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**Research article**

# Optimizing Short Sprint Interval Training for Young Soccer Players: Unveiling Optimal Rest Distributions to Maximize Physiological Adaptations

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## Abstract

Present study aimed to compare the effects of SSIT intervention with varying rest distributions on hormonal, physiological, and performance adaptations in soccer players. Thirty-six players were randomly divided into three SSIT groups, each performing 4 sets of 6 - 10 repetitions of 6-second all-out running with rest intervals at ratios of 1:3, 1:6, and 1:9. Prior to and following the 7-week training period, aerobic fitness indices and anaerobic power were evaluated using a graded exercise test with a gas collection system and a lower-body Wingate test, respectively. Also, sport-specific bio-motor abilities were determined by measuring vertical jump, 20-m sprint, and T-test change of direction speed, Yo-Yo IR1 and maximal kicking distance. Hormonal status was also monitored by evaluating testosterone and cortisol levels. Following the 7-week training period, all SSIT interventions resulted in significant enhancements ($p < 0.05$) in soccer-related performance, physiological parameters, and hormonal adaptations, exhibiting effect sizes that ranged from small to large. Comparative analysis indicated that the 1:9 SSIT results in greater adaptive responses ($p < 0.05$) in the vertical jump, peak power, testosterone, and cortisol compared to the 1:3 SSIT group. By contrast, the 1:3 SSIT group induced more adaptive responses ($p < 0.05$) in the mean power output, maximum oxygen consumption ($\dot{V}O_{2max}$), and Yo-Yo IR1 compared to the 1:9 SSIT group. Hence, for enhancing physical performance, especially vertical jump height, anaerobic peak power, and hormonal adaptations, the 1:9 SSIT ratio is preferable. Conversely, shorter rest intervals (specifically, the 1:3 SSIT ratio) are better suited for eliciting heightened adaptive responses in mean power output, $\dot{V}O_{2max}$, and Yo-Yo IR1 over the 7-week training period among young male soccer players.

**Key words:** Sprint interval training, power, metabolic conditioning, aerobic capacity.

## Introduction

Soccer stands as a renowned team sport characterized by intermittent explosive movements, including acceleration and deceleration, repetitive changes of direction, jumping, sprinting, passing, kicking, tackling, and rapid shifts in pace (Sheykhlouvand and Gharaat, 2024; Arazi et al., 2020; Ramirez-Campillo et al., 2014; Stølen et al., 2005). The effectiveness of crucial moments in a soccer match, such as gaining possession, scoring, assisting, or preventing goals, relies on players' capacity to execute high-speed tasks and generate power (Söhnlein et al., 2014). Sprint interval training (SIT) stands out as a time-efficient practical training strategy within soccer (Clemente et al., 2021). This training approach, when tailored to meet the demands of the sport, not only conserves valuable time but has also shown its effectiveness in producing noteworthy (i.e., jumping ability, sprinting speed and change of direction speed) and physiological (i.e., cardiorespiratory fitness and anaerobic power output) improvements among soccer players (Kunz et al., 2019; Lee et al., 2020; Boullosa et al., 2022; Sheykhlouvand and Gharaat, 2024). Implementing SIT in soccer provides a straightforward approach to significantly enhancing players' athletic performance (Arazi et al., 2017; Lee et al., 2020). In addition to the array of SIT techniques available, a recent review study by Boullosa et al. (2022) has shown that short SIT (SSIT) intervals lasting between 3 to 10 seconds can yield comparable adaptive responses to traditional SIT methods with longer durations. This is primarily due to the fact that the most significant mechanical responses occur during the initial stages of sprints. SSIT efficiently mitigates peripheral fatigue within the initial 10 seconds of exercise by decreasing reliance on the glycolytic pathway and increasing utilization of ATP-PCr (Boullosa et al., 2022). As a result, SSIT protocols offer a promising and enjoyable approach to improving physical fitness attributes in male soccer players (Lee et al., 2020).

When developing an effective SSIT program, various factors must be considered, including the number of sets, repetitions, intensity, type of exercise, and rest intervals (Buchheit and Laursen, 2013). Modification of rest periods between high-intensity efforts is crucial for eliciting significant responses to interval interventions. The rest intervals between efforts during a training session play a significant role in metabolic conditioning, as emphasized by Rogers et al. (2024). The duration and intensity of rest periods within SIT sessions can be specified to target specific metabolic pathways in muscle cells (Zhang et al., 2024). Research suggests that, for intense activities lasting less than 6 seconds, a 1:10 ratio of rest to activity is sufficient to ensure proper recovery between efforts in men (Harris et al., 1976; Girard et al., 2011). Notably, when sprints exceed 4 seconds (i.e., >25 m) with a recovery interval of less than 20 seconds, the initial rate of blood lactate accumulation remains consistently high (i.e., >10 mmol·L$^{-1}$·5 min$^{-1}$) in female athletes (Rogers et al., 2024). Conversely, shorter sprints followed by extended recovery durations may impose less strain on the anaerobic energy system (Laursen and Buchheit, 2019). According to the literature, rest intervals may vary depending on the particular movement characteristics of athletes' training interventions. Coaches and athletes must identify the ideal work-to-recovery ratio

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tailored to their training dynamics to optimize their adaptive responses.

Through meticulous adjustment of rest intervals, trainers can optimize metabolic conditioning and improve the overall effectiveness of the SSIT program. Manipulating the duration of rest intervals between trials can impact power production by resulting in lower blood lactate and $H^+$ levels after longer rest periods, while also utilizing ATP-PCr (Iaia et al., 2017; Rogers et al., 2024). Nonetheless, all metabolic energy pathways are actively engaged during a soccer match (Buchheit and Laursen, 2013; Stølen et al., 2005). For example, executing a jump and heading the ball during a corner that lasts approximately 5 seconds necessitates the utilization of muscle ATP-PCr, whereas a counter-attack lasting between 5 to 10 seconds requires the glycolytic metabolic pathway (Domene, 2013). Therefore, identifying an appropriate rest period between trials during SSIT is crucial to optimize adaptations in the physical fitness attributes and cardiorespiratory fitness, as well as anaerobic power performance of soccer players (Iaia et al., 2017).

Manipulation of rest intervals between sprint trials has been shown to have a significant impact on performance, hormonal levels, and physiological variables in male and female athletes (Zhang et al., 2024; Rogers et al., 2024). Reilly (2007) suggested that for sprint trials in soccer players, the ideal rest period should be approximately 4 to 5 times the duration of the exercise to ensure proper recovery. In contrast, Gaitanos et al. (1993) found that a 30-second rest period was insufficient for recovery after a 6-second sprint in physically active men. In terms of adaptations following different exercise to rest ratios, recently, Zhang and colleagues (2024) revealed that shorter ratios are more suitable for maximizing adaptations in maximum oxygen consumption, while longer rest periods are better for physical performance and power output during the Wingate anaerobic test for the male college judo athletes. However, the optimal exercise to rest ratios for SSIT have yet to be determined.

