%								

Figure 4. Forest plot of between-mode effect sizes with 95% confidence intervals (CIs) in time of linear sprint (s). IV: inverse variance method; SD: standard deviation; Std: standardized.

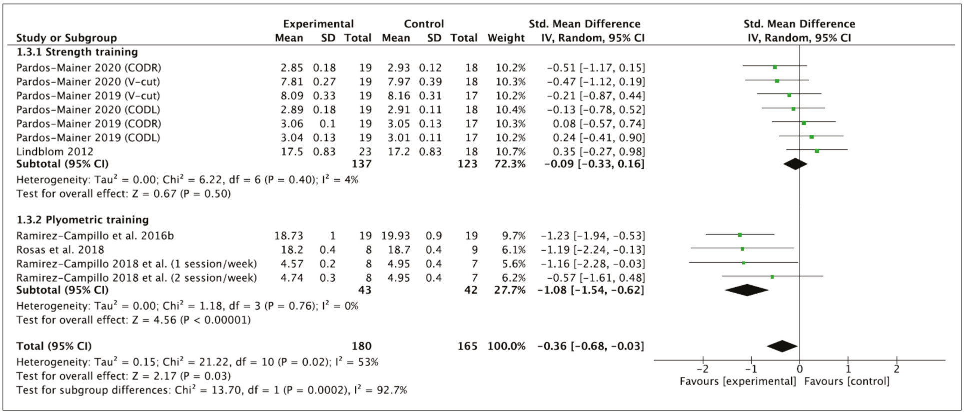


Study or Subgroup	Post Mean	SD	Total	Pre Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
8.2.1 Strength training								
Pardos-Mainer et al. 2020	3.45	0.13	19	3.6	0.12	19	12.9%	−1.17 [−1.87, −0.48]
Pedersen et al. 2019	2.64	0.12	19	2.66	0.1	19	13.4%	−0.18 [−0.81, 0.46]
Lindblom 2012	3.57	0.23	23	3.58	0.19	23	13.9%	−0.05 [−0.62, 0.53]
Subtotal (95% CI)			**61**			**61**	**40.2%**	**−0.45 [−1.12, 0.22]**
Heterogeneity: Tau² = 0.25; Chi² = 6.68, df = 2 (P = 0.04); I² = 70%								
Test for overall effect: Z = 1.30 (P = 0.19)								
8.2.2 Plyometric training								
Ramirez-Campillo 2018 et al. (2 session/week)	3.1	0.1	8	3.43	0.1	8	6.3%	−3.12 [−4.70, −1.54]
Ramirez-Campillo 2018 et al. (1 session/week)	3.01	0.1	8	3.28	0.1	8	7.2%	−2.55 [−3.97, −1.14]
Ozbar 2014	3.4	0.2	9	3.7	0.3	9	10.1%	−1.12 [−2.13, −0.11]
Ramirez-Campillo et al. 2016b	5.4	0.32	19	5.69	0.31	19	13.1%	−0.90 [−1.57, −0.23]
Siegler et al. 2003	2.9	0.13	17	3	0.15	17	12.9%	−0.70 [−1.39, −0.00]
Rosas et al. 2018	3.77	0.4	8	3.89	0.4	8	10.3%	−0.28 [−1.27, 0.70]
Subtotal (95% CI)			**69**			**69**	**59.8%**	**−1.24 [−1.91, −0.56]**
Heterogeneity: Tau² = 0.44; Chi² = 14.40, df = 5 (P = 0.01); I² = 65%								
Test for overall effect: Z = 3.58 (P = 0.0003)								
Total (95% CI)			**130**			**130**	**100.0%**	**−0.91 [−1.41, −0.41]**
Heterogeneity: Tau² = 0.38; Chi² = 26.53, df = 8 (P = 0.0009); I² = 70%								
Test for overall effect: Z = 3.57 (P = 0.0004)								
Test for subgroup differences: Chi² = 2.65, df = 1 (P = 0.10), I² = 62.2%								

Figure 5. Forest plot of within-mode effect sizes with 95% confidence intervals (CIs) in time of linear sprint (s) e. IV: inverse variance method; SD: standard deviation; Std: standardized.

