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Research article

Effects of Short Sprint Interval Training Frequency on Physical and Physiological Performance Adaptations in Male Soccer Players

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Abstract
The study aimed to evaluate the effects of varying frequencies (1 vs. 2 vs. 3) of short sprint interval training (sSIT) on young male soccer players' physical performance and physiological parameters. Forty young male soccer players were randomly assigned to four experimental groups engaging in 36 trials sSIT for a duration of 6 weeks as follows: once weekly (1sSIT = 4 sets of 9 × 5 sec all-out runs), twice weekly (2sSIT = 2 sets of 9 × 5 sec all-out runs), and three times weekly (3sSIT = 2 sets of 6 × 5 sec all-out runs), or an active control group which continued their soccer practice routines. Before and after the 6-week training period, physical performance (countermovement vertical jump, 20-m sprint, Illinois change of direction, Yo-Yo intermittent recovery level 1 [Yo-Yo IR 1] and kicking distance) and physiological parameters (cardiorespiratory fitness, peak and average power output) were evaluated. All sSIT groups demonstrated significant ($p < 0.01$) and small to very large training effects (i.e., effect size) on measured parameters. More importantly, a comparison of inter-individual variability in the adaptive changes revealed that the 3sSIT group results in lower residuals in changes in cardiorespiratory fitness and anaerobic power, coupled with lower coefficient of variations in the mean group changes and perceived exertion throughout the training period. The findings indicate that incorporating one, two, or three weekly sessions of sSIT into routine soccer training can lead to similar enhancements in soccer players' physiological and performance adaptations. More importantly, higher training frequencies result in more homogenized adaptations among team members by reducing inter-individual variability in the magnitude of the adaptive responses.

Key words: Intermittent exercise, team sport, performance, anaerobic power, maximal oxygen consumption.

Introduction

Soccer is an intermittent team sport, requiring many physiological and biochemical factors influencing a player's performance (Helgerud et al., 2001). A soccer match involves repeated bouts of high-intensity sprinting, interspersed with short periods of low-to-moderate-intensity activities (Reilly, 1994). Anaerobic metabolism supplies energy for intensive actions such as sprinting, changing direction and jumping, while aerobic energy metabolism prevails during less intense activities such as jogging, walking, and standing (Mohr et al., 2003). Studies have demonstrated a favorable correlation between aerobic fitness and the rapid recovery of power during successive rounds of intense interval exercise (Arazi et al., 2017; Clemente et al., 2022). Therefore, both aerobic and anaerobic metabolic systems are essential in soccer performance (Arazi et al., 2017; Clemente et al., 2021; Sheykhlouvand and Gharaat, 2024).

Although, numerous training methods (i.e., plyometric training, concurrent training, and interval training) are available to improve the mentioned qualities in soccer players (Ramirez-Campillo et al., 2014; Kunz et al., 2019; Youcef et al., 2022), recent studies highlighted that the short sprint interval training (sSIT) is an appropriate training modality for the adaptations of both physical and physiological components of soccer players (Sheykhlouvand and Gharaat, 2024; Li and Xue, 2024; Zhang et al., 2024). In fact, shorter durations of sprints (≤ 10 sec efforts) can yield greater adaptive responses compared to other interval training models (i.e., small-sided games) (Boullosa et al., 2022; Sheykhlouvand and Gharaat, 2024; Lee et al., 2020), with lower rate of perceived exertion (Boullosa et al., 2022). Therefore, sSIT protocols could be considered a new time-efficient and enjoyable approach to improve both aerobic and anaerobic metabolic pathways in soccer players (Boullosa et al., 2022).