Besides performance and physiological outcomes, hormonal responses to training are thought to be crucial for the development of physical fitness attributes (Kraemer and Ratamess, 2005). Variations in cortisol and testosterone levels following the training periods are believed to mirror the state of muscle tissue (Kraemer and Ratamess, 2005). These changes, whether they increase or decrease, may occur at different stages depending on the manipulation of training parameters, such as rest intervals (Meckel et al., 2011). Previous research has suggested that longer rest periods could reduce cortisol, while also improving testosterone levels (Rahimi et al., 2011). However, the optimal exercise-to-rest ratios for hormonal adaptations to SSIT remains unclear.

Currently, there is limited understanding regarding the effects of different exercise-to-rest ratios in SSIT for achieving optimal adaptive responses. This gap in knowledge hinders our ability to identify the most effective rest intervals for enhancing specific performance and physiological parameters in soccer players. Thus, this study aimed to examine the effects of three different work-to-recovery ratios (1:3, 1:6, and 1:9) during all-out SSIT on male soccer players' hormonal, physiological, and performance adaptations.

## Methods

### Study design

A randomized controlled trial study was conducted using a pre/post-test design, consisting of three experimental groups and one active control group lasting for 9 weeks (i.e., 1-week pre-testing, 7 weeks of training intervention, and 1-week post-testing) between July to September 2023 (Figure 1). Participants underwent physical (vertical jump, 20-m sprint, and T-test) and soccer-related performance tests (Yo-Yo IR1, and kicking distance), along with physiological assessments to evaluate cardiorespiratory fitness and anaerobic power on separate days with 48-hour rest intervals. After conducting anthropometric measurements, participants underwent a lower-body Wingate test to evaluate anaerobic power. On the second occasion, a graded exercise test assessed cardiorespiratory fitness. Physical performance tests were conducted on the third day, and the Yo-Yo IR1 and maximal kicking distance were measured on the fourth day. Resting testosterone and cortisol levels were analyzed by drawing blood samples 48 hours before the initiation of the training and 48 hours after the last training session. All groups participated in soccer training sessions on Monday, Wednesday, and Friday. Meanwhile, the experimental groups underwent SSIT prior to their soccer practice sessions on Monday and Friday afternoons.

| Study duration (weeks) | | | | | | |
|---|---|---|---|---|---|---|
| Week 1 (Pre-test) | | Week 2 to 8 | | | Week 9 (Post-test) | |
| Testing days | | Training Intervention | | | Testing days | |
| Weekly days | Assessments | Training days | Experimental groups | Control group | Weekly days | Assessments |
| Monday | Anthropometric | | | | Monday | Anthropometric |
| | Wingate test | Monday | SSIT + SP | SP | | Wingate test |
| | GXT | Tuesday | Rest | - | | GXT |
| Wednesday | VJ | Wednesday | SP | SP | Wednesday | VJ |
| | 20-m sprint | Thursday | Rest | - | | 20-m sprint |
| | T-test | Friday | SSIT + SP | SP | | T-test |
| Friday | MKD | Saturday | Rest | - | Friday | MKD |
| | Yo-Yo IR1 | Sunday | Rest | - | | Yo-Yo IR1 |

**Figure 1. Study design.**

### Participants
Thirty-six young male amateur soccer players participated in the study. They were matched by playing position and randomly allocated to three different exercise-to-rest ratios of SSIT groups, along with an active control group (Table 1). For this study, the sample size estimation was conducted using G*Power software (version 3.1) (Faul et al., 2009). With an effect size of 0.8, power of 0.8, and a p-value of 0.05, 8 participants per training group were determined (Arazi et al., 2017). However, the sample size was raised to 9 participants per group to account for potential participant dropouts during data collection. The players were members of the local soccer academy team and adhered to the same training regimens and workloads (including tactical and technical drills three times a week, with sessions lasting between 60 and 80 minutes each) throughout the study period, classifying them as "Trained" players based on the criteria established by McKay et al. (2022). Group allocation was done using a computer-generated random number, ensuring an unbiased selection process, using R software (version 2.14, Foundation for Statistical Computing). In order to qualify for participation, players had to ensure they were free from any injuries, illnesses, or physical limitations during the study, complete all pre-post test procedures, and abstain from participating in matches throughout the study period. Before the study commenced, players were given a detailed explanation of the research procedures, requirements, benefits, and risks and gave written consent. The study's design was approved by the Ethics Committee of the Shandong Women's University and also the Declaration of Helsinki.

**Table 1. Subjects characteristics (Values are mean ± SD) *.**

| Groups | Age (y) | Height (cm) | Body mass (kg) | Training age (y) |
|---|---|---|---|---|
| **1:3 SSIT** | 17.2 ± 1.4 | 175.6 ± 11.5 | 73.5 ± 7.1 | 2.1 ± 1.5 |
| **1:6 SSIT** | 17.3 ± 0.8 | 174.2 ± 9.7 | 75.8 ± 6.9 | 2.6 ± 1.1 |
| **1:9 SSIT** | 17.8 ± 1.7 | 178.6 ± 9.1 | 77.5 ± 9.2 | 2.5 ± 1.9 |
| **CON** | 17.5 ± 1.9 | 179.6 ± 9.3 | 76.1 ± 6.3 | 2.7 ± 1.2 |

*Each group consisted of 9 subjects including 4 defenders, 3 midfielders, and 2 attackers.

### Testing procedure
All subjects were instructed to continue with their usual daily routines and dietary habits throughout the study. Prior to the testing day, participants were given specific guidelines to follow: a) get at least 8 hours of quality sleep, b) consume the recommended amount of carbohydrates tailored to each individual, while staying well-hydrated, and c) wear the same type of footwear for both pre and post-tests. Prior to the actual tests, all subjects completed a 15-minute warm-up session, consisting of a 5-minute jog, a 5-minute stretching routine, and 5 minutes of low-intensity sprints. All assessments were conducted on a soccer grass pitch with a temperature maintained between 27 - 29°C in the afternoon (i.e., 5 to 7 PM). Furthermore, all measurements were carried out by expert strength and conditioning coaches in a blinded manner. This ensured that the tester remained unaware of the group allocation for each subject.

### Anthropometric assessments
The participants' height was measured by a wall-mounted stadiometer (± 0.5 cm, Seca 222, Terre Haute, IN). For determining the body mass of the participants, a digital scale (± 0.1 kg, Tanita, Japan) was used. All measurements were conducted twice to ensure accuracy.

### Physical performance assessments
The vertical jump (VJ) (Asadi et al., 2018), 20-m sprint (Ramirez-Campillo et al., 2014), and T-test change of direction speed (T-CODS) (Miller et al., 2006) were measured using the previously described methods. The VERTEC (Power System, USA) apparatus was utilized for assessing vertical jump (VJ) on the soccer grass pitch. Players were instructed to flex their knees to approximately 90 degrees and execute a maximal jump. The highest VJ from three measurements with a 3-minute interval was chosen for analysis. The sprinting speed was assessed using photocell gates (Newtest Power Timer 300-Series Testing System, Finland) positioned at 0 meters and 20 meters. The trial that yielded the fastest sprint time out of three, with intervals of 3 minutes, was chosen for analysis. The T-CODS test was used to assess players' ability to accelerate, decelerate, and change direction, and the best performance out of three attempts with a 3-minute rest was recorded for analysis. The inter-class correlation and coefficient of variation for the VJ, 20-m sprint and T-CODS were as follows: 0.95; 2.56%, 0.93; 4.89%, and 0.96; 2.53%, respectively.