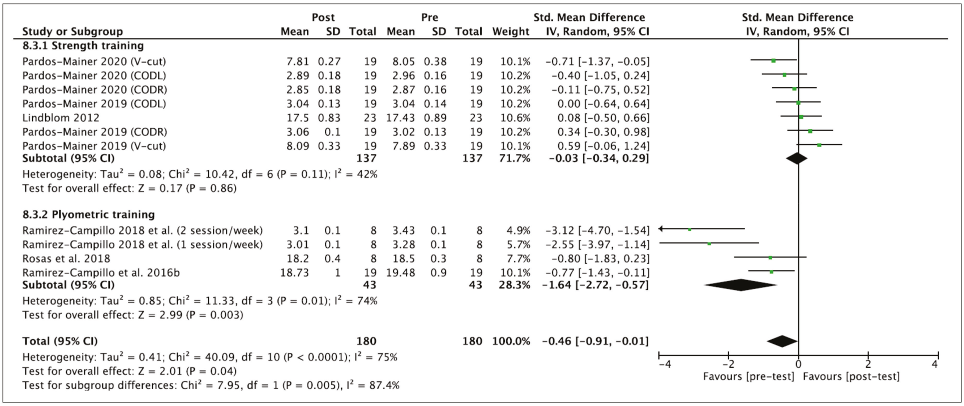
3.4.3. COD Time

Seven effects were analyzed from 12 original studies. The COD performance was measured in time (seconds). The performance of training programs was associated with a small and significant reduction in the time of COD (ES −0.36 (95% CI −0.68, −0.03), Z = 2.17 (p = 0.03)). There was a significant level of between-study heterogeneity (I^2 = 53% (p = 0.02)). Concerning the subgroup analyses, non-significant performance improvements were observed after ST (ES −0.09 (95% CI −0.33, 0.16), Z = 0.67 (p = 0.50)). A significant difference was observed for PT (ES −1.08 (95% CI −1.54, −0.62), Z = 2.17 (p = 0.03)). Significant differences among subgroups were observed (p = 0.0002). Within-mode ESs were small and large (ST: ES −0.03 (95% CI −0.34, 0.29), Z = 0.17 (p = 0.86); PT: ES −1.64 (95% CI −2.72, 0.57), Z = 2.99 (p = 0.003)), respectively. Significant differences among subgroups were observed (p = 0.005). These results are displayed in Figure 6 (ST vs. PT) and Figure 7 (baseline vs. follow-up).



Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.3.1 Strength training								
Pardos-Mainer 2020 (CODR)	2.85	0.18	19	2.93	0.12	18	10.2%	−0.51 [−1.17, 0.15]
Pardos-Mainer 2020 (V-cut)	7.81	0.27	19	7.97	0.39	18	10.3%	−0.47 [−1.12, 0.19]
Pardos-Mainer 2019 (V-cut)	8.09	0.33	19	8.16	0.31	17	10.2%	−0.21 [−0.87, 0.44]
Pardos-Mainer 2020 (CODL)	2.89	0.18	19	2.91	0.11	18	10.4%	−0.13 [−0.78, 0.52]
Pardos-Mainer 2019 (CODR)	3.06	0.1	19	3.05	0.13	17	10.3%	0.08 [−0.57, 0.74]
Pardos-Mainer 2019 (CODL)	3.04	0.13	19	3.01	0.11	17	10.2%	0.24 [−0.41, 0.90]
Lindblom 2012	17.5	0.83	23	17.2	0.83	18	10.7%	0.35 [−0.27, 0.98]
Subtotal (95% CI)			**137**			**123**	**72.3%**	**−0.09 [−0.33, 0.16]**
Heterogeneity: Tau² = 0.00; Chi² = 6.22, df = 6 (P = 0.40); I² = 4%								
Test for overall effect: Z = 0.67 (P = 0.50)								
1.3.2 Plyometric training								
Ramirez-Campillo et al. 2016b	18.73	1	19	19.93	0.9	19	9.7%	−1.23 [−1.94, −0.53]
Rosas et al. 2018	18.2	0.4	8	18.7	0.4	9	6.1%	−1.19 [−2.24, −0.13]
Ramirez-Campillo 2018 et al. (1 session/week)	4.57	0.2	8	4.95	0.4	7	5.6%	−1.16 [−2.28, −0.03]
Ramirez-Campillo 2018 et al. (2 session/week)	4.74	0.3	8	4.95	0.4	7	6.2%	−0.57 [−1.61, 0.48]
Subtotal (95% CI)			**43**			**42**	**27.7%**	**−1.08 [−1.54, −0.62]**
Heterogeneity: Tau² = 0.00; Chi² = 1.18, df = 3 (P = 0.76); I² = 0%								
Test for overall effect: Z = 4.56 (P < 0.00001)								
Total (95% CI)			**180**			**165**	**100.0%**	**−0.36 [−0.68, −0.03]**
Heterogeneity: Tau² = 0.15; Chi² = 21.22, df = 10 (P = 0.02); I² = 53%								
Test for overall effect: Z = 2.17 (P = 0.03)								
Test for subgroup differences: Chi² = 13.70, df = 1 (P = 0.0002), I² = 92.7%								

