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Research article

The Effects of a 6-Week Plyometric and Sprint Interval Training Intervention on Soccer Player's Physical Performance

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Abstract

Despite the well-documented benefits of sprint interval training (SIT) and plyometric training (PT) in improving the physical fitness of soccer players, it remains unclear which of these training methods is superior for enhancing players' aerobic and anaerobic performance. Therefore, this study aimed to compare the effects of SIT and PT on physical performance measures of male soccer players. Thirty male soccer players were randomly assigned to PT (n = 10), SIT (n = 10), and an active control group (CON, n = 10). Before and after the training period, participants underwent a battery of tests consisting of vertical jump, Wingate, linear sprint with and without ball dribbling, change of direction, ball kick, and the Yo-Yo intermittent recovery level 1 (Yo-Yo IR1) tests. Both groups exhibited similar improvements in maximal kicking distance (PT, effect size [ES] = 0.68; SIT, ES = 0.92) and measures of aerobic fitness including maximum oxygen uptake (PT, ES = 1.24; SIT, ES = 1.26) and first (PT, ES = 0.85; SIT, ES = 1.08) and second (PT, ES = 0.86; SIT, ES = 0.98) ventilatory thresholds. However, PT intervention resulted in greater changes in vertical jump (ES = 1.72 vs. 0.82, $p = 0.001$), anaerobic power (peak power, ES = 1.62 vs. 0.97, $p = 0.009$; mean power, ES = 1.15 vs. 1.20, $p = 0.05$), linear speed (20-m, ES = -1.58 vs. -0.98, $p = 0.038$; 20-m with ball, ES = -0.93 vs. 0.71, $p = 0.038$), and change of direction ability (ES = -2.56 vs. -2.71, $p = 0.046$) than SIT. In conclusion, both PT and SIT demonstrated effectiveness in enhancing aerobic performance among male soccer players. However, PT yielded superior improvements in anaerobic power, vertical jump, linear speed, and change of direction performance compared to SIT. These findings suggest that PT may offer additional benefits beyond aerobic conditioning.

Key words: Interval training, jump training, exercise performance, aerobic capacity.

Introduction

Soccer is a renowned team sport distinguished by intermittent bursts of intense movements, such as accelerations and decelerations, repetitive short-distance sprints, jumping, and multidirectional turns, tackling, kicking and holding off opposing players fueled by the anaerobic metabolic pathway (Kunz et al., 2019; Mohr et al., 2023). While the aerobic system primarily fuels play throughout the match, these brief, explosive, and decisive actions, which encompass a range of forceful and explosive concentric, eccentric, and isometric muscle contractions, can ultimately determine the match's outcome (Strudwick, 2016). Aerobic capacity dominates during less strenuous activities, facilitating quicker recovery and plays a determinant role in sustaining efforts throughout matches (Rampinini et al., 2011; Nyberg et al., 2016; Arazi et al., 2017).

A previous study showed significant associations between maximum oxygen uptake ($\dot{V}O_{2max}$) and the capacity for repeated sprint performance (Strudwick, 2016). A high level of $\dot{V}O_{2max}$ enables individuals to exercise at a higher intensity by utilizing oxygen efficiently to generate energy (Stojmenović et al., 2023). During a 90-minute match, players typically reach 80 to 90 percent of their maximum heart rate, corresponding to 70 to 80 percent of their VO_{2max} (Stølen et al. 2005). Submaximal thresholds, such as the aerobic threshold (first ventilatory threshold [VT_1]) and maximal lactate steady state/critical power (second ventilatory threshold [VT_2]), occurring at higher exercise intensities and significantly lower sub-maximal lactate concentrations, facilitate athletes in maintaining relatively high percentages of their $\dot{V}O_{2max}$ for extended durations, thereby aiding in the postponement of fatigue (Stølen et al., 2005; Dolci et al., 2020; Laursen and Buchheit, 2019).

Sprint interval training (SIT) has proven to be an effective method for improving cardiorespiratory fitness and anaerobic power in soccer athletes (Dai and Xie, 2023). It also leads to muscle fiber hypertrophy (Estes et al., 2017) and neural adaptations (Lewis et al., 2017), which can enhance jumping ability (Wahl et al., 2014), linear sprinting (Moran et al., 2019), and change of direction (Song and Deng, 2023).

Besides SIT, there has been a noticeable increase in research examining the effects of plyometric training (PT) on strength, power, and change-of-direction ability in soccer players (Asadi et al., 2018; Ramirez-Campillo et al., 2022). Studies have particularly highlighted improvements in neuromuscular properties, rate of force development, and firing rates (Ramirez-Campillo et al., 2022; Asadi et al., 2018). Notably, PT has been found to induce meaningful improvements in skill related performance such as 20-m sprint with dribbling the ball and maximal kicking velocity and shooting distance in soccer players (Sedano et al., 2011; Ramirez-Campillo et al., 2014; Asadi et al., 2018). However, despite its positive effects on sport-specific bio-motor abilities, the impact of PT on aerobic performance of other athletes have been examined recently (Ma et al., 2024), the effects of PT in soccer players' cardiorespiratory fitness remain unclear. In a comparative anal-

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ysis of cardiorespiratory response to different high-intensity interval training (HIIT) interventions, Ducrocq and colleagues (2020) indicated that engaging in high-intensity interval drop jumping elicits a similar response in the cardiorespiratory and oxidative systems as interval running. By eliciting ~90% $\dot{V}O_{2max}$ during interval drop jumps, these researchers suggested that interval drop jumping may have a superior benefit over running HIIT by concurrently enhancing both endurance and aerobic performance.

Previous studies have examined the effects of SIT or PT on performance measures of soccer players, typically reporting the overall group response without considering the individual variability in response to exercise training (Ramirez-Campillo et al., 2014; Arazi et al., 2017; Asadi et al., 2018). Furthermore, most studies that have analyzed individual responses to SIT have primarily focused on cardiorespiratory fitness and metabolic measures (Álvarez et al., 2017; 2018), neglecting other measures more relevant to soccer players, such as jumping ability or skill-based performance such as sprinting speed with the ball and maximal shooting distance. In addition, studies reporting the inter-individual variability in response to PT are limited (Ramirez-Campillo et al., 2018) and the adaptations to PT or SIT, focusing on inter-individual responses to training in physiological parameters and physical fitness attributes, still need to be fully understood. Therefore, this study aimed to compare the effects of a 6-week PT and SIT intervention on the physical performance of male soccer players.