Selecting an appropriate sSIT regimen necessitates a thoughtful analysis of diverse parameters, encompassing factors like match-play requirements and expected long-term adaptations. This can be achieved by skillfully manipulating variables, including the number of repetitions, training volume, intensity, distribution of rest intervals, and frequency of training sessions (Buchheit and Laursen, 2013; Sheykhlouvand et al., 2018a; 2018b). Several studies have explored the effects of sSIT on physiological adaptations (Lee et al., 2020; Sheykhlouvand and Gharaat, 2024; Li and Xue, 2024; Zhang et al., 2024; Tao et al., 2024), revealing that a minimum training duration of two weeks, encompassing a minimum of six sessions, is essential to trigger these transformative changes (Boullosa et al., 2022). Recently, Lee and colleagues (2020) reported a significant improvement in aerobic and anaerobic adaptations following a four-week sSIT, characterized by sprints lasting ≤10 sec, spanning 12 sessions. In other study, Belfry and colleagues (2020) have indicated four weeks of sSIT (≤10 sec sprints) is the optimal training dose for improving aerobic performance. Recently, Marzouki et al. (2021) indicated that one and two sessions per week of sprint training induces comparable improvements in linear sprint, change of direction, and jumping ability among soccer players. However, for cardiorespiratory fitness, two sessions were more effective than one session. Consequently, it becomes imperative for coaches to maximize their players' athletic performance by optimizing training frequency to minimize fatigue resulting from training. However, the

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ideal number of sSIT weekly sessions for soccer players remains uncertain (Marzouki et al., 2021; Boullosa et al., 2022) and the impacts of sSIT at varying frequencies on both physiological parameters and physical performance adaptations remain unknown.

More importantly, studies typically report responses to diverse exercise interventions as average group values, assuming these values reflect individual responses (Arazi et al., 2017; Lee et al., 2020; Boullosa et al., 2022; Mann et al., 2014). Recently, Sheykhlouvand and Gharaat (2024) stated that to clarify the adaptations related to training the calculating of inter-individual variability in team players should be consider. Therefore, to identify an appropriate weekly training frequency of sSIT, determining the inter-individual variability in the adaptive responses to training is important. Therefore, the present study aimed to compare different weekly sSIT frequencies in soccer athletes under volume-matched conditions to determine the optimal frequency of sSIT for physical and physiological performance adaptations. The second objective of this study was to determine inter-subject variability in the adaptations to sSIT with different weekly frequencies.

Methods

The determination of the sample size was carried out using the G*Power software (Version 3.1.9.2, University of Kiel, Germany). Initially, eight subjects were calculated for each group, taking into account a 95% confidence interval and an analysis power of 0.80. However, to mitigate the potential dropout of participants during data collection, the sample size was subsequently augmented to 10 participants per group based on the study conducted by Zhang et al. (2024) who examined the effects of sSIT on physical and physiological performance of soccer players. A total of 40 participants were selected from college teams engaged in national-level competition (McKay et al., 2022: Category III). During the most recent college national championship, these players achieved placements ranging from fourth to second. At the time of recruitment, each player was participating in three training sessions weekly and one competitive match weekly (Table 1). Therefore, the players exhibited similar competitive schedules and levels of engagement in soccer drills, leading to uniform soccer-specific weekly training loads across all groups involved in the study.

The players were matched according to playing position and then were randomly assigned to 4 groups engaging in one session sSIT (1sSIT, n = 10), two sessions sSIT (2sSIT, n = 10), three sessions sSIT (3sSIT, n = 10) per week, or an active control group (CON, n = 10) consisting of 4 defenders, 4 midfielders, and 2 attackers (Table 2). Participants were familiar with sprint-type interval training but did not engage in intensive interval intervention two months before initiation of the study. Exclusion criteria consisted of a) the presence of upper and lower body injuries within the three months leading up to their participation in the study and b) the absence of any medical or orthopedic conditions that could hinder their participation or performance capabilities. All participants signed an informed consent and volunteered to participate. All procedures were in accordance with the principles of Declaration of Helsinki and were approved by the institutional review board of Jiangxi Science and Technology Normal University.