Figure 6. Forest plot of between-mode effect sizes with 95% confidence intervals (CIs) in the time of change of direction (s). IV: inverse variance method; SD: standard deviation; Std: standardized.



Study or Subgroup	Post Mean	Post SD	Post Total	Pre Mean	Pre SD	Pre Total	Weight	Std. Mean Difference IV, Random, 95% CI
8.3.1 Strength training								
Pardos-Mainer 2020 (V-cut)	7.81	0.27	19	8.05	0.38	19	10.1%	−0.71 [−1.37, −0.05]
Pardos-Mainer 2020 (CODL)	2.89	0.18	19	2.96	0.16	19	10.2%	−0.40 [−1.05, 0.24]
Pardos-Mainer 2020 (CODR)	2.85	0.18	19	2.87	0.16	19	10.2%	−0.11 [−0.75, 0.52]
Pardos-Mainer 2019 (CODL)	3.04	0.13	19	3.04	0.14	19	10.2%	0.00 [−0.64, 0.64]
Lindblom 2012	17.5	0.83	23	17.43	0.89	23	10.6%	0.08 [−0.50, 0.66]
Pardos-Mainer 2019 (CODR)	3.06	0.1	19	3.02	0.13	19	10.2%	0.34 [−0.30, 0.98]
Pardos-Mainer 2019 (V-cut)	8.09	0.33	19	7.89	0.33	19	10.1%	0.59 [−0.06, 1.24]
Subtotal (95% CI)			**137**			**137**	**71.7%**	**−0.03 [−0.34, 0.29]**
Heterogeneity: Tau² = 0.08; Chi² = 10.42, df = 6 (P = 0.11); I² = 42%								
Test for overall effect: Z = 0.17 (P = 0.86)								
8.3.2 Plyometric training								
Ramirez-Campillo 2018 et al. (2 session/week)	3.1	0.1	8	3.43	0.1	8	4.9%	−3.12 [−4.70, −1.54]
Ramirez-Campillo 2018 et al. (1 session/week)	3.01	0.1	8	3.28	0.1	8	5.7%	−2.55 [−3.97, −1.14]
Rosas et al. 2018	18.2	0.4	8	18.5	0.3	8	7.7%	−0.80 [−1.83, 0.23]
Ramirez-Campillo et al. 2016b	18.73	1	19	19.48	0.9	19	10.1%	−0.77 [−1.43, −0.11]
Subtotal (95% CI)			**43**			**43**	**28.3%**	**−1.64 [−2.72, −0.57]**
Heterogeneity: Tau² = 0.85; Chi² = 11.33, df = 3 (P = 0.01); I² = 74%								
Test for overall effect: Z = 2.99 (P = 0.003)								
Total (95% CI)			**180**			**180**	**100.0%**	**−0.46 [−0.91, −0.01]**
Heterogeneity: Tau² = 0.41; Chi² = 40.09, df = 10 (P < 0.0001); I² = 75%								
Test for overall effect: Z = 2.01 (P = 0.04)								
Test for subgroup differences: Chi² = 7.95, df = 1 (P = 0.005), I² = 87.4%								

Figure 7. Forest plot of within-mode effect sizes with 95% confidence intervals (CIs) in the time of change of direction (s). IV: inverse variance method; SD: standard deviation; Std: standardized.

3.5. Effect of Moderator Variables

A summary of the effect of moderator variables can be viewed in Tables 4 and 5.