Methods

Study design

This study employed a randomized parallel experimental design involving two training groups and a control group. The allocation of groups was determined using a computerized random number generator, resulting in unpredictable group assignments based on chance. This method was carried out in compliance with the guidelines specified in the "CONSORT" statement (http://www.consort-statement.org) (Figure 1). All players competed in the U23 national championship cup. The study lasted for a total of eight weeks, with one week allocated for pre-testing, six weeks for the training intervention, and a final week for post-testing. Before the commencement of the study, participants underwent a set of assessments, including both lab- and field-based measurements, to assess cardiorespiratory fitness indicators and soccer-specific bio-motor abilities. Anthropometric measurements, such as height and body mass, were taken during the initial visit. A graded exercise test was conducted to determine maximum oxygen uptake and other physiological variables. The second visit focused on measuring Wingate-based anaerobic power. Jumping ability, maximal kicking distance, and Yo-Yo intermittent recovery test level 1 were assessed during the third testing session. Change of direction (COD) and linear speed were evaluated during the fourth occasion. Testing sessions were spaced 24 hours apart, with participants instructed to avoid caffeine, alcohol, and strenuous exercise. Training sessions were scheduled in the afternoon to minimize circadian variations. Participants underwent the same tests post-training period to compare results (Table 1). Prior to the initiation of the tests, a 15-minute general warm-up routine was carried out to all participants. The performance tests were conducted on a soccer field of natural grass, with temperatures ranging from 26 - 28°C and wind speeds below 20 km/h. Additionally, lab-based physiological parameters were measured in the laboratory, where the temperatures ranged from 25 - 27°C and the humidity ranged from 45 - 50%. To eliminate any potential effects of shoes, all players were instructed to wear the same footwear during the pre- and post-tests.

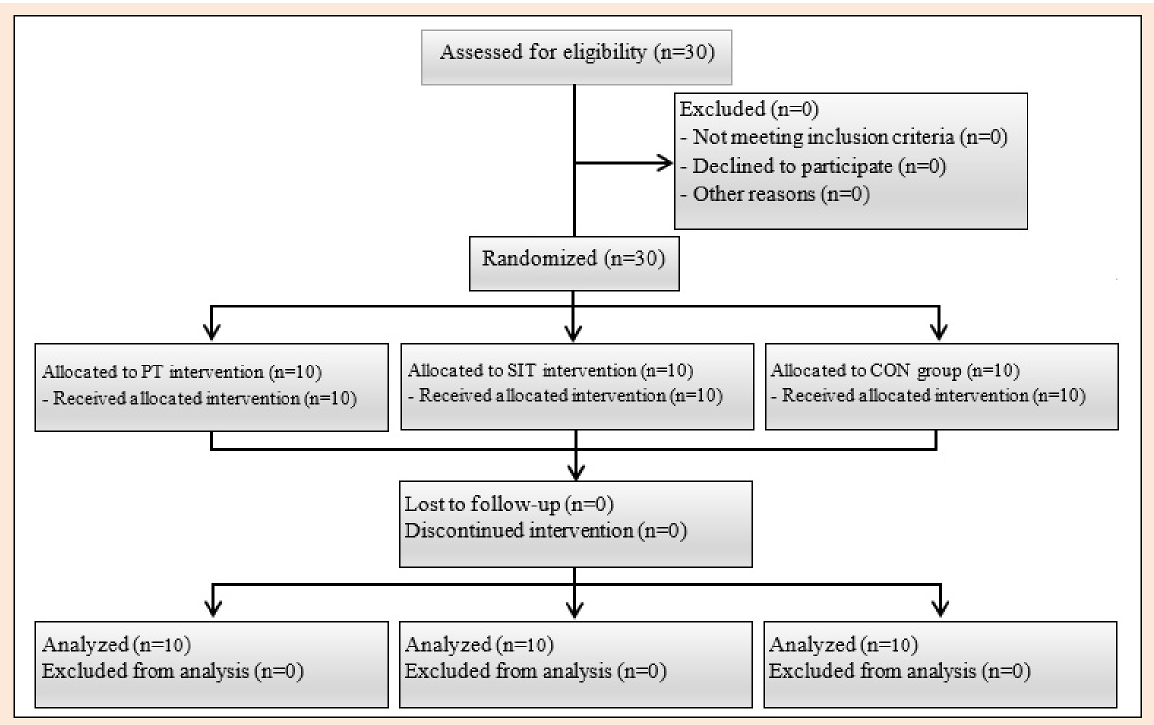

Figure 1. Study flow.

Table 1. An overview the training program for a one-week example during the experimental period.

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Morning session	Individual fitness*	Rest	Video or multidisciplinary activities	Massage therapy	Video or multidisciplinary activities	Individual fitness	Rest
Evening session	PT or SIT + Technical-tactical drills	Technical-tactical drills, Simulated competitive games	PT or SIT + Technical-tactical drills	Technical-tactical drills, Small-sided games	PT or SIT + Technical-tactical drills	Rest	Rest

* Individual Fitness: Development and strengthening of individual physical potential according to playing position on the pitch.