Study design

Figure 1 indicates experimental design in detail. This study utilized a randomized-controlled design. Group allocation was decided through the use of a computerized random number generator, leading to group assignments that were unpredictable and based on chance. This approach adhered to the guidelines outlined in the "CONSORT" statement. After the baseline measurements, the experimental groups (1sSIT, 2sSIT, and 3sSIT) completed sSIT before their soccer training sessions. All training sessions and performance tests were conducted in the afternoon (4:00 to 6:00 P.M) to minimize the impact of circadian variations in the results. The measurements of the tests were conducted on a grass soccer field, with temperatures ranging from 27-29°C, humidity less than 60% and an average tailwind of ~3.4 $m \cdot s^{-1}$ with experienced researcher.

Anthropometric measure

The height was measured with a wall-mounted stadiometer (Seca 222, Terre Haute, IN) and recorded to within 0.5 cm and body mass (Tanita, BC-418MA, Tokyo, Japan) with an accuracy of 0.1 kg.

Table 1. A description of the training program for a one-week case during the experimental duration.

Week days	Morning session	Evening session
Monday	Recovery	Technical-tactical training and small-sided games
Tuesday	Individual fitness *	Recovery
Wednesday	Recovery	Technical and tactical training, stimulated competitive games
Thursday	Video or multidisciplinary activities	Recovery
Friday	Recovery	Tactical drills, small-sided games and stimulated competitive games
Saturday	Recovery	Recovery
Sunday	Recovery	Official game

* Individual fitness: conditioning exercises which were applied in accordance with the players' position on the pitch with body weight.

Table 2. Participants' characteristics (mean ± SD).

Groups	N	Age (y)	Body mass (kg)	Height (cm)	Soccer experience (y)
1sSIT	10	22.1 ± 1.9	78.1 ± 3.5	180.9 ± 3.6	6.3 ± 1.1
2sSIT	10	22.9 ± 2.3	75.9 ± 2.7	178.1 ± 3.2	6.6 ± 1.6
3sSIT	10	22.7 ± 2.6	77.1 ± 4.8	181.6 ± 3.4	7.1 ± 1.3
CON	10	22.5 ± 1.8	76.4 ± 2.2	175.4 ± 5.1	6.9 ± 0.9

sSIT: short sprint interval training, CON: control group.