3.6. Strength Training

Subgroup analysis suggested high levels of between-group heterogeneity with session duration in linear sprint performance and total number of training session and session duration in COD performance, achieving statistical significance ($p = 0.01$).

Table 4. Effect of moderator variables with 95% confidence intervals in strength training.

Variable	Subgroup	Effect Size with 95% Confidence Interval	Effect Descriptor	Groups	*n*	Within-Group I^2 (%)	Within-Group p [a]	Between-Group I^2 (%)	Between-Group p 1 [b]
CMJ	<8 weeks	−0.02 (−0.66; 0.61)	Trivial	1	61	NE	0.94	0.0	0.39
	≥8 weeks	0.33 (−0.16; 0.81)	Small	3	19	44.0	0.18		
	<2 sessions/week					NE			
	≥2 sessions/week	0.24 (−0.14; 0.62)	Small	4	80	31.0	0.22		
	≤16 sessions	0.28 (−0.32; 0.88)	Small	2	38	43.0	0.36	0.0	0.88
	>16 sessions	0.21 (−0.48; 0.90)	Small	2	42	61.0	0.55		
	<30 min/session	0.21 (−0.48; 0.90)	Small	2	42	61.0	0.55	44.0	0.18
	≥30 min/session	0.59 (−0.06; 1.24)	Small	1	19	NE	0.08		
Sprint test	<8 weeks	−0.18 (−0.81; 0.46)	Trivial	1	19	NE	0.59	0.0	0.43
	≥8 weeks	−0.59 (−1.70; 0.51)	Small	2	42	83.0	0.29		
	<2 sessions/week					NE			
	≥2 sessions/week	−0.45 (−1.12; 0.22)	Small	3	61	70.0	0.19		
	≤16 sessions	−0.67 (−1.64; 0.31)	Moderate	2	38	0.77	0.18	12.5	0.28
	>16 sessions	−0.05 (−0.62; 0.53)	Trivial	1	23	NE	0.87		
	<30 min/session	−0.05 (−0.62; 0.53)	Trivial	1	23	NE	0.87	83.3	0.01
	≥30 min/session	−1.17 (−1.87; −0.48)	Large	1	19	NE	<0.001		
COD tests	<8 weeks					NE			
	≥8 weeks	−0.03 (−0.34; 0.29)	Trivial	7	137	42.0	0.86		
	<2 sessions/week					NE			
	≥2 sessions/week	−0.03 (−0.34; 0.29)	Trivial	7	137	42.0	0.86		
	≤16 sessions	−0.40 (−0.78; −0.03)	Small	3	57	0.0	0.03	85.1	0.01
	>16 sessions	0.24 (−0.07; 0.55)	Trivial	4	80	0.0	0.13		
	<30 min/session	0.24 (−0.07; 0.55)	Trivial	4	80	0.0	0.13	85.1	0.01
	≥30 min/session	0.40 (−0.18; −0.03)	Small	3	57	0.0	0.03		

[a]: Test of null (2-tail), mixed model; [b]: p value, heterogeneity, total between, mixed model; NE: Not estimable.

Table 5. Effect of moderator variables with 95% confidence intervals in plyometric training.