### Soccer-related performance assessments
The Yo-Yo IR1 and maximal kicking distance test (MKDT) were employed to assess soccer-specific performance. The Yo-Yo IR1 test, conducted in accordance with the methodology outlined by Krustrup and colleagues (2003), is a standardized assessment used to evaluate the fitness levels of soccer players. Participants performed 20-meter shuttles at escalating speeds with 10-second recovery intervals. The test protocol required participants to exercise until they reached voluntary exhaustion, and the total distance covered by the athletes was recorded for subsequent analysis. The MKDT (Maximum Kicking Distance Test) was utilized to establish the maximum distance soccer players could kick a Size 5 Nike ball using their dominant foot. This standardized assessment method has been previously detailed (Ball, 2009). Players kicked a ball on a grass field, with a 60-meter tape measure employed to accurately measure the distance of the kicks. The kick achieving the highest score out of three attempts, with a 3-minute break between each, was selected for analysis.

### Physiological performance assessments
Lower body Wingate test (Sheykhlouvand and Gharaat, 2024) and an incremental exercise test (Eston and Reilly, 2009) were used to determine the participants' anaerobic power and cardiorespiratory fitness. The 30-second maximal Wingate test assessed the peak power output (i.e., the 5-second of highest power performance) and mean power output (i.e., average power throughout the test). Participants utilized a mechanically braked cycle ergometer (model 894E, Monark, Sweden) with a resistance equivalent to 0.075 $kg \cdot kg^{-1}$ of their body mass. They initiated pedaling at maximum speed against the device's inertial

resistance, followed by adding a personalized load. They were verbally encouraged to exert their maximum effort throughout the test (Sheykhlouvand and Forbes, 2017). To assess the participants' cardiorespiratory fitness, participants completed a graded exercise test on a treadmill (Technogym, Italy) using a breath-by-breath gas collection system (Hans Rudolph Inc., situated in Shawnee, KS, USA). The test was initiated at a pace of 8 $km \cdot hr^{-1}$ and increased by 1 $km \cdot hr^{-1}$ every 3 minutes until the individuals reached a stage of exhaustion. Blood samples were taken during the 30-second rest period between stages to determine blood lactate concentrations (Lactate Pro 2 LT-1730, Japan). The highest value recorded within a 30-second interval during the test was considered the $\dot{V}O_{2max}$, representing the maximum oxygen consumption. Multiple criteria were utilized to determine if the athlete attained $\dot{V}O_{2max}$, which included a) a stabilization of $\dot{V}O_2$ levels despite an increase in workload, b) a respiratory exchange ratio (RER) higher than 1.10, c) a blood lactate concentration of 8 $mmol \cdot L^{-1}$ or above, d) a maximum heart rate (HRmax) equal to or exceeding 95% of the age-predicted maximum (220 - age), and e) reaching volitional exhaustion (Fereshtian et al., 2017; Sheykhlouvand et al., 2016a; 2016b).

### Blood sampling and analysis

After a 10-hour fasting and 8 hours of sleep over night, a 10-mL blood sample was collected from the antecubital vein both pre- and post-training. The sample was centrifuged at 3,000 rpm for 15 minutes at 4°C and was frozen at -80°C for subsequent analysis using standard ELISA kits (CD Creative Diagnostics, NY, USA with less than 10% an intra-assay CV) to quantify serum testosterone and cortisol levels.

### Training program

The participants adhered to their usual training regimen, which included tactical exercises, technical drills, and practice matches on Monday, Wednesday, and Friday afternoons. Each session lasted 60 to 70 minutes. Every training session began with a 20-minute warm-up, which included 10 minutes of running, 5 minutes of stretching, and 5 minutes of sprinting and ballistic movements. The training groups completed their SSIT programs (~20 minutes) before soccer training sessions on Monday and Friday (Table 2) (Buchheit and Laursen, 2013; Boullosa et al., 2022). The SSIT program for the training groups involved completing linear sprints on a 50-m soccer field, equivalent to half the size of a standard soccer pitch. During the sessions, two distinct sounds were employed: the first sound indicated the start of maximal effort runs, while the second sound signaled the cessation of the runs and the transition to self-paced walking or running. Participants were advised to sprint as fast as possible (i.e., all-out) during each trial. A specialized soccer and strength and conditioning coach closely supervised the players throughout the sessions to ensure the correct execution of training techniques with the ratio of 1:5 (coach:player). The active CON group continued with their typical soccer training routine. The rating of perceived exertion (RPE) was recorded using the Borg 0-10 RPE Scale ten minutes after SSIT sessions (Arazi et al., 2020) determined the training load.

### Statistical analysis

The data was presented using the mean ± standard deviation (SD). The normality of the distribution was assessed using the Shapiro-Wilk test for both pre- and post-test values, and Levene's test was employed to evaluate the homogeneity of variances. A repeated-measures analysis of variance (ANOVA) with a two-factor design (time [2] × group [4]) was conducted, followed by a Bonferroni post-hoc test to determine differences between groups. The effect size (ES) with a 95% confidence interval (CI) was used to evaluate the magnitude of training effects. Hedge's g was employed to calculate the ES for all measures. According to the classification proposed by Hopkins et al. (2009), an ES of < 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 > 4.0 was nearly perfect. The significance level was set at 0.05.

## Results

Throughout the study, all players demonstrated complete adherence, resulting in an impressive accomplishment of achieving a 100% success rate. Furthermore, there were no reported incidents of injuries associated with the testing and training protocols. Moreover, no statistically significant differences ($p > 0.05$) were observed among the groups at the baseline. Additionally, the CON group exhibited trivial and non-significant changes in all variables after the training period.

All SSIT interventions significantly ($p < 0.05$) improved physical (VJ, 1:3 = 5.8%; 1:6 = 8.1%; 1:9 = 10.4%, 20-m sprint, 1:3 = -4.0%; 1:6 = -4.1%; 1:9 = -4.8%, and T-CODS, 1:3 = -4.1%; 1:6 = -3.7%; 1:9 = -4.3%) and soccer-related performance (Yo-Yo IR1, 1:3 = 20.3%; 1:6 = 12.3%; 1:9 = 8.7%, and MKDT, 1:3 = 9.8%; 1:6 = 10.5%; 1:9 = 9.1%), physiological parameters ($VO_{2max}$, 1:3 = 8.4%; 1:6 = 5.6%; 1:9 = 4.3%, peak power, 1:3 = 9.0%; 1:6 = 11.9%; 1:9 = 18.0%, and mean power, 1:3 = 14.4%; 1:6 = 10.6%; 1:9 = 8.1%), and hormonal adaptations (testosterone, 1:3 = 7.4%; 1:6 = 11.2%; 1:9 = 11.7%, and cortisol, 1:3 = -3.3%; 1:6 = -6.7%; 1:9 = -10.3%) following the 7-week training ranging between small to large ES (Figure 2, Figure 3, Figure 4, Figure 5, Figure 6 and Table 3).