Participants

The sample size was determined using G*Power software (Version 3.1.9.2, University of Kiel, Germany). Initially, based on a 95% confidence interval and an analysis power of 0.80, eight subjects were calculated for each group. However, to mitigate potential participant dropout during data collection, the sample size was subsequently increased to 10 participants per group. A total of thirty male soccer players (twelve defenders, twelve midfielders, and six attackers) who were members of a local academy soccer team, participated in the study. They were matched based on their playing position (4 defenders, 4 midfielders, and 2 attackers, n = 10 for each group) and the level of cardiorespiratory fitness (i.e., $\dot{V}O_{2max}$) and were randomly divided into plyometric training (PT; n = 10: age = 21.2 ± 1.4 years, height = 178.6 ± 7.5 cm, body mass = 75.5 ± 7.1 kg, and soccer experience = 7.1 ± 2.5 years), sprint interval training (SIT; n = 10: age = 22.4 ± 1.6 years, height = 179.2 ± 7.7 cm, body mass = 75.8 ± 6.9 kg, and soccer experience = 7.6 ± 2.1 years) and an active control group (CON; n = 10: age = 22.2 ± 1.9 years, height = 174.6 ± 8.8 cm, body mass = 77.5 ± 5.1 kg, and soccer experience = 6.4 ± 3.2 years). Exclusion criteria were applied to players with potential medical issues or a history of ankle, knee, or back problems within three months before the study. Additionally, players with medical or orthopedic problems that could compromise their participation or performance in the study and those who had undergone lower extremity reconstructive surgery within the past two years or had unresolved musculoskeletal disorders were also excluded before commencement of the study. All players were thoroughly informed about the experimental procedures, as well as the potential risks and benefits associated with their inclusion in the study, and they signed an informed consent document prior to any testing. The study was conducted in accordance with the Declaration of Helsinki and received approval from the ethics committee of the University of Chengdu Aeronautic Polytechnic.

Lower-body Wingate test

In addition, the 30-second maximal Wingate anaerobic test was used to evaluate soccer players' lower-body peak power output (PPO) and mean power output (MPO). Athletes performed the test on a mechanically braked cycle ergometer (model 894E, Monark, Sweden) and pedaled against a resistance equivalent to 0.075 kg/kg of their body mass. They began the test by pedaling at maximum speed against the device's inertial resistance, followed by applying a personalized load. The players were verbally encouraged to pedal at maximum effort for 30 seconds. The highest power achieved at the 5-second mark (i.e., PPO) and the average power throughout the test (i.e., MPO) were identified for further analysis (Bayati et al., 2011). The ICC for this test was 0.94.

Vertical jump performance

This study utilized the vertical jump to evaluate the jumping ability of the lower body, using the wall mounted VERTEC (Power System, USA), as previously described in detail (Song and Deng, 2023). The players underwent a warm-up phase consisting of 3 submaximal jumps, followed by three maximal vertical jumps, with the objective of reaching the highest possible height in cm. A 10-second rest period was provided between each trial. The best score of the three measurements was selected for further analysis, and the intraclass correlation coefficient (ICC) was 0.93.

Linear sprint (with and without the ball)

The selection of a 20-meter sprint test is based on its frequent application in evaluating the sprinting speed of soccer players (Burgess et al., 2006; Asadi et al., 2018; Dai and Xie, 2023). Two self-paced practice trials were provided to each player for a specific warm-up. Once the players were prepared, they commenced the run from a stationary position 0.5 m behind the starting line. Upon the command "GO," the players ran along a 20-m linear track, both with and without dribbling the ball (size-5 Nike). The fastest sprint time from the three trials, with a 1-minute rest in between, was chosen for further analysis. The running time was accurately recorded using photocell gates (Muscle Lab, Technology) positioned 0.4 m above the ground, with a precision of 0.001 s. The ICC for the sprint test was 0.94 and 0.92 for the trials with and without the ball, respectively.

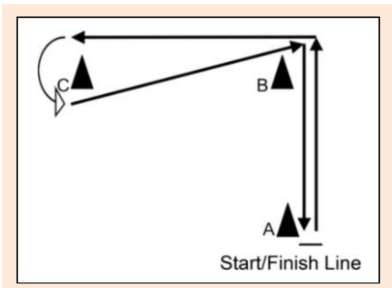

Figure 2. L-Run procedure. For the L-run, 3 cones were placed 5 m apart in the shape of an L. Players were instructed to run as quickly as possible along the L.

L-run change of direction

The L-run COD test was implemented to evaluate the ability of soccer players to accelerate, decelerate, and take turns in various directions (Langley and Chetlin, 2017). Following the warm-up, participants were presented with a diagram (refer to Figure 2) and given a written description of the agility course. Afterward, the researcher led the participants throughout the agility test to ensure understanding. Following a series of practice attempts, participants were directed to stand at the starting line (marked by A cone) and commence the trial upon instruction. Participants were then instructed to begin running upon the command to "GO". The time taken to complete the run was precisely measured using photocell gates (Muscle Lab, Technology) positioned 0.4 m above the ground, with an accuracy of 0.001 s at the start/finish cone. Three attempts were made, with a minimum of one minute of rest between each attempt, and the best performance was chosen for subsequent statistical analysis. The ICC of this test was 0.94.

Maximal kicking distance measurement

Maximal kicking distance (MKD) is a skill-based measure of extensor muscle power which is frequently used by studies to evaluate this parameter (Ramírez-Campillo et al., 2014; Asadi et al., 2018). To evaluate the maximal distance of a soccer player who kicks a ball with one foot (i.e., dominant foot), the MKD test is used as a standard test described in detail previously (Ramirez-Campillo et al., 2015). Briefly, following a warm-up, each player was instructed to kick a size-5 Nike Seitiro, a FIFA-certified ball, for the farthest distance possible on a grass soccer field. A 60-meter metric tape was placed across the field to measure the distance accurately, spanning from the kicking line to the opposite end. An evaluator positioned near the ball's landing spot marked the point of impact and determined the distance traveled by the ball. The recorded distance was rounded to the nearest 20 cm. The best kick out of three attempts, with a one-minute rest between each trial, was selected for analysis purposes. The ICC of this test was 0.89.

Yo-Yo Intermittent Recovery level 1

The Yo-Yo IR1 was utilized as a standardized fitness assessment for the aerobic capacity of soccer players using a valid procedure previously described in detail by Krustrup et al. (2003). The test involves a series of 20-m shuttle runs, with the pace gradually increasing. Each shuttle run covers a distance of 20 m and is followed by a 10-second active recovery period. Players were instructed to continue running until they reached a point of voluntary exhaustion. For analysis purposes, the total distance covered by the shuttles was recorded, excluding the distance covered during the rest interval. The ICC of this test was 0.93.