	Subgroup	Effect Size with 95% Confidence Interval	Effect Descriptor	Groups	n	Within-Group I^2 (%)	Within-Group p [a]	Between-Group I^2 (%)	Between-Group p [b]
CMJ	<8 weeks	0.41 (−0.06; 0.87)	Small	3	37	0.0	0.08	52.2	0.15
	≥8 weeks	0.96 (0.37; 1.56)	Moderate	6	62	57.0	0.002		
	<2 sessions/week	1.00 (0.19; 1.80)	Moderate	3	27	46.0	0.01	0.0	0.42
	≥2 sessions/week	0.62 (0.15; 1.08)	Moderate	6	72	43.0	0.009		
	≤16 sessions	0.61 (0.27; 0.95)	Moderate	7	72	1.0	0.0004	0.0	0.52
	>16 sessions	1.22 (−0.60; 3.04)	Large	2	27	86.0	0.19		
	<30 min/session	0.41 (−0.07; 0.90)	Small	3	33	0.0	0.10	58.8	0.12
	≥30 min/session	1.44 (0.25; 2.63)	Large	3	38	78.0	0.02		
Sprint test	<8 weeks	−1.39 (−2.29; −0.48)	Large	5	50	72.0	0.003	0.0	0.40
	≥8 weeks	−0.90 (−1.57; −0.23)	Moderate	1	19	NE	0.008		
	<2 sessions/week	−1.75 (−3.14; −0.36)	Large	2	17	62.0	0.01	0.0	0.38
	≥2 sessions/week	−1.03 (−1.82; −0.23)	Moderate	4	52	68	0.01		
	≤16 sessions	−1.42 (−2.29; −0.56)	Large	5	52	80	0.02	39.2	0.20
	>16 sessions	−0.70 (−1.39; 0)	Small	1	17	NE	0.05		
	<30 min/session	−2.01 (−3.64; −0.37)	Very Large	3	33	82.0	0.02	0	0.37
	≥30 min/session	−1.12 (−2.13; −0.11)	Large	1	9	NE	0.03		
COD test	<8 weeks	−0.78 (−1.34; −0.22)	Moderate	2	27	0.0	0.006	91.0	0.0009
	≥8 weeks	−2.80 (−3.86; −1.75)	Very Large	2	16	0.0	<0.00001		
	<2 sessions/week	−1.16 (−2.28; −0.03)	Large	1	8	NE	0.04	0.0	0.77
	≥2 sessions/week	−0.97 (−1.48; −0.47)	Moderate	3	35	0.0	0.0002		
	≤16 sessions	−1.64 (−2.72; −0.57)	Large	4	43	74.0	0.003	NE	NE
	>16 sessions					NE			
	<30 min/session	−2.80 (−3.86; −1.75)	Very large	2	16	0.0	<0.00001	NE	NE
	≥30 min/session					NE			

[a]: Test of null (2-tail), mixed model; [b]: p value, heterogeneity, total between, mixed model; NE: Not estimable.

Differences were trivial to small between each training type across subgroups in vertical jump and COD performance and trivial to large in linear sprint performance. In linear sprint performance, interventions with a total number of training sessions of less than 16 sessions produced moderate effects (ES −0.67 (95%CI = −1.64; 0.31), Z = 1.34 (p = 0.18)) compared to those that lasted longer than 16 sessions (ES −0.05 (95%CI = −0.62; 0.53), Z = 0.16 (p = 0.87)). Sessions that lasted longer than 30 min were substantially more effective (ES −1.17 (95%CI = −1.87; −0,48), Z = 3.31 (p = 0.0009)) than those that lasted less than 30 min (ES −0.05 (95%CI = −0.62; 0.53)), Z = 0.16 (p = 0.87)). In COD performance, interventions with a total number of training sessions of less than 16 sessions produced smaller effects (ES −0.40 (95%CI = −0.78; −0.03), Z = 2.12 (p = 0.03)) than those that lasted longer than 16 sessions (ES 0.24 (95%CI = −0.07; 0.55), Z = 1.51 (p = 0.13)). Sessions that lasted longer than 30 min were substantially more effective (ES −0.40 (95%CI = −0.78; 0.03), Z = 2.12 (p = 0.03)) than those that lasted less than 30 min (ES 0.24 (95%CI = −0.07; 0.55), Z = 1.51 (p = 0.13)). In vertical jump and COD performance, the level of heterogeneity was higher in subgroups with longer programs, greater training frequency, more training sessions and fewer minutes per session. In linear sprint performance, levels of heterogeneity were higher in subgroups with longer programs, greater training frequency and fewer training sessions.

3.7. Plyometric Training

Subgroup analysis suggested high levels of between-group heterogeneity, with program duration in COD performance achieving statistical significance ($p < 0.001$). Differences were small to large in vertical jump, trivial to very large in linear sprint and moderate to very large in COD performance. All subgroup variables in linear sprint and COD performance demonstrated a significant effect. In vertical jump performance, only interventions with a total number of training sessions of more than 16 sessions (ES −1.22 (95%CI = −0.60; 3.04), Z = 1.32 (p = 0.19)) and which lasted less than 30 min (ES 0.41 (95%CI = −0.07; 0.90), Z = 1.66 (p = 0.10)) did not demonstrate a significant effect. In vertical jump performance, the level of heterogeneity was higher in subgroups with shorter programs, lower training frequency and more training sessions and minutes per session. In linear sprint performance, levels of heterogeneity were higher in subgroups with shorter programs, greater training frequency, fewer training sessions and fewer minutes per session. The level of heterogeneity in COD performance was higher in subgroups with fewer training sessions.