**Table 2. Progressive overload short sprint interval training program.**

| Groups | Exercise to rest ratio (sec) | Training weeks (sets × trials) | | | | | | | Rest between sets (sec) |
|---|---|---|---|---|---|---|---|---|---|
| | | Week 1 | Week 2 | Week 3 | Week 4 | Week 5 | Week 6 | Week 7 | |
| **1:3 SSIT** | 6/18 | 4 × 6 | 4 × 7 | 4 × 8 | 4 × 9 | 4 × 8 | 4 × 9 | 4 × 10 | 120 |
| **1:6 SSIT** | 6/36 | 4 × 6 | 4 × 7 | 4 × 8 | 4 × 9 | 4 × 8 | 4 × 9 | 4 × 10 | 120 |
| **1:9 SIT** | 6/54 | 4 × 6 | 4 × 7 | 4 × 8 | 4 × 9 | 4 × 8 | 4 × 9 | 4 × 10 | 120 |

Comparative analysis of between-group differences indicated that the 1:9 SSIT resulted in greater adaptive responses ($p < 0.05$) than the 1:3 SSIT in the VJ, peak power (Moderate ES), testosterone (Small ES), and cortisol (Small ES). In contrast, the 1:3 SSIT showed more adaptive responses ($p < 0.05$) in the mean power (Moderate ES), $\dot{V}O_{2max}$ (Moderate ES), and Yo-Yo IR1 (Moderate ES) than the 1:9 SSIT over the training period.

Table 4 presents the training workload parameters. All SSIT groups displayed a similar training load for the entire training period.

## Discussion

Numerous studies have investigated the effectiveness of SSIT in improving soccer players' aerobic and anaerobic capacities (Arazi et al., 2017; Kunz et al., 2019; Lee et al., 2020). However, the optimal rest intervals during trials to maximize the adaptive changes in these qualities remain a matter of debate. This study aimed to investigate the impacts of varying exercise-to-rest ratios on hormonal, physiological, and performance adaptations to identify the optimal rest intervals between SSIT trials. Our findings suggested that a 1:3 SSIT ratio is more effective in improving mean power output and aerobic fitness. By contrast, when targeting physical performance and peak power output, a more extended rest interval, 1:9, elicits significantly greater adaptive responses. These findings highlight the crucial role of rest intervals in optimizing training outcomes for soccer players.

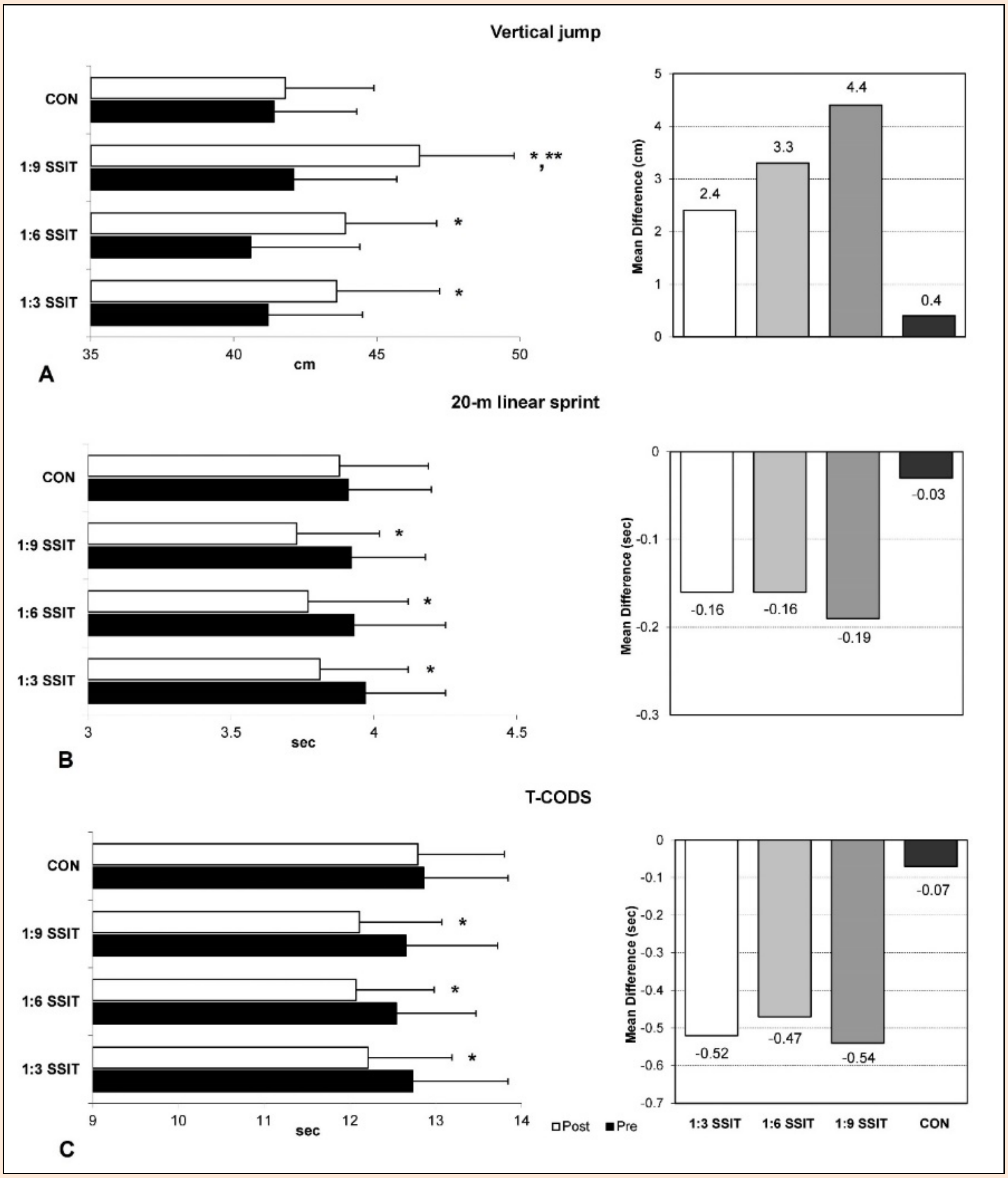


**Figure 2. Changes in vertical jump, 20-m linear sprint and T-CODS following the 7-week SSIT (Mean ± SD).** * indicates significant differences versus pre-value and CON ($p < 0.05$). **indicates significant differences compared with 1:3 SSIT ($p < 0.05$).