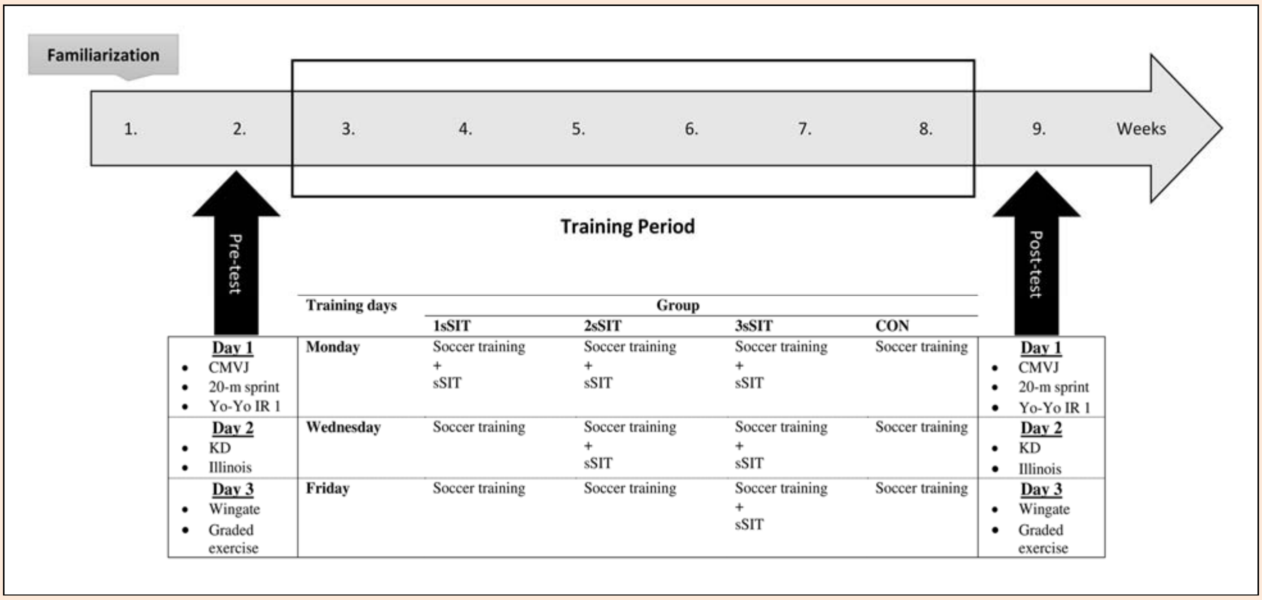

Figure 1. Overview of the study design. CMVJ: countermovement vertical jump, Yo-Yo IR1; Yo-Yo intermittent recovery level 1, KD: kicking distance, sSIT: short sprint interval training.

Cardiorespiratory fitness

To assess maximum oxygen consumption ($\dot{V}O_{2max}$), a graded exercise test was conducted on a treadmill (SportsArt Fitness, T645L, Everett, WA 98203, USA), utilizing a breath-by-breath gas collection system (Hans Rudolph Inc., USA) (Sheykhlouvand and Gharaat, 2024). After a 10-minute general warm-up including stretching movement and ballistic exercises, the test protocol was initiated at a speed of 8 km/h, with the speed increasing by 1 km/h every 3 minutes until participants reached a point of volitional exhaustion. Various criteria were employed to determine the attainment of $\dot{V}O_{2max}$, including: a) maintaining a stable $\dot{V}O2$ despite an increase in workload, b) achieving a respiratory exchange ratio greater than 1.10, c) attaining a blood lactate concentration of 8 mmol/L or higher, d) reaching a maximum heart rate equal to or greater than 95% of the age-predicted maximum (220–age), and e) experiencing volitional exhaustion (Sheykhlouvand and Forbes, 2017; Gharaat et al., 2020b; Sheykhlouvand et al., 2022). Following criteria elaborated by Sheykhlouvand and Gharaat (2024), the first and second ventilatory thresholds (VT_1 and VT_2) were determined for further analysis.

Wingate anaerobic power test

The assessment of the lower body's peak power output (PPO) and average power output (APO) involved a 30-sec maximal Wingate anaerobic test. This test utilized a mechanically braked cycle ergometer (model 894E, Monark, Sweden) with resistance adjusted to 0.075 $kg \cdot kg^{-1}$ of the participant's body mass. Following the 10-minute warm-up including a 5-minute ballistic movements and a 5-minute cycling, the participants initiated the test by pedaling at maximum speed against the device's inertial resistance, followed by the addition of a personalized load. Verbal encouragement was consistently provided throughout the 30-sec duration to ensure participants maintained their maximum effort. PPO was determined as the highest power achieved at the 5-sec mark, while APO represented the average power output throughout the entire test (Forbes and Sheykhlouvand, 2016).

Jump performance

The study used Vertec Power Systems (Knoxville, Tennessee, TN, USA) to measure countermovement vertical jump (CMVJ). Following a standardized warm-up (5 minutes stretching exercises, 5 minutes ballistic movements and 5 CMVJ trials), participants began crouching with a knee joint angle of about 90°, with no arm swing and then jumped up to reach maximum height. Each participant performed the test three times with a 3-minute break, and the best value of the three measurements was used for analysis (Markovic et al., 2007). The reliability coefficient (ICC) for repeated measurements at CMVJ was 0.95.

Sprint performance

The 20-m sprint test was conducted on a natural grass field. After a standardized warm-up (including two 20-m trials) the participants initiated the sprint from a standing start behind the starting line. On the "Go" command, they ran 20-m as fast as possible and the sprint time was initiated automatically when the participants passed the first time slot at the 0-m mark and continued until he passed the last gate at 20-m (Newtest Power timer 300-series testing system, Finland). Times were recorded within 0.01 (Rimmer and Sleivert, 2000). The ICC for this test was 0.94.