Cardiorespiratory fitness

The maximal oxygen consumption ($\dot{V}O_{2max}$), oxygen pulse ($\dot{V}O_2$/HR), and measures of respiratory system consisting of maximal ventilation ($\dot{V}_E$), tidal volume ($\dot{V}_T$), and respiratory frequency (R_f) were evaluated using an incremental exercise test on a treadmill (Technogym, Italy) and a breath-by-breath gas collection system (2700 series; Hans Rudolph Inc., Shawnee, KS, USA). The test was initiated with 8 km/hr intensity and increased by 1 km/hr every 3 minutes until the players reached volitional exhaustion. A 30-second rest interval for blood sampling followed each stage. Blood lactate concentrations (BLa) were determined from the earlobe using a blood lactate measurement device (Lactate Pro 2 LT-1730, Arkray, Japan). The $\dot{V}O_{2max}$ was determined as the highest 30-second value during the test. According to the study of Sheykhlouvand and colleagues (2022), several criteria including a) a leveling off of $\dot{V}O_2$ despite an increase in workload; b) a respiratory exchange ratio greater than 1.1; c) BLa levels of 8 mmol/L or higher; d) HRmax of at least 95% of the age-predicted maximum (220 - age); and e) volitional exhaustion were used to determine if the athlete reached $\dot{V}O_{2max}$. The first and second ventilatory thresholds (VT_1 and VT_2) were determined using previously standardized criteria (Sheykhlouvand and Gharaat, 2024). The ICC was 0.96.

Training intervention

The players followed their regular schedule on each day of the week (see Table 1). They players in training groups participated in PT or SIT on Monday, Wednesday, and Friday afternoons, specifically from 5:00 to 7:00 P.M, before their soccer training sessions, while the active CON group engaged in soccer practice only. A 15-minute warm-up (i.e., 5 minutes of running, 5 minutes of stretching, and 5 minutes of sprinting and ballistic movements) was conducted. The PT program consisted of four different exercises: squat jump, tuck jump, lateral box jump utilizing a 40-cm box, and depth jump from a 45-cm box (Chu, 1998). Each exercise consisted of three sets of ten repetitions with maximal intensity (i.e., *all-out*), with rest intervals of 30 and 60 seconds between sets and exercises, respectively (Ramirez-Campillo et al., 2014). On the other hand, the SIT group engaged in four sets of ten repetitions of five-second *all-out* running, with a recovery period of 1:3 ratios (i.e., 5 seconds of run: 15 seconds of rest) between efforts and three minutes of recovery between sets (Boullosa et al., 2022).

A specialist soccer and strength and conditioning coach closely monitored all training sessions to ensure proper techniques were employed. The training groups were prescribed with the same training frequency, number of series, work duration, and rest duration to ensure a consistent exercise prescription (Venegas-Carro et al., 2023).

Dietary control

All players were instructed to maintain their dietary habits throughout the study. Furthermore, they were requested to document and evaluate their food diaries for three days before the baseline testing using software (COMP EAT 4.0; National Analysis System, London, United Kingdom). The players adhered to comparable dietary patterns, with their caloric intake comprising 25% protein, 60% carbohydrates, and 15% fat. Moreover, they were advised against other supplements and were only instructed to consume 1000 mg of Vitamin C daily during the training sessions to enhance recovery.

Statistical analysis

The data are presented as the mean ± standard deviation (SD). To compare the differences between groups, a 3 (group) x 2 (time) analysis of variance (ANOVA) was conducted. The magnitude of training effects was assessed using the effect size (ES) with a 95% confidence interval (CI). Hedge's g was used to calculate the effect size for all measures. According to the classification proposed by Hopkins et al. (2009), an effect size of less than 0.2 was considered trivial, 0.2 - 0.6 was small, 0.6 - 1.2 was moderate, 1.2 - 2.0 was large, 2.0 - 4.0 was very large and greater than 4.0 was nearly perfect. Individual percent changes (Δ% = (post - pre) / pre × 100) over time were calculated for each variable. Additionally, individual residuals in percent changes were calculated by taking the square root of the squared difference between the individual percent change and the mean percent change for each tested variable. The significance level was set at 0.05.

Results

Pre- to post-intervention changes in physical performance and aerobic and anaerobic fitness measures are presented in Table 2 and Table 3, respectively. All players demonstrated complete adherence, resulting in a success rate of 100%. Furthermore, there were no reported occurrences of injuries associated with the training interventions. Additionally, no statistically significant differences ($p > 0.05$) were noted between the groups at the baseline. In addition, after the training period both SIT and PT groups indicated significant differences compared with CON group in all measures ($p = 0.001$). Significant ($p < 0.05$) changes in measures were observed in both the PT and SIT groups at post-intervention, with ESs ranging from medium to very large ($p = 0.001$). In the vertical jump ($p = 0.001$), PPO ($p = 0.009$), MPO ($p = 0.05$), 20-m linear sprint ($p = 0.038$), 20-m sprint with dribbling ball ($p = 0.036$) and L-run CODS ($p = 0.046$), the PT group indicated significant differences compared with SIT group.

The comparison of group changes revealed that the PT group exhibited significantly greater improvements in vertical jump ($p = 0.001$), PPO ($p = 0.007$), MPO ($p = 0.013$) (see Figure 3), 20-m linear sprint performance ($p = 0.034$), 20-m sprint performance with dribbling ($p = 0.025$), and COD ($p = 0.001$) (see Figure 4) compared to the SIT group. However, the observed changes in MKD (see Figure 5), Yo-Yo IR1, $\dot{V}O_{2max}$, VT_1, and VT_2 (see Figure 6) did not differ significantly between the groups ($p > 0.05$). Additionally, the analysis of individual residuals in adaptive changes indicated similar inter-subject variability in response to PT and SIT ($p > 0.05$). Furthermore, the variables related to gains in cardiorespiratory fitness including VO_2/HR, V_E and R_f increased significantly ($p < 0.05$) after training, without significant differences between the SIT and PT groups (Table 3).

Discussion

The aim of this study was to compare the effects of SIT and PT on physical performance of male soccer players. The findings revealed that PT is significantly superior to SIT in eliciting greater changes in vertical jump, PPO, MPO, 20-m sprint with and without the ball, and L-run CODS. However, both groups exhibited similar improvements in MKD and measures of aerobic capacity, including Yo-Yo IR1, $\dot{V}O_{2max}$, VT_1, and VT_2.