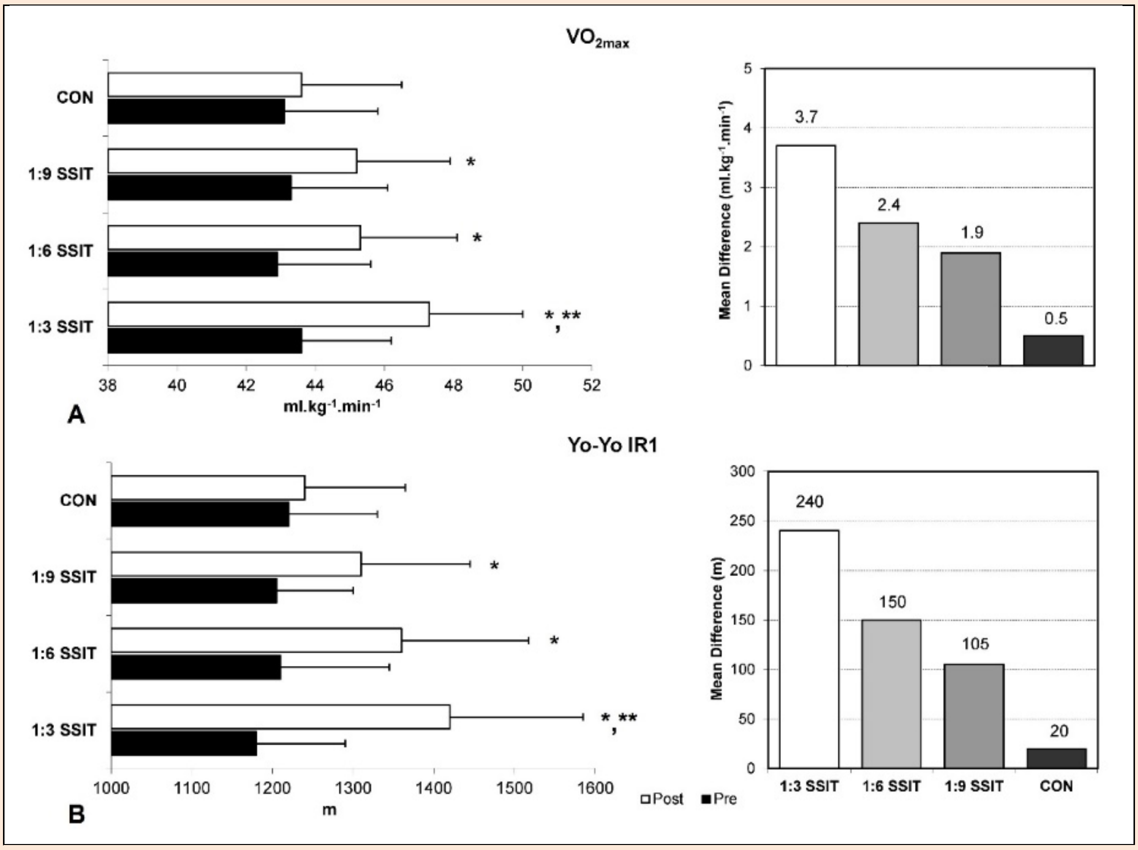


**Figure 3. Changes in aerobic capacity following the 7-week SSIT (Mean ± SD)**. * indicates significant differences versus pre-value and CON ($p < 0.05$). **indicates significant differences compared with 1:9 SSIT ($p < 0.05$).

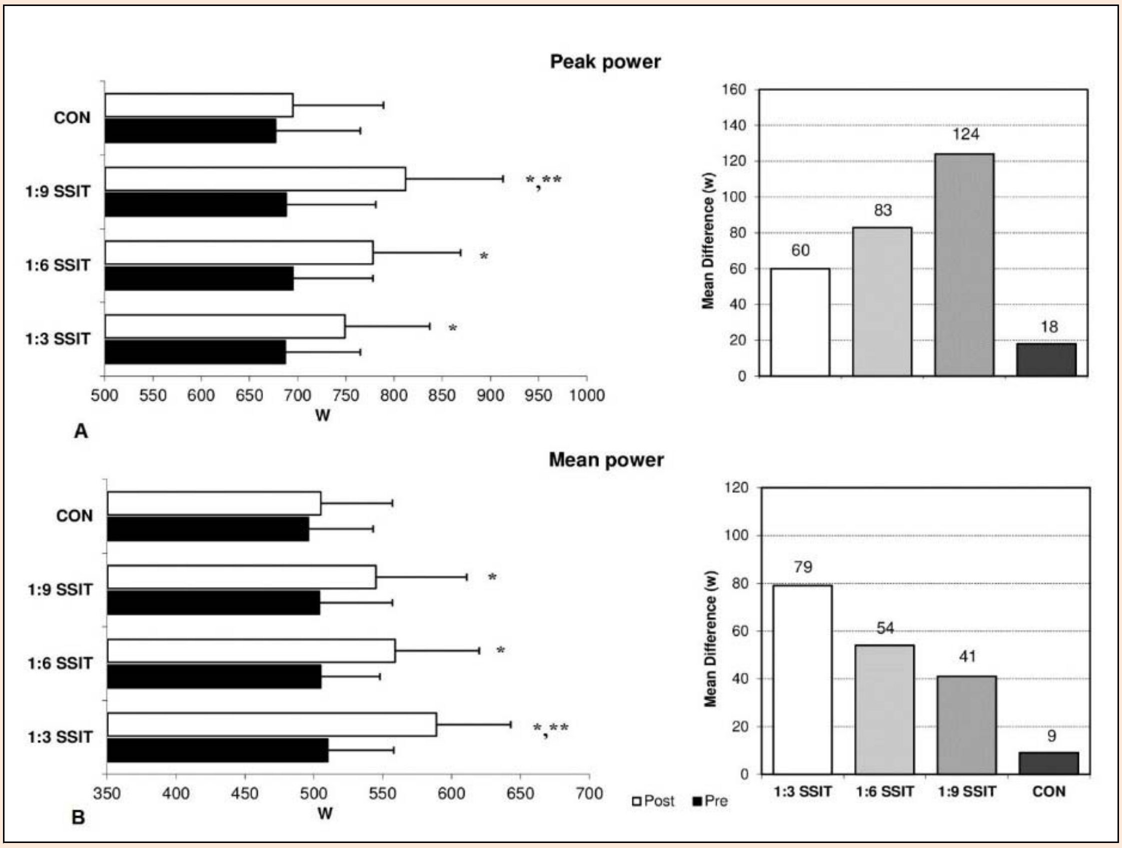


**Figure 4. Changes in anaerobic peak and mean power output following the 7-week SSIT (Mean ± SD)**. * indicates significant differences versus pre-value and CON ($p < 0.05$). **indicates significant differences compared with 1:3 SSIT in peak power and with 1:9 SSIT in mean power ($p < 0.05$).

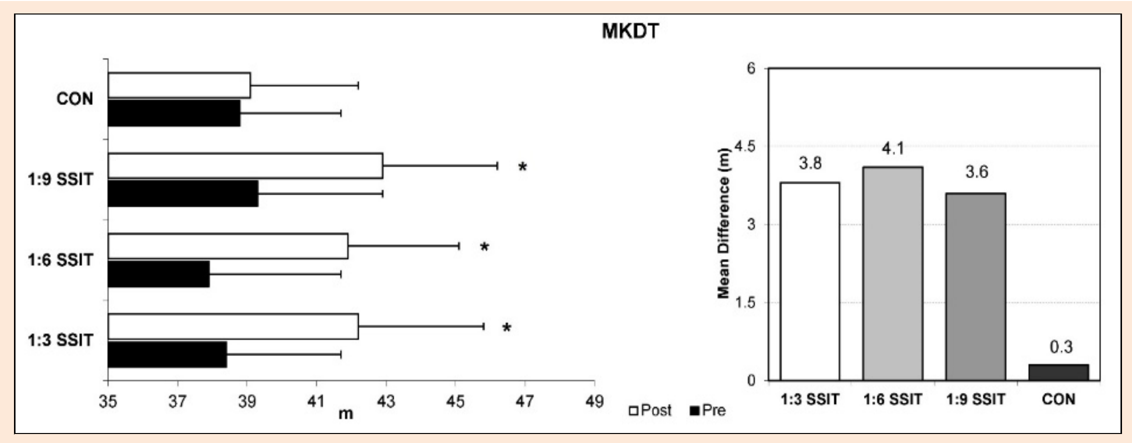


**Figure 5. Changes in MKDT following the 7-week training (Mean±SD).** * indicates significant differences versus pre-value and CON ($p < 0.05$).