Change of direction ability

The Illinois change of direction (COD) test, completed on a natural grass pitch, was used to assess the ability of soccer players (Miller et al., 2006). Each participant received a specific warm-up, which included two Illinois COD trials, before completing two maximal effort trials with a two-minute rest period between them. For analysis in this study, the fastest time from the two trials was selected (Newtest Power timer 300-series testing system, Finland). The ICC for this test was 0.97.

Yo-Yo intermittent recovery level 1

The Yo-Yo intermittent recovery level 1 (Yo-Yo IR1) protocol has been previously described in detail (Bangsbo et al., 2008). Briefly, after completing two trials of a 20-m sprint test for a specific warm-up, each participant was instructed to perform shuttle runs on a 20-m track with 10 sec of rest. These trials continued until the participant was voluntarily exhausted, and the total distance traveled was recorded for subsequent analysis.

Maximal kicking distance

The maximal kicking distance (MKD) test is used to measure the maximal distance of a soccer player who kicks a ball with one foot (i.e., dominant foot). After the self-selected warm-up (including a 10-minute running and ballistic movement and 5 MKD trials), each participant was instructed to kick a ball (size-5, Nike Seitiro, FIFA certified) for a maximum distance on a soccer field (i.e., grass). The greatest distance achieved from the three kicking trials was used for the analysis. One minute of rest was allowed in between the trials (Ramirez-Campillo et al., 2014).

Training program

The soccer players conducted their training practices, encompassing tactical drills, technical exercises, and small-sided games on Monday, Wednesday, and Friday afternoons, lasting between 70 to 80 minutes from 4:00 to 6:00 P.M. Each session initiated with a standardized 15-minute warm-up, involving jogging and dynamic stretching, followed by sprint repetitions. Before the soccer training sessions, the training groups adhered to their designated training programs, incorporating linear sprints performed at maximum effort (i.e., all-out) with one, two, or three sessions per week, each featuring an equal volume load (Table 3) (Boullosa et al., 2022). The CON group exclusively participated in routine soccer training programs. A specialist conditioning coach supervised all training sessions to ensure proper execution. To control training load, the rating of perceived exertion (RPE) was recorded using the Borg 0-10 RPE Scale (Borg, 1982).

Table 3. sSIT program intervention.

Training variables	Groups		
	1sSIT	2sSIT	3sSIT
Sets (numbers)	4	2	2
Repetitions (numbers)	9	9	6
Trials time (sec)	5	5	5
Rest between trials (sec)	15	15	15
Rest between sets (sec)	180	180	180
Work to rest ratio (work : rest)	1:3	1:3	1:3
Weekly number of trials (reps)	36	36	36
Total number of trials (reps)	216	216	216

Statistical analysis

Data were presented as mean ± standard deviation (SD). The normality of the distribution was assessed using Shapiro-Wilk's tests. Group differences were analyzed using a two-factor (time×group) repeated-measure analysis of variance (ANOVA), followed by a Bonferroni post-hoc test to control type 1 error. Effect sizes (ES) were calculated using Hedge's g with a 95% confidence interval (CI) to determine the magnitude of training effects. Significance levels were categorized as follows: <0.2, trivial; 0.2 - 0.6, small; 0.6 - 1.2, moderate; 1.2 - 2.0, large; 2.0 - 4.0, very large; and >4.0, nearly perfect benchmark (Hopkins et al., 2009). Inter-individual variability for changes over time was assessed by calculating the coefficient of variations (CV). Initially, the individual percent change from pre- to post-training was computed for each variable, and the mean ± SD of individual percent changes was determined. Subsequently, the CV (ratio of SD to the Mean) of percent changes for each variable was calculated. Furthermore, individual residuals were computed as the square root of the squared difference between the individual and the mean value for each tested variable. The between-group mean residuals were then compared for each variable to discern the effects of sSIT with different weekly frequencies on inter-subject variability in physiological and performance variables (Zhang et al., 2024). The alpha level for statistical significance was set at 0.05.