Following the 6-week intervention, both the PT and SIT groups exhibited enhancements in their anaerobic power performance, as measured by vertical jump, PPO, and MPO. Moreover, significant differences were observed between the training groups and an active CON group, suggesting that soccer training alone may not effectively foster adaptations in anaerobic power performance. These findings are supported by previous studies highlighting the effects of PT (Ramirez-Campillo et al., 2018; Asadi et al., 2018) and SIT (Moran et al., 2019; Kunz et al., 2019; Boullosa et al., 2022) on improving the vertical jump, PPO, and MPO of soccer players. Previous findings indicate that improvements in anaerobic power performance induced by SIT are associated with enhanced neuromuscular adaptations, such as increased rate of force development and firing rate of muscles (Buchheit and Laursen, 2013). Conversely, the increased anaerobic power performance resulting from short-term PT can be attributed to neuromuscular adaptations, including enhanced muscular coordination, inhibition of antagonist muscles, and activation and contraction of synergistic muscles and motor units (Ramirez-Campillo et al., 2014; Asadi et al., 2018).

Table 2. Changes in performance variables from pre- to post-training for all groups (Mean±SD).

Variable		Group		
		PT (n = 10)	SIT (n = 10)	CON (n = 10)
Vertical jump (cm)	Pre	45.6 ± 2.9	45.6 ± 3.1	44.8 ± 3.1
	Post	51.2 ± 3.2 *, **	48.4 ± 3.6*	45.1 ± 3.6
	ES (95% CI)	1.72 (0.69 to 2.75)	0.82 (-0.09 to 1.74)	-
20-m sprint (sec)	Pre	3.88 ± 0.19	3.88 ± 0.21	3.89 ± 0.18
	Post	3.54 ± 0.22 *, **	3.70 ± 0.15*	3.88 ± 0.21
	ES (95% CI)	-1.58 (-2.59 to -0.58)	-0.98 (-1.90 to -0.05)	-
20-m sprint with ball (sec)	Pre	5.13 ± 0.35	5.15 ± 0.16	5.14 ± 0.12
	Post	4.81 ± 0.31 *, **	4.92 ± 0.16*	5.13 ± 0.11
	ES (95% CI)	-0.93 (-1.58 to 0.00)	-0.71 (-1.61 to 0.19)	-
L-run COD (sec)	Pre	8.58 ± 0.23	8.55 ± 0.19	8.53 ± 0.21
	Post	8.05 ± 0.16 *, **	8.12 ± 0.11*	8.56 ± 0.19
	ES (95% CI)	-2.56 (-3.74 to -1.38)	-2.71 (-3.93 to -1.50)	-
MKD (m)	Pre	38.5 ± 4.9	39.4 ± 3.1	40.1 ± 2.9
	Post	42.1 ± 5.6*	42.7 ± 3.8*	40.2 ± 3.1
	ES (95% CI)	0.68 (-0.22 to 1.58)	0.92 (0.00 to 1.84)	-
Yo-Yo IR 1 (distance)	Pre	1382 ± 116	1366 ± 147	1354 ± 176
	Post	1626 ± 118*	1608 ± 155*	1378 ± 158
	ES (95% CI)	2.00 (0.92 to 3.07)	1.53 (0.54 to 2.53)	-

* Significantly greater than pre-training value and significantly greater change than the CON group. ** Significantly greater changes than SIT group.

Table 3. Changes in cardiorespiratory fitness and anaerobic power output variables from pre- to post-training for all groups (Mean±SD).

Variable		Group		
		PT (n = 10)	SIT (n = 10)	CON (n = 10)
$\dot{V}O_{2max}$ (ml.kg^{-1}.min^{-1})	Pre	50.1 ± 2.2	50.2 ± 2.3	50.1 ± 2.6
	Post	53.2 ± 2.5*	53.3 ± 2.3*	50.4 ± 2.9
	ES (95% CI)	1.24 (0.29 to 2.20)	1.26 (0.30 to 2.22)	-
VT_1 (% $\dot{V}O_{2max}$)	Pre	69.1 ± 3.0	69.4 ± 2.7	69.7 ± 2.8
	Post	72.0 ± 3.6*	72.3 ± 2.5*	68.4 ± 2.9
	ES (95% CI)	0.85 (-0.07 to 1.76)	1.08 (0.14 to 2.02)	-
VT_2 (% $\dot{V}O_{2max}$)	Pre	84.0 ± 3.9	84.0 ± 3.2	83.1 ± 4.2
	Post	87.6 ± 4.1*	87.4 ± 3.3*	83.4 ± 3.9
	ES (95% CI)	0.86 (-0.06 to 1.77)	0.98 (0.05 to 1.91)	-
$\dot{V}O_2$/HR (ml·b^{-1}·min^{-1})	Pre	22.1 ± 1.6	21.6 ± 1.9	21.6 ± 2.8
	Post	24.1 ± 1.7 *	23.9 ± 1.7*	21.9 ± 2.9
	ES (95% CI)	1.21 (0.22 to 1.85)	1.27 (0.11 to 1.94)	-
$\dot{V}_E$ (l·min^{-1})	Pre	129.4 ± 16.8	131.8 ± 18.1	126.6 ± 14.6
	Post	142.8 ± 17.1 *	149.7 ± 17.8*	129.8 ± 16.1
	ES (95% CI)	1.12 (0.34 to 1.75)	1.27 (0.25 to 2.01)	-
$\dot{V}_T$ (l·b^{-1})	Pre	2.64 ± 0.3	2.48 ± 0.2	2.32 ± 0.3
	Post	2.63 ± 0.2	2.45 ± 0.3	2.33 ± 0.3
	ES (95% CI)	-	-	-
R_f (b·min^{-1})	Pre	49.01 ± 4.9	53.14 ± 5.7	54.56 ± 7.6
	Post	54.29 ± 5.1*	61.10 ± 5.3*	55.71 ± 8.9
	ES (95% CI)	1.05 (0.41 to 1.87)	1.44 (0.14 to 2.02)	-
PPO (w)	Pre	809.2 ± 44.7	809.1 ± 50.5	798.2 ± 43.2
	Post	895.3 ± 57.5 *, **	866.5 ± 60.9*	804.1 ± 52.7
	ES (95% CI)	1.62 (0.61 to 2.63)	0.97 (0.04 to 1.90)	-
MPO (w)	Pre	472.4 ± 51.7	471.6 ± 34.0	468.2 ± 28.4
	Post	532.5 ± 48.4 *, **	517.7 ± 28.5*	472.9 ± 33.2
	ES (95% CI)	1.15 (0.20 to 2.09)	1.20 (0.25 to 2.15)	

* Significantly greater than pre-training value and significantly greater change than the CON group. ** Significantly greater changes than SIT group.