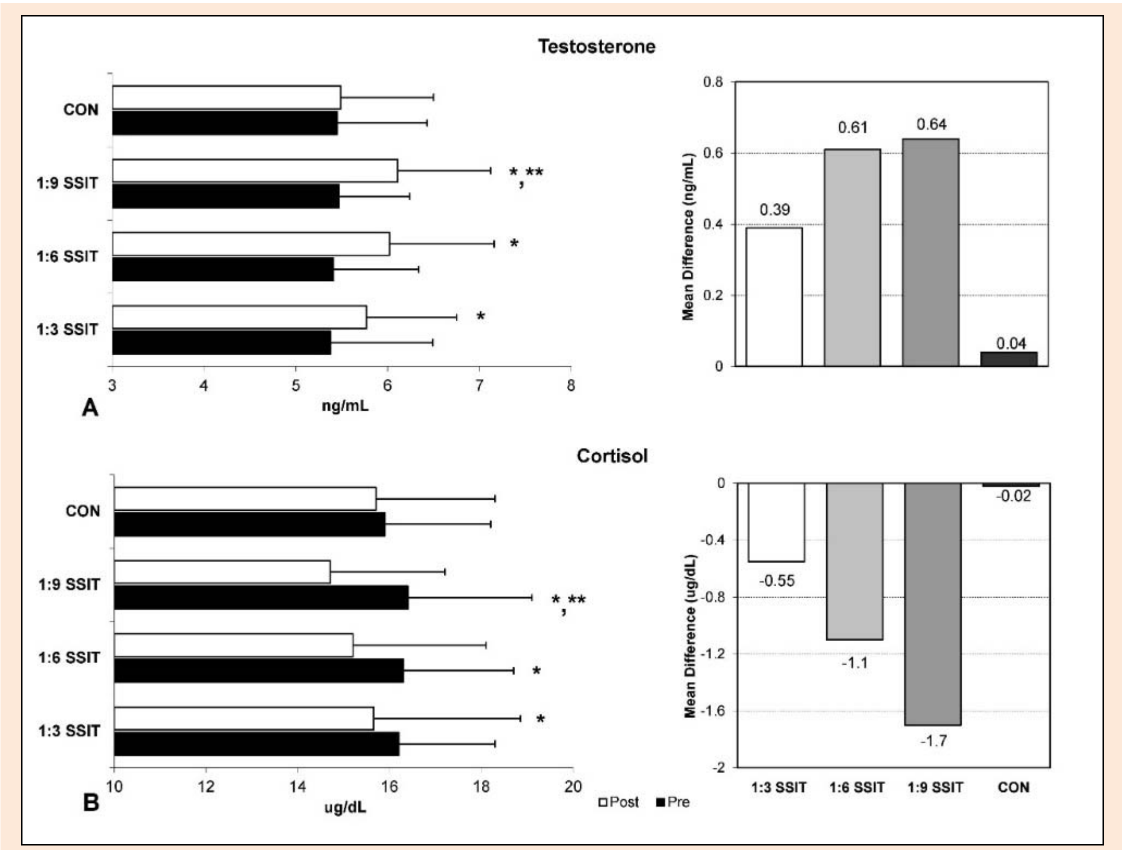


**Figure 6. Changes in testosterone and cortisol following the 7-week SSIT (Mean ± SD).** * indicates significant differences versus pre-value and CON ($p < 0.05$). **indicates significant differences compared with 1:3 SSIT ($p < 0.05$).

In accordance with previous studies indicating the positive effects of SIT on physical performance in soccer players (Arazi et al., 2017; Iaia et al., 2017; Lee et al., 2020; Clemente et al., 2021; Sheykhlouvand and Gharaat, 2024), our results displayed that SSIT with different rest intervals between trials has notable moderate to large effects on vertical jump (VJ), small to moderate effects on the 20-meter linear sprint, and small beneficial effects on the T-CODS. Improvements in the bio-motor abilities of soccer players after SSIT could be due to enhancements in neuromuscular adaptations (Kunz et al., 2019). Buchheit and Laursen (2013) have indicated that different forms of interval training effectively improve the mechanical attributes of the muscle-tendon systems by enhancing muscle and nerve coordination and increasing the firing frequency rate. In addition, the involvement of type II muscle fibers in conjunction with fast-twitch actions throughout the SSIT could induce adaptations in physical performance (Clemente et al., 2021; Fang and Jiang, 2024).

Regarding the VJ, players in the 1:9 SSIT group exhibited greater adaptive responses than the 1:3 SSIT group, indicating that prolonged rest duration enables the replenishment of PCr and phosphagen pathways (Rogers et al., 2024), which are crucial for muscle fibers to exert maximum effort during explosive movements leading to greater adaptations (Zhang et al., 2024). Engaging in SSIT significantly boosts metabolites such as blood lactate and $H^+$, which play a role in blunting phosphagen pathways (Iaia et al., 2017). More extended rest periods help replenish PCr, and repeating these processes in muscle fibers seems to enhance their ability to quickly recover and exert maximum force during tasks requiring maximal effort (Rogers et al., 2024). This ultimately leads to greater improvements in VJ performance, especially in the group with longer rest intervals (e.g., 1:9 SSIT).