Results

Every player exhibited absolute compliance, leading to a 100% success rate. Additionally, there were no documented instances of injuries linked to the training or testing interventions. At the baseline, no significant differences were observed among groups, and the CON group exhibited no significant changes in physical performance and physiological variables ($p > 0.05$) over time. Furthermore, at post-test, all training groups demonstrated greater adaptive responses compared to the CON group ($p < 0.05$).

Physical performance

All training groups exhibited significant ($p < 0.05$) improvements, ranging from small to large, in the CMVJ, 20-m sprint, Illinois COD, Yo-Yo IR1, and MKD following 6 weeks of training (Table 4).

When analyzing percent change and residuals in changes for physical performance variables, no significant differences were noted among the groups in 20-m sprint (p = 0.51 and 0.99), Illinois COD (p = 0.79 and 0.17), Yo-Yo IR1 (p = 0.96 and 0.48) (Figure 2), CMVJ (p = 0.82 and 0.74), and MKD (p = 0.61 and 0.85) (Figure 3).

Additionally, the 3sSIT group exhibited lower CV in mean individual changes in the abovementioned variables than other groups (Figure 6).

Physiological variables

All training groups displayed significant improvements, ranging from small to very large ($p < 0.05$), in $\dot{V}O_{2max}$, VT_1, VT_2, APO, and PPO after 6 weeks of training (Table 5).

Analyzing percent change in physiological variables revealed no significant differences among the groups in $\dot{V}O_{2max}$ ($p = 0.83$), VT_1 ($p = 0.88$), VT_2 ($p = 0.156$) (Figure 4), and APO ($p = 0.81$), except for PPO ($p = 0.011$) (Figure 5). When comparing individual residuals in changes, no significant differences were observed in VT_1 ($p = 0.35$) and APO ($p = 0.21$). However, the 3sSIT group resulted in significantly lower residuals in individual changes in $\dot{V}O_{2max}$ ($p = 0.016$), VT_2 ($p = 0.020$), and PPO

(p = 0.01) than the other groups.

Additionally, the 3sSIT group exhibited lower CVs in mean individual changes in the physiological variables than other groups (Figure 6).

Descriptive data for session RPE (sRPE) are presented in Figure 7. The results indicate that the sRPE decreases with an increase in the number of training sessions, with the order being 1sSIT > 2sSIT > 3sSIT.

Table 4. Changes in physical performance from pre- to post-training (mean ± SD).

Variable	Groups				Statistics
	1sSIT (n = 10)	2sSIT (n = 10)	3sSIT (n = 10)	CON (n = 10)	
CMVJ (cm)					
Pre	38.7 ± 4.3	38.8 ± 3.7	39.1 ± 3.9	39.1 ± 4.0	Group, p = 0.686
Post	42.3 ± 3.9*	42.2 ± 4.0*	42.3 ± 4.1*	38.9 ± 3.6	Time, p = 0.001
ES (95% CI)	0.84 (-0.07 to 1.75)^{c}	0.85 (-0.07 to 1.76)^{c}	0.77 (-0.14 to 1.67)^{c}	-0.05 (-0.93 to 0.83)	Group x time, p = 0.001
20-m sprint (sec)					
Pre	3.82 ± 0.27	3.86 ± 0.21	3.87 ± 0.18	3.89 ± 0.22	Group, p = 0.528
Post	3.70 ± 0.29*	3.74 ± 0.22*	3.72 ± 0.21*	3.88 ± 0.21	Time, p = 0.001
ES (95% CI)	-0.41 (-1.30 to 0.48)^{b}	-0.53 (-1.43 to 0.36)^{b}	-0.73 (-1.64 to 0.17)^{c}	-0.04 (-0.92 to 0.83)	Group x time, p = 0.002
Illinois COD test (sec)					
Pre	18.54 ± 1.12	18.47 ± 0.71	18.54 ± 1.01	18.57 ± 0.81	Group, p = 0.737
Post	17.94 ± 0.86*	17.87 ± 0.87*	18.06 ± 1.07*	18.56 ± 0.78	Time, p = 0.001
ES (95% CI)	-0.58 (-1.47 to 0.32)^{b}	-0.72 (-1.63 to 0.18)^{c}	-0.44 (-1.33 to 0.45)^{b}	-0.01 (-0.89 to 0.86)	Group x time, p = 0.026
Yo-Yo IR 1 (distance, m)					
Pre	1384 ± 120.4	1366 ± 147.5	1366 ± 126.5	1362 ± 185.1	Group, p = 0.079
Post	1658 ± 145.4*	1634 ± 171.8*	1624 ± 126.4*	1378 ± 163.1	Time, p = 0.001
ES (95% CI)	1.97 (0.90 to 3.04)^{d}	1.61 (0.6 to 2.62)^{d}	1.96 (0.89 to 3.03)^{d}	0.09 (-0.79 to 0.96)	Group x time, p = 0.002
MKD (m)					
Pre	46.86 ± 4.30	46.71 ± 4.21	46.94 ± 5.32	45.96 ± 6.23	Group, p = 0.66
Post	49.27 ± 4.39*	49.63 ± 4.06*	49.52 ± 4.52*	46.37 ± 5.59	Time, p = 0.001
ES (95% CI)	0.53 (-0.36 to 1.42)^{b}	0.68 (-0.22 to 1.58)^{c}	0.50 (-0.39 to 1.39)^{b}	0.07 (-0.81 to 0.94)	Group x time, p = 0.005