The PT group demonstrated significantly greater improvements in anaerobic power performance compared to the SIT group in this investigation. These results are contrary to a recent study conducted by Venegas-Carro et al. (2023), which indicated similar adaptations in countermovement jump through the use of jump and interval training. The discrepancy could be attributed to differences in the training protocols employed. Moreover, utilizing a combination of plyometric exercises, such as squat jumps and drop jumps, may be more effective in enhancing jump performance than focusing solely on countermovement jump, as done in the study by Venegas-Carro et al. (2023). The enhanced adaptations in anaerobic power performance observed with PT may be linked to more significant changes in neural adaptation and neuromuscular coordination associated with jump training. Benítez-Flores et al. (2023) reported that SIT may reduce neuromuscular function, contrasting with Kons et al. (2023) who suggested that PT is a suitable method for improving neuromuscular adaptations and vertical jump performance.

It was revealed that both the PT and SIT methods positively affect the adaptations in the 20-m sprint with and without the ball and COD. Moreover, both training groups displayed significant differences in comparison to the CON group. These findings are consistent with previous studies that have shown the positive impact of PT (Ramirez-Campillo et al., 2018; Asadi et al., 2018) and SIT (Moran et al., 2019; Kunz et al., 2019) on enhancing sprinting speed and CODS in soccer players. The activation of fast twitch muscle fibers and rate of force development could potentially explain the gains in sprinting and CODS following PT (Miller et al., 2006; Asadi et al., 2018; Ramirez-Campillo et al., 2018). On the other hand, improvements in stride length and frequency resulting from power generation during SIT, along with the principle of training specificity, may be the current mechanisms for enhancing sprinting speed and CODS through the incorporation of SIT (Song and Deng, 2023).

The PT group showed greater training effects compared to the SIT group in sprint performance and CODS after the 6-week intervention. While the specificity of training is crucial for optimal adaptations, the study's results indicated that PT led to more adaptations than SIT. This could be attributed to the strength gains achieved through PT. Venegas-Carro et al. (2023) found that jump training is more effective than sprint training in enhancing strength, while Seitz et al. (2014) demonstrated the positive transfer of lower-body strength to sprint performance. This could be attributed to the strength gains achieved through PT.

The results of the study revealed that both the PT and SIT methods have a positive impact on the adaptations in MKD after the 6-week intervention. These findings are in accordance with previous research studies that have reported the effectiveness of PT (Sedano et al., 2011; Ramírez-Campillo et al., 2015) and SIT (Wong et al., 2010) in improving maximal kicking speed and shooting distance for both the dominant and non-dominant leg following a training period (Sedano et al., 2011). Masuda et al. (2005) emphasized that gains in kicking speed and shooting performance are not fully determined by increases in muscle power since technical skill is also a crucial factor. In fact, the integration of both training methods with soccer training may enhance technical stability and lead to improvements in MKD; however, additional studies are required to elucidate the adaptations that take place for MKD enhancements.

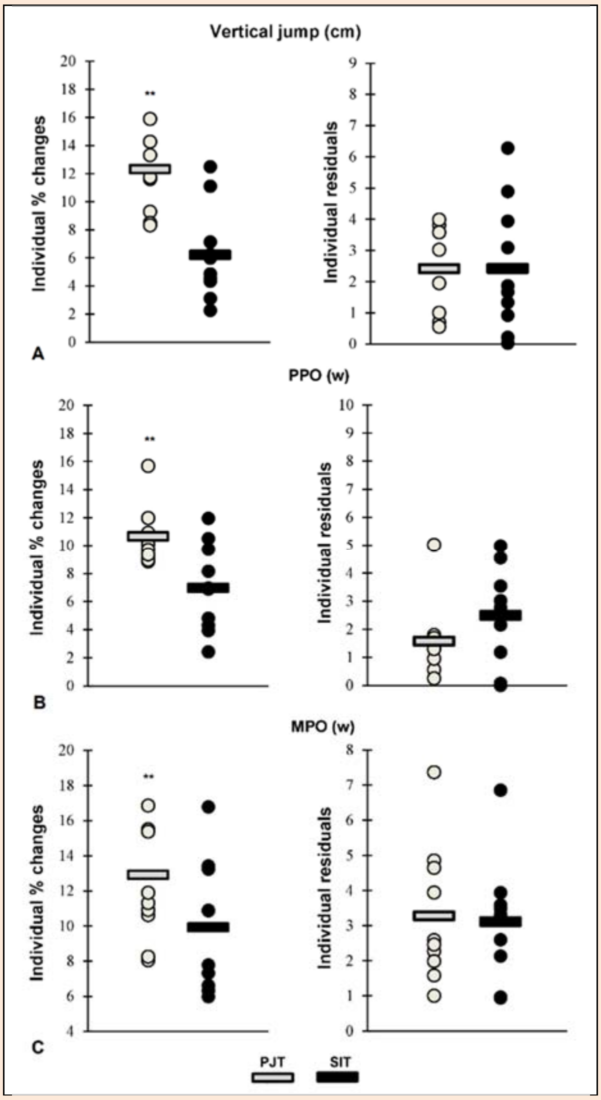

Figure 3. Changes in vertical jump, PPO and MPO following the 6-week training (Mean ± SD). * Denotes significant differences versus pre-value ($p = 0.001$). ** Denotes significant differences between training groups ($p \leq 0.05$).