**Table 3. ESs with 95% CI.**

| Variables | | Between Groups ES | | | | |
|---|---|---|---|---|---|---|
| | | Pre vs. Post | Post vs. CON | Post, 1:3 vs. 1:6 | Post, 1:3 vs. 1:9 | Post, 1:6 vs. 1:9 |
| VJ (cm) CON | 1:3 SSIT | 0.66 (-0.29 to 1.61) Moderate | 0.51 (-0.43 to 1.45) Small | 0.08 (-0.84 to 1.01) Trivial | 0.80 (-0.16 to 1.76) Moderate | 0.76 (-0.20 to 1.72) Moderate |
| | 1:6 SSIT | 0.89 (-0.07 to 1.86) Moderate | 0.63 (-0.31 to 1.58) Moderate | | | |
| | 1:9 SSIT | 1.21 (0.21 to 2.22) Large | 1.40 (0.37 to 2.43) Large | | | |
| | CON | 0.13 (-0.80 to 1.05) Trivial | | | | |
| 20-m sprint (sec) | 1:3 SSIT | -0.52 (-1.46 to 0.42) Small | -0.22 (-1.14 to 0.71) Small | 0.12 (-0.81 to 1.04) Trivial | 0.25 (-0.67 to 1.18) Small | 0.12 (-0.81 to 1.04) Trivial |
| | 1:6 SSIT | -0.45 (-1.39 to 0.48) Small | -0.32 (-1.25 to 0.61) Small | | | |
| | 1:9 SSIT | -0.62 (-1.57 to 0.32) Moderate | -0.48 (-1.41 to 0.46) Small | | | |
| | CON | -0.10 (-1.02 to 0.83) Trivial | | | | |
| T-CODS (sec) | 1:3 SSIT | -0.47 (-1.41 to 0.46) Small | -0.56 (-1.50 to 0.39) Small | 0.14 (-0.78 to 1.07) Trivial | 0.11 (-0.83 to 1.02) Trivial | 0.04 (-0.88 to 0.96) Trivial |
| | 1:6 SSIT | -0.49 (-1.42 to 0.45) Small | -0.71 (-1.67 to 0.24) Moderate | | | |
| | 1:9 SSIT | -0.51 (-1.44 to 0.43) Small | -0.66 (-1.61 to 0.29) Moderate | | | |
| | CON | -0.07 (-0.99 to 0.86) Trivial | | | | |
| $VO_{2max}$ (ml.kg$^{-1}$.min$^{-1}$) | 1:3 SSIT | 1.33 (0.31 to 2.35) Large | 1.26 (0.25 to 2.27) Large | 0.69 (-0.26 to 1.64) Moderate | 0.74 (-0.21 to 1.70) Moderate | 0.03 (-0.89 to 0.96) Trivial |
| | 1:6 SSIT | 0.83 (-0.13 to 1.79) Moderate | 0.57 (-0.37 to 1.51) Small | | | |
| | 1:9 SSIT | 0.66 (-0.29 to 1.61) Moderate | 0.54 (-0.40 to 1.48) Small | | | |
| | CON | 0.17 (-0.76 to 1.10) Trivial | | | | |
| Yo-Yo IR1 (m) | 1:3 SSIT | 1.63 (0.56 to 2.70) Large | 1.17 (0.17 to 2.17) Moderate | 0.35 (-0.58 to 1.28) Small | 0.69 (-0.26 to 1.65) Moderate | 0.32 (-0.61 to 1.25) Small |
| | 1:6 SSIT | 0.97 (0.00 to 1.95) Moderate | 0.80 (-0.16 to 1.76) Moderate | | | |
| | 1:9 SSIT | 0.86 (-0.11 to 1.82) Moderate | 0.51 (-0.43 to 1.45) Small | | | |
| | CON | 0.16 (-0.76 to 1.09) Trivial | | | | |
| Peak power (w) | 1:3 SSIT | 0.71 (-0.24 to 1.66) Moderate | 0.56 (-0.38 to 1.51) Small | 0.31 (-0.62 to 1.24) Small | 0.63 (-0.31 to 1.58) Moderate | 0.34 (-0.59 to 1.27) Small |
| | 1:6 SSIT | 0.91 (-0.06 to 1.88) Moderate | 0.85 (-0.11 to 1.82) Moderate | | | |
| | 1:9 SSIT | 1.22 (0.21 to 2.22) Large | 1.14 (0.15 to 2.14) Moderate | | | |
| | CON | 0.19 (-0.74 to 1.11) Trivial | | | | |
| Mean power (w) | 1:3 SSIT | 1.47 (0.43 to 2.51) Large | 1.51 (0.46 to 2.56) Large | 0.50 (-0.44 to 1.43) Small | 0.69 (-0.26 to 1.65) Moderate | 0.21 (-0.72 to 1.14) Small |
| | 1:6 SSIT | 0.97 (0.00 to 1.95) Moderate | 0.91 (-0.06 to 1.88) Moderate | | | |
| | 1:9 SSIT | 0.65 (-0.30 to 1.60) Moderate | 0.64 (-0.31 to 1.59) Moderate | | | |
| | CON | 0.19 (-0.73 to 1.12) Trivial | | | | |

**Table 3. Continue.**

| Variables | | Between Groups ES | | | | |
|---|---|---|---|---|---|---|
| | | Pre vs. Post | Post vs. CON | Post, 1:3 vs. 1:6 | Post, 1:3 vs. 1:9 | Post, 1:6 vs. 1:9 |
| MKDT (m) | 1:3 SSIT | 1.05 (0.06 to 2.03) Moderate | 0.88 (-0.09 to 1.85) Moderate | 0.08 (-0.84 to 1.01) Trivial | 0.19 (-0.73 to 1.12) Trivial | 0.29 (-0.64 to 1.22) Small |
| | 1:6 SSIT | 1.08 (0.09 to 2.07) Moderate | 0.85 (-0.12 to 1.81) Moderate | | | |
| | 1:9 SSIT | 0.99 (0.01 to 1.97) Moderate | 1.13 (0.14 to 2.13) Moderate | | | |
| | CON | 0.10 (-0.83 to 1.02) Trivial | | | | |
| Testos-terone (ng/mL) | 1:3 SSIT | 0.35 (-0.58 to 1.29) Small | 0.27 (-0.66 to 1.20) Small | 0.22 (-0.70 to 1.15) Small | 0.33 (-0.60 to 1.26) Small | 0.08 (-0.84 to 1.00) Trivial |
| | 1:6 SSIT | 0.56 (-0.38 to 1.50) Small | 0.47 (-0.47 to 1.41) Small | | | |
| | 1:9 SSIT | 0.68 (-0.27 to 1.63) Moderate | 0.62 (-0.33 to 1.57) Moderate | | | |
| | CON | 0.04 (-0.89 to 0.96) Trivial | | | | |
| Cortisol (µg/dL) | 1:3 SSIT | -0.19 (-1.12 to 0.73) Trivial | -0.02 (-0.94 to 0.91) Trivial | 0.14 (-0.78 to 1.07) Trivial | 0.32 (-0.61 to 1.24) Small | 0.18 (-0.75 to 1.10) Trivial |
| | 1:6 SSIT | -0.39 (-1.33 to 0.54) Small | -0.17 (-1.10 to 0.75) Trivial | | | |
| | 1:9 SSIT | -0.62 (-1.57 to 0.32) Moderate | -0.37 (-1.31 to 0.56) Small | | | |
| | CON | -0.08 (-1.00 to 0.85) Trivial | | | | |

**Table 4. An overview of training workload.**

| Variables | Groups | | |
|---|---|---|---|
| | 1:3 SSIT | 1:6 SSIT | 1:9 SSIT |
| sRPE | 8.1 ± 0.7 | 6.7 ± 0.8 | 5.9 ± 0.4 |
| Training duration (min) | 249.6 | 369.6 | 489.6 |
| Training load | 2021.6 ± 174.7 | 2476.3 ± 295.6 | 2888.6 ± 195.8 |

sRPE; sessions rating of perceived exertion, training load = RPE × training time.