*Denotes significant differences from the corresponding pre and CON group values (p < 0.05). b: small, c: moderate, d: large, and e: very large ES. CMVJ: countermovement vertical jump, COD: change of direction, Yo-Yo IR 1: Yo-Yo intermittent recovery level 1, MKD: maximal kicking distance, m = meter.

Table 5. Changes in physiological variables from pre- to post-training (mean ± SD).

Variable	Groups				Statistics
	1sSIT (n = 10)	2sSIT (n = 10)	3sSIT (n = 10)	CON (n = 10)	
$\dot{V}O_{2max}$ (ml.kg^{-1}.min^{-1})					
Pre	49.9 ± 1.7	49.6 ± 3.2	50.2 ± 2.3	49.8 ± 3.3	Group, p = 0.82
Post	52.9 ± 2.1*	52.4 ± 3.6*	53.1 ± 2.4*	49.9 ± 2.8	Time, p = 0.001
ES (95% CI)	1.50 (0.51 to 2.50)^{d}	0.79 (-0.12 to 1.70)^{c}	1.18 (0.23 to 2.13)^{c}	0.03 (-0.85 to 0.91)	Group x time, p = 0.019
VT_1 (%$\dot{V}O_{2max}$)					
Pre	68.4 ± 3.4	69.3 ± 2.5	70.0 ± 5.2	69.3 ± 2.2	Group, p = 0.650
Post	72.0 ± 3.7*	73.2 ± 2.4*	74.0 ± 5.0*	69.5 ± 2.5	Time, p = 0.001
ES (95% CI)	2.05 (0.97 to 3.13)^{e}	1.52 (0.53 to 2.52)^{d}	0.75 (-0.16 50 1.66)^{c}	0.08 (-0.80 to 0.96)	Group x time, p = 0.003
VT_2 (%$\dot{V}O_{2max}$)					
Pre	83.0 ± 5.4	83.5 ± 5.2	83.7 ± 4.8	83.3 ± 3.4	Group, p = 0.954
Post	85.7 ± 5.6*	86.8 ± 5.0*	87.2 ± 4.9*	83.5 ± 2.9	Time, p = 0.001
ES (95% CI)	0.47 (-0.42 to 1.36)^{b}	0.62 (-0.28 to 1.52)^{c}	0.69 (-0.21 to 1.59)^{c}	0.06 (-0.82 to 0.94)	Group x time, p = 0.041
PPO (W)					
Pre	810.2 ± 43.7	803.1 ± 51.5	805.2 ± 56.2	806.9 ± 46.2	Group, p = 0.95
Post	871.3 ± 41.5*	863.5 ± 75.9*	891.1 ± 69.7*	810.6 ± 43.5	Time, p = 0.001
ES (95% CI)	1.39 (0.41 to 2.37)^{d}	0.89 (-0.03 to 1.81)	1.30 (0.34 to 2.27)^{d}	0.08 (-0.8 to 0.96)	Group x time, p = 0.001
APO (W)					
Pre	471.4 ± 34.7	472.6 ± 51.0	482.2 ± 20.4	479.4 ± 29.5	Group, p = 0.771
Post	512.5 ± 37.4*	514.7 ± 52.5*	522.9 ± 24.2*	481.7 ± 33.2	Time, p = 0.001
ES (95% CI)	1.09 (0.15 to 2.03)^{c}	0.78 (-0.13 to 1.69)^{c}	1.74 (0.71 to 2.77)^{d}	0.07 (-0.81 to 0.95)	Group x time, p = 0.026