After the 6-week intervention, both the PT and SIT groups demonstrated improvements in measures of aerobic fitness assessed by Yo-Yo IR1 and graded exercise test ($\dot{V}O_{2max}$, VT_1, and VT_2). Additionally, significant differences were observed between the training groups and an active CON group, indicating positive effects of PT and SIT on measured qualities. These findings align with previous research that emphasized the impact of SIT on the aerobic capacity parameters mentioned above (Moran et al., 2019; Kunz et al., 2019; Boullosa et al., 2022; Dai and Xie, 2023; Sheykhlouvand and Gharaat, 2024). Recently, Ramírez-Campillo and colleagues (2022) have indicated positive effects of PT on Yo-Yo IR1, confirming the effectiveness of jump training on aerobic performance adaptations (Ramirez-Campillo et al., 2022). In other experiment, Sheykhlouvand and Gharaat (2024) have indicated that six weeks of short sprint interval training effectively stimulates adaptive mechanisms involved in enhancing cardiorespiratory fitness in soccer players. Performing exercise at intensities beyond red zone, which typically involves reaching an intensity surpassing 90% of their $\dot{V}O_{2max}$, stimulates adaptive mechanisms involved in the enhancement of cardiorespiratory fitness (Laursen and Buchheit, 2019).

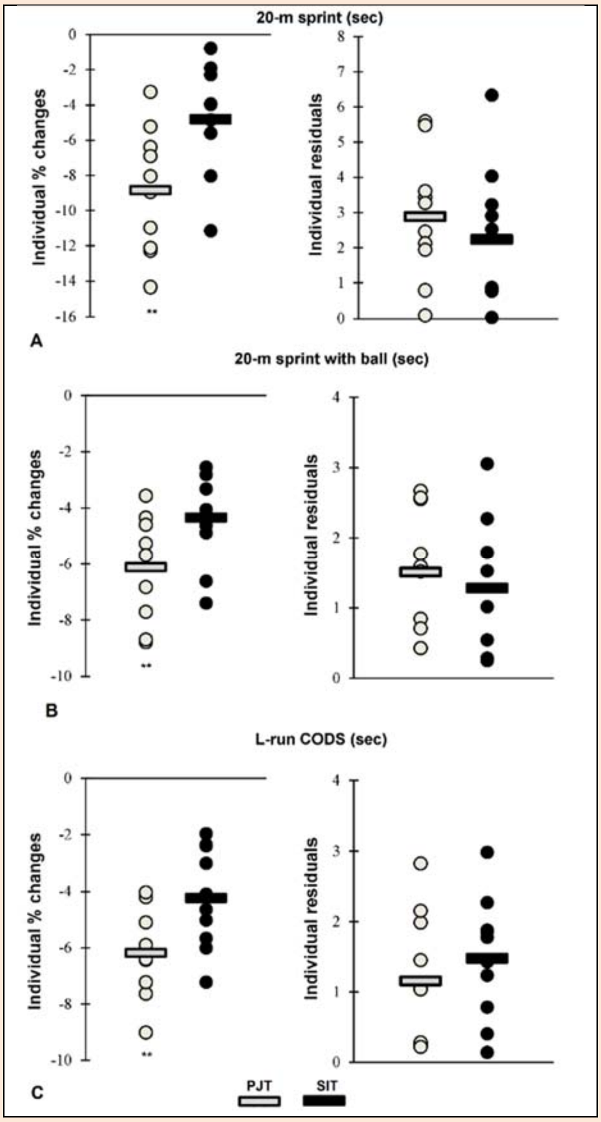

Figure 4. Changes in 20-m sprint with and without dribbling ball and L-run COD following the 6-week training (Mean ± SD). * Denotes significant differences versus pre-value ($p = 0.001$). ** Denotes significant differences between training groups ($p \leq 0.05$).

As we mentioned earlier, studies have indicated that performing repeated jumps with maximal exertion results in eliciting a high percentage of $\dot{V}O_{2max}$ possibly due to low recovery time between *all-out* exertions (Ducrocq et al., 2020) leading to enhanced aerobic fitness over the training period. While the adaptations in aerobic capacity parameters have been extensively documented in the aforementioned studies, the beneficial effects of PT-induced improvements in aerobic performance adaptation remain inconclusive. PT is typically characterized by eccentric training methods and previous research has demonstrated that eccentric exercise can improve cardiorespiratory fitness by 10 to 15% (Meyer et al., 2003; Julian et al., 2018). The repeated eccentric movements in PT cause alterations in the biomechanical properties of soft tissues and skeletal muscles, leading to increased oxygen consumption during contractions and subsequent cardiorespiratory adaptations (Penailillo et al., 2015). Enhanced cardiorespiratory fitness is attributed to enhanced oxygen-carrying capacity (i.e., oxygen delivery [Sheykhlouvand et al., 2022 and Sheykhlouvand and Gharaat, 2024; Rasouli Mojez et al., 2021]) and the extraction and utilization of delivered oxygen by active muscles (Fereshtian et al., 2017; Sheykhlouvand et al., 2018a). Significantly enhanced $\dot{V}O_{2max}$ in our study could result from improved cardiac function or oxygen pulse (i.e., $\dot{V}O_2$/HR). Recent studies have indicated that $\dot{V}O_2$/HR is a reliable indirect measure of stroke volume in trained subjects (Bernardi et al., 2020; Gharaat et al., 2020; Sheykhlouvand et al., 2016; 2018b). During exercise, the cardiovascular and respiratory systems work together as a coordinated unit to transport gases involved in respiration (McConnell, 2013). Our gas exchange results indicated that both training interventions significantly enhanced maximal ventilation over the training period. A previous study conducted by Sheykhlouvand and colleagues (2018b) has indicated a positive correlation between $\dot{V}_E$ and $\dot{V}O_{2max}$. Inhaled oxygen from the atmosphere through the respiratory system (i.e., elevated $\dot{V}_E$) and enhanced oxygen carrying capacity (i.e., elevated $\dot{V}O_2$/HR) could be justifying mechanisms of enhanced $\dot{V}O_{2max}$. Heightened $\dot{V}_E$ could result from elevated respiratory frequency as tidal volume remained unchanged from pre- to post-training.