4. Discussion

The main findings of this meta-analysis indicate that PT can be used instead of ST to target vertical jump, linear sprint and COD performance in female soccer players. This has important implications for coaches because it means that female soccer players can developed vertical jump, linear sprint and COD qualities and technical skills concurrently, thus representing a more performance-efficient approach to training.

4.1. Vertical Jump Performance

The within- and between-mode analyses reveal that PT provides better benefits than ST in enhancing vertical jump performance in female soccer players. The magnitude of the improvements was deemed trivial for ST (ES = 0.13) and moderate for PT (ES = 0.81). However, the differences observed among the within- and between-groups were not significant. Therefore, the present meta-analysis cannot provide conclusive information regarding the best program to increase vertical jump performance in female soccer players.

Several reviews and meta-analyses support the notion that PT is an effective training program for the improvement of vertical jump performance in female athletes [12,36,46]. On the contrary, to the authors' knowledge, there have been no reviews conducted regarding the effects of ST on vertical jump performance in this population. The main reason is that less research is available for this population and, therefore, more studies are needed.

The purpose of ST is to promote maximal strength and muscular hypertrophy to improve physical performance [22], and this method has often been used by physical trainers in soccer training routines [7,47]. Two studies by Pardos-Mainer et al. [5,6] found that ST exerted a borderline small–moderate effect on vertical jump performance whilst Lindblom et al. [39] and Pedersen et al. [38] resulted only a trivial ES, and even the effect was negative. It is possible that the exercises included in the ST programs do not demonstrate a significant transference effect to soccer-specific physical performance and conditioning programs with higher load and intensity would be necessary in order to benefit from the training [8,35]

Moreover, if we observe the different exercises used in ST of the current meta-analysis, it can be argued that there is low resemblance between the exercises carried out and the evaluated CMJ performance test. These exercises were generally carried out at slow speeds, while the CMJ test included high-speed components.

PT concerns exercises that have the aim to improve muscle, mainly through the use of jump training [48,49]. Plyometric exercises represent a natural part of majority sport movement because they involve jumping, hopping and skipping [46,47,50]. Ozbar et al. [42] and Sedano-Campo et al. [43] found that PT exerted a large effect and Rubley et al. [44] found a moderate effect on vertical jump performance, whilst the rest of the PT studies [36,37,40,41] resulted only in a small ES. These results are in line with the results of two meta-analyses which showed that PT increases vertical jump performance for female athletes [8,35].

The aforementioned magnitude differences in vertical jump performance after ST and PT among female soccer players may be due to the diversity of training programs (e.g., frequency, duration, total time and total number of ST and PT sessions). To analyze this possibility, the effects of potential moderator variables were explored.

Subgroup analyses of programming parameters revealed that ST interventions were more effective with longer study durations (8 weeks or more), greater training frequency (2 sessions or more per week), more training sessions (16 or more) and longer session times (30 min or more) to improve vertical jump performance. However, only four studies [5,6,38,39] provided data and, owing to the homogeneity of programming parameters used across studies, more research, utilizing varying study durations, amounts of sessions, training sessions and session times, should be carried out to establish more robust recommendations regarding these parameters.

On the other hand, certain programming characteristics of PT interventions, such as longer study durations (8 weeks or more), reduced training frequency (less than 2 sessions per week), more training sessions (16 or more) and longer session times (30 min or more), could enhance the effectiveness of vertical jump performance, although there is no suggestion that these factors are necessarily synergistic when combined. Regarding PT frequency, interventions with less than two sessions per week [40,42,44] produced a moderate effect (ES: 1.00), while those with two or more sessions per week [36,37,40,41,45] also produced a moderate but weaker effect (ES: 0.62). Then, such ES values must be interpreted cautiously. In this sense, the large effect observed in training sessions and session times may be inflated, probably related with the results from Ozbar et al. [42], Sedano-Campo et al. [43] and Rubley et al. [44]. Two [38,40] of these three studies showed a moderate–large effect on vertical jump performance (ES = 0.87–2.21) after the PT program. Such substantial improvements may be related to the initial vertical jump values of female soccer players, which are too high compared to the rest of the studies included in the current meta-analysis. Furthermore, Sedano-Campo et al. [43] performed the PT intervention with elite female soccer players, with an average of 10 h of training a week. Then, the characteristics of participants may explain the moderate effect (ES = 0.87) increase in vertical jump performance. Finally, no significant subgroup differences were noted for any of the moderator variables.