Consistent with prior studies (Arazi et al., 2017; Kunz et al., 2019; Clemente et al., 2021; Boullosa et al., 2022), the findings of the present study suggest that SSIT serves as a viable training method for eliciting moderate to large training effects on aerobic fitness, as evidenced by improvements in $\dot{V}O_{2max}$ and Yo-Yo IR1. The enhancements in cardiorespiratory fitness may be attributed to the oxygen delivery (i.e., central component) (Sheykhlouvand et al., 2022) and oxygen use by active muscles (i.e., peripheral component) (Kunz et al., 2019; Sheykhlouvand et al., 2018a; 2018b; Rasouli Mojez et al., 2021; Sayevand et al., 2022). Regarding the superiority of each training method, the 1:3 SSIT resulted in greater changes and exhibited larger training effects than the other groups. Notably, these disparities were statistically significant when compared to the 1:9 SSIT ratio, indicating that shorter rest intervals between SSIT sessions may elicit greater adaptive responses in the aforementioned mechanism. To optimize cardiorespiratory fitness, athletes are advised to allocate a prolonged period per training session within their red zone, which typically involves reaching an intensity surpassing 90% of their $\dot{V}O_{2max}$ (Laursen and Buchheit, 2019). The utilization of shorter exercise-to-rest ratios appears to result in a reduced decline in $\dot{V}O_{2max}$ during rest, facilitating quicker attainment of $\dot{V}O_{2max}$ during subsequent efforts, thereby accumulating substantial time at 90% of their $\dot{V}O_{2max}$. This mechanism might partially account for the significantly greater change in $\dot{V}O_{2max}$ in the 1:3 group compared to longer rest intervals. A diminished recovery duration contributes to an increased overall work completed within a given period and the associated physiological response (Laursen and Buchheit, 2019).

On the other hand, shorter rest periods between SSIT trials can elevate lactate and $H^+$ production, potentially enhancing the activity of oxidative enzymes (Iaia et al., 2017). The SIT with a lower exercise-to-rest ratio has demonstrated an increase in monocarboxylate transporters 1, which are crucial in regulating muscle pH during intense exercise (Rogers et al., 2024). This affirms the efficacy of SSIT in pH regulation through shorter rest intervals between trials, resulting in greater adaptations in aerobic metabolic conditioning (Brooks and Mercier, 1994). Incorporating high-intensity tasks during SSIT with lower rest intervals led to prolonged exhaustion and exertion while surpassing the lactate threshold (Massamba et al., 2021). This particular training approach (i.e., SSIT) with shorter rest intervals is tailored to meet individual requirements, promote maximal effort, and induce physiological stress, consequently enhancing aerobic capacity as measured by $\dot{V}O_{2max}$ and Yo-Yo IR1 in young male soccer players.

Anaerobic power stands as one of the most essential qualities influencing soccer performance, which is crucial for short-term maximal effort (peak power) and sustained powerful abilities (mean power) during a game (Kumar and Singh, 2014). The 7-week SSIT induced significant homeostatic stress on mechanisms involved in anaerobic power performance in young soccer players, which corroborates previous studies (Kunz et al., 2019; Boullosa et al., 2022). Enhancements in anaerobic power following the SSIT are related to increases in PCr concentration, activity of the anaerobic enzymes, and conversion from slow-twitch to fast-twitch muscle fibers (Kohn et al., 2011). The significant enhancements seen in mean power output with the 1:3 SSIT and the greater improvements in peak power adaptations with the 1:9 SSIT underscore the crucial influence of rest intervals during SSIT (Iaia et al., 2017). Extended rest periods facilitate rapid recovery of muscle fibers by prioritizing PCr replenishment (Rogers et al., 2024). Utilizing longer rest intervals in SSIT may effectively target the ATP-PCr pathway, which is crucial for maximizing peak power output. Conversely, shorter rest periods in SSIT promote increased activation of aerobic enzymes (Iaia et al., 2017) and elevate buffering capacity (Sheykhlouvand et al., 2022), leading to sustaining power production over a set duration (e.g., 30 seconds). Consequently, the evidence suggests that longer rest intervals between SSIT trials lead to the activation of muscle fiber cells in the ATP-PCr pathway, while extended durations promote the engagement of oxidative metabolic pathways, ultimately leading to significant enhancements in peak and mean power output during the Wingate anaerobic test, respectively (Rogers et al., 2024).

Concerning MKDT, all training groups demonstrated similar moderate training outcomes, consistent with previous studies suggesting that SIT effectively improves soccer-specific performance (Ball, 2009; Lee et al., 2020). These findings can be linked to improvements in specific biomechanical factors essential for achieving maximum kicking distance, such as leg maximum linear speed enhancements due to neuromuscular adaptations to SIT (Lees et al., 2010). Therefore, all three SSIT interventions are recommended to induce desirable effects on MKDT performance in soccer players.

Regarding the hormonal adaptations, it was found that all training interventions led to an increase in testosterone levels and a decrease in serum cortisol concentrations. These results corroborate previous research highlighting the anabolic effects of SIT (Ambroży et al., 2021; Song and Deng, 2023). An increase in resting testosterone levels and a decrease in cortisol typically indicate an anabolic environment. Higher resting testosterone levels create a favorable hormonal environment, which is beneficial for maximizing performance adaptations. Interestingly, the current study showed that longer rest durations result in more adaptive responses, with greater testosterone levels and reductions in cortisol levels. Increasing rest intervals during training (e.g., 1:9) allows for a more anabolic environment and a decrease in stress hormone production, such as cortisol, when compared with short rest intervals between SSIT trials.

A key aspect of this study was to document injury incidents throughout the training program. It was noted that none of the players encountered any injuries. Additionally, the study provides a practical framework for incorporating SSIT with different rest intervals between trials. This method not only facilitates physiological adaptations, but also promotes physical fitness improvements without any instances of injury. However, the current study has a number of methodological limitations that warrant further discussion. Firstly, the inclusion of a relatively small number of athletes (n = 9 for each group) has affected the study's statistical power. However, we have conducted a priori power analysis, which indicates that this sample size is sufficient to achieve adequate statistical power. Secondly, the findings of this study are only applicable to male soccer players. Further research is needed to determine whether these findings can be extrapolated to female players and soccer players in different age groups and fitness levels. Lastly, it would have been valuable to include a longer training duration to assess the long-term effects of different exercise-to-rest ratios on adaptations via controlling the maturation of players. In this study, we did not control maturity offset of players and more studies are needed to clarify the influence of different exercise to rest ratio using different maturity status of male players. To validate our results, future studies should consider these variables. Keeping these limitations in mind, we recommend that future studies explore longer-term investigations, different athletic populations, or additional factors that may influence the effectiveness of SSIT.

## Conclusion

While the effectiveness of SSIT in enhancing various components of athletic performance is acknowledged, an ongoing debate persists regarding the most suitable SSIT approach for improving different aspects of athletes' physical fitness. Our findings suggest that SSIT effectively triggers mechanisms responsible for enhancing physiological and performance measures in young soccer players. This study demonstrated that manipulating rest intervals can significantly impact the adaptive response to SSIT. The group with more extended rest periods (i.e., 1:9 SSIT) showed greater improvements in the VJ, peak power output, and testosterone and cortisol levels. Shorter rests (i.e., 1:3 SSIT) showed greater adaptive responses in the mean power output, $\dot{V}O_{2max}$, and Yo-Yo IR1 after the 7-week training period. Hence, tailoring the SSIT rest distribution to specific objectives could facilitate desirable outcomes.

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## Key points

- By incorporating a 7-week SSIT into the usual soccer training routine, male soccer athletes experience enhanced physical and sport-related performance, as well as physiological and hormonal adaptations.
- The 1:9 SSIT approach results in greater adaptive changes in VJ, peak power output, and hormonal adaptations.
- The 1:3 SSIT method demonstrates a notable advantage over other methods when optimizing adaptations in aerobic capacity.
- No significant differences were observed among the different exercise-to-rest ratios of S.
- SIT groups in MKDT, 20-m linear sprint, and T-CODS.

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