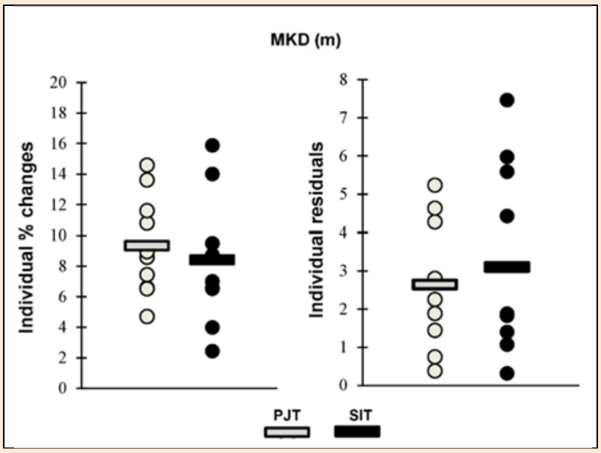

Figure 5. Changes in MKD following the 6-week training (Mean ± SD). * Denotes significant differences versus pre-value (p = 0.001).

Conversely, enhancing metabolic demand subsequent to eccentric action caused by PT can lead to a systemic effect on skeletal muscle physiological processes and peripheral circulatory adaptations (Nikolaidis et al., 2008), resulting in an increase in skeletal muscle capillarization and angiogenesis along with improvements in mitochondrial respiration and capillary-to-fiber ratio post eccentric training (LaStayo et al., 2000). Taken together, these findings may indicate that incorporating eccentric action in PT could elicit a similar level of stress on oxygen transport and utilization needs (Touron et al., 2021), leading to comparable enhancements in aerobic capacity for both PT and SIT. However, further research is essential to determine which adaptations may be more prevalent.

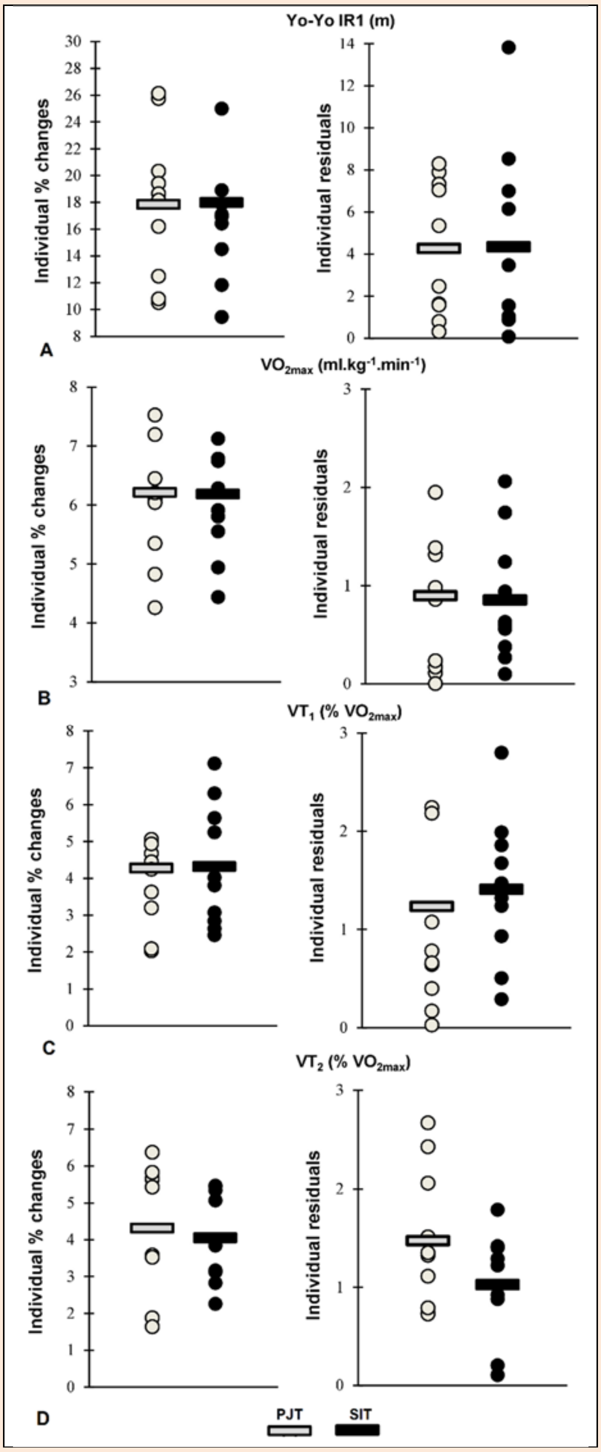

Figure 6. Changes in aerobic capacity parameters following the 6-week training (Mean ± SD). * Denotes significant differences versus pre-value (p = 0.001).

A limitation of this study was the inability of the authors to establish a cause-effect relationship for the training interventions, as multiple regression analysis was not utilized. Furthermore, the authors did not adequately control for soccer practice by monitoring intensity and running distance in each training session using GPS. Moreover, the PT group did not directly assess the underlying mechanism associated with aerobic performance adaptation. It is suggested that future studies employ laboratory measurements to identify the specific adaptations that contribute to enhancing cardiorespiratory fitness through the implementation of PT.

Conclusion

The study findings demonstrate that three sessions per week of either PT or SIT effectively enhance various physiological and performance parameters in male soccer players. PT yielded significantly greater improvements in vertical jump, PPO, MPO, 20-meter sprint speed with and without the ball, and COD compared to SIT. However, both PT and SIT groups showed similar enhancements in MKD and aerobic capacity measures such as Yo-Yo IR1, V̇O2max, and VT1. These findings underscore the efficacy of PT and SIT in enhancing key physical attributes crucial for soccer performance.

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The measurement complied with the current laws of the country in which they were performed. The authors have no conflicts of interest to declare. The datasets generated and analyzed during the current study are not publicly available, but are available from the corresponding author who was an organizer of the study.

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Key points

- Both PT and SIT are suitable training approaches for enhancing cardiorespiratory fitness, anaerobic power, and biomotor abilities in soccer players.
- PT results in greater gains in vertical jump, anaerobic power, linear sprint speed and COD ability than SIT.
- Both interventions could be used to enhance the mentioned qualities in this study by considering the priority of the interventions' objectives.

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Employment
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