In general, the evidence suggests that the moderator roles of ST in vertical jump performance in female soccer player are not clear and more research is necessary. Meanwhile, the moderator roles of PT in vertical jump performance are more conclusive and such information may aid sports coaches and trainers in selecting programming characteristics of PT in this population.

4.2. Liner Sprint Time

In the present meta-analysis, the within-mode analyses reveal that PT shows better benefits in enhancing the time of linear sprint in female soccer players than ST. In addition, the improvements were significant for the PT program. The magnitude of the improvements was deemed trivial for ST (ES = 0.01) and large for PT (ES = −1.12). The subgroup differences were significant. However, these results must be interpreted conservatively. Between-mode analysis provided a greater effect in both types of programs. ST produced a small effect (ES = −0.45) while PT produced a large effect (ES = −1.24). Moreover, no significant subgroup differences were noted for linear sprint performance ($p = 0.10$). It is interesting to observe the between-mode analysis due to the comparison between the same ST or PT group (intra-group), whilst within-mode analysis is a comparison between EG and CG of ST or PT training and, occasionally, this mode of analysis does not represent the reality of the results. In this sense, Pardos-Mainer et al. [5] demonstrated a large effect (ES = −1.17) in linear sprint performance after an ST which is combined with power exercises. Similar results have been found by Ozbar et al. [42] (ES = −1.12) after a PT. It is well acknowledged that horizontal force production has an important application in sprint acceleration performance [51]. Both PT and ST incorporated horizontal stimulus, and this may have increased the chances of gaining adaptations. Hence, these results highlight the importance of developing both lower body strength and power, which may enhance linear sprint performance in female soccer players.

Based on the data presented in Tables 4 and 5, on the one hand, certain ST programming characteristics, such as longer study durations (8 weeks or more), greater training frequencies (2 sessions or more per week), fewer training sessions (16 or less) and longer session times (30 min or more), could enhance the effectiveness of linear sprint performance. Indeed, significant subgroup differences were noticed ($p = 0.01$) regarding the session time. Regarding the duration and total number of ST sessions, interventions with durations of 30 min or more per session and 16 or fewer sessions demonstrated large (ES = −1.17) and moderate (ES = −0.67) effects, respectively. However, these findings are not clear but this could be due to the relatively low number of studies in this field [36,37], thus necessitating more research to clarify the time course of adaptation to ST in linear sprint performance in female soccer players. On the other hand, PT program characteristics such as short study durations (less than 8 weeks), lower training frequencies (2 sessions per week or less), fewer training sessions (16 or less) and short session times (less than 30 min) could improve the effectiveness of linear sprint performance. Nevertheless, no significant subgroup differences were noted for moderator variables. Characteristics of PT programs with low dosage may maximize one's probability of improving linear sprint performance and other meta-analysis studies support this finding [49].

It can be concluded that a PT program can enhance liner sprint performance over a distance down to 30 m in length. In addition, PT results in an increase in linear sprint performance, especially over the initial meter, between 15 and 30 m distances. A meaningful portion of the PT exercises in studies included in the current meta-analysis implicated slow stretch shortening cycle (SSC) muscle actions. These actions mimic those encountered during the acceleration phase of a sprint [52,53] compared to the faster SSC muscle actions of the maximal velocity of a sprint [52]. For this reason, the specificity principle of training may help to explain the enhancement in the linear sprint after a PT program [54]. In this sense, coaches and trainers should consider incorporating sprint specific exercises as part of the PT program.

4.3. COD Time

Within- and between-mode analyses reveal that PT is more beneficial in improving the time of COD performance in female soccer players than ST. The magnitude of the enhancements was deemed trivial for ST (ES = −0.03) and large for PT (ES = −1.64). Moreover, the subgroup differences were significant. Neuromuscular adaptations during the initial weeks in ST and PT are important [55,56]. Neural adaptations and improvement of motor unit recruitment are mechanisms that can lead to an enhancement in COD performance [56]. Improvements in COD ability require rapid force development, the eccentric strength of the thigh muscles and a rapid switch from eccentric to concentric muscle action in the leg-extensor muscles, and it seems that PT can improve these factors [57,58]. It is probable that PT studies [36,37,40] showed very large to moderate effects (ES = −3.12 to −0.77) because these programs incorporated vertical, horizontal and unilateral jumps that increased COD performance. However, Pardos-Mainer et al. [5] observed a moderate effect (ES = −0.71) after ST combined with isometric exercises. The isometric strength seems to be decisive to optimize the triple extension during COD tests, as a result of permitting the correct alignment of the lower limbs to then subsequently reaccelerate thereafter [59].

Further subgroup analyses of programming parameters also revealed some interesting findings. ST interventions were more effective with longer study durations (8 weeks or more), greater training frequencies (2 sessions or more per week), fewer training sessions (16 or less) and longer session times (30 min or more). Meanwhile, PT interventions were more effective with longer study durations (8 weeks or more), lower training frequencies (less than 2 sessions per week), fewer training sessions (16 or less) and longer session times (30 min or more). However, these results must be interpreted cautiously being as there are no existing ST and PT studies which examine these programming parameters.

On the one hand, significant ST subgroup differences were noted for total number and duration of sessions (p = 0.01); nevertheless, two studies [4,6] reported more than one outcome to evaluate the COD performance and may have overestimated the precision of this ability. On the other hand, significant subgroup differences were noticed regarding the PT duration (p = <0.01). However, ES values must be interpreted conservatively. The very large effect (ES = −2.80) observed with programs which were 8 weeks or longer may be inflated, probably related to the results from one [36] of the three studies that observed duration of training.

Overall, the evidence suggests that PT significantly improves COD performance; nevertheless, we cannot strongly recommend optimal training variables to improve COD performance in female soccer players. Researchers are therefore encouraged to conduct studies examining different ST and PT programming parameters in female soccer players.

4.4. Limitations

Besides the inherent limitations associated with the meta-analytic technique itself, a number of specific limitations of the current meta-analysis have to be considered. This meta-analysis does not allow coaches and trainers to provide definite ST or PT programs to enhance vertical jump, linear sprint and COD performance because mainly no significant subgroup differences were noticed according to moderator variables. However, the current meta-analysis indicates that PT improves, to a greater extent, these variables of performance than ST; nevertheless, the current results should be interpreted with caution and confirmed in the future. A limitation of the present body of literature is the relatively high number of researchers who did not incorporate a control group into their study design. Six studies [7,60–64] were excluded from the current meta-analysis because they did not provide any, or sufficient, control group data. The recruitment of individuals to studies can be difficult and the addition of a control group is not always possible in female soccer due to the smaller number of female players in comparison to their male counterparts. In this regard, we encourage future studies to compare the effects of ST and PT against a control group to elucidate which are the most beneficial in vertical jump, linear sprint or COD performance in female soccer players. Furthermore, due to the lack of studies in this population, we decided to pool the data of youth and adult female players in the meta-analysis to include a broader number of studies. However, the specific information of each study, presented in Tables 2 and 3, together the within- and between- values provided in Figures 2–7, allows interested readers to re-conduct the meta-analysis if they wish to delimitate the range of maturity status and age of studies further.

5. Conclusions

The findings of this systematic review and meta-analysis suggest that PT seems to provide better benefits than ST to improve vertical jump, linear sprint and COD performance in female soccer players. However, significant limitations in the current literature prevent assured PT and ST prescriptions recommendations being made. Based on our results, it seems that theses physical performance gains may be optimized by the use of vertical, horizontal and unilateral jumps at high speed and these exercises represent a natural part of the majority of sport movement because they involve jumping, hopping and skipping. In addition, exercises included in ST were generally carried out at slow speeds and could decrease the performance. Further research is needed in adolescent, recreational, elite and adult female soccer players to investigate the effects of PT and ST on performance. Furthermore, longer-term studies are also needed to determine and compare the long-term effectiveness of both training programs on performance.

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