* Denotes significant differences from the corresponding pre and CON group values (p ≤ 0.05). b: small, c: moderate, d: large, and e: very large ES. VO2max: maximum oxygen consumption, VT: ventilatory thresholds, PPO: peak power output, APO: average power output.

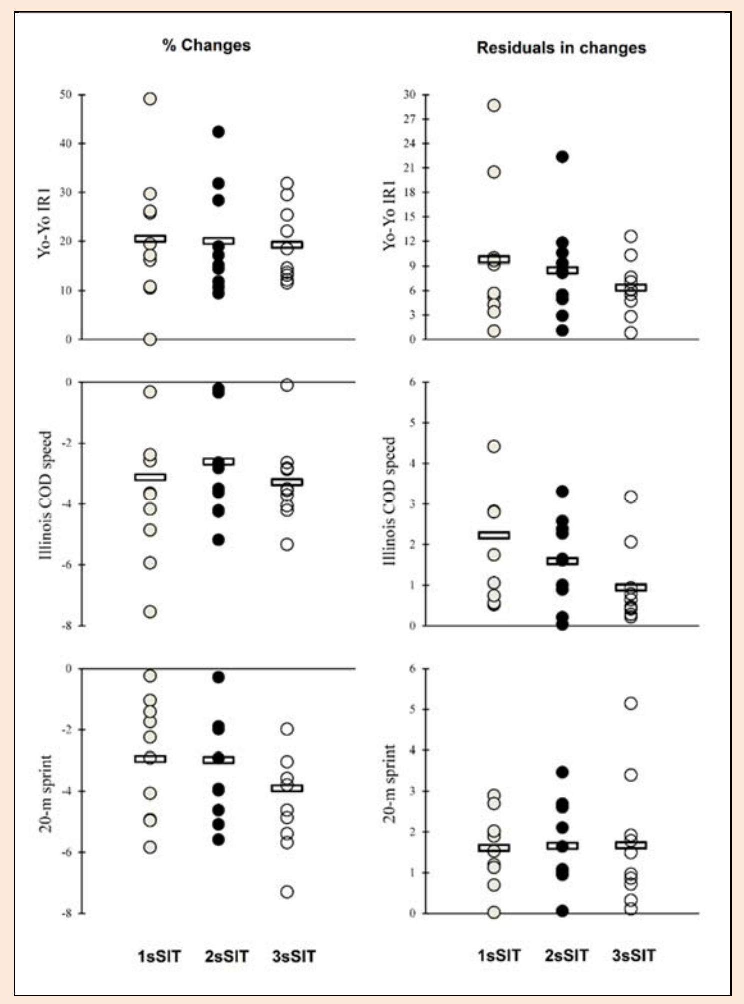

Figure 2. **Individual changes (%) from pre-to post-training and residuals in percent change as the squared root of the squared differences for the 1sSIT, 2sSIT, and 3sSIT groups in 20-m sprint, change of direction (COD), and Yo-Yo IR1 performance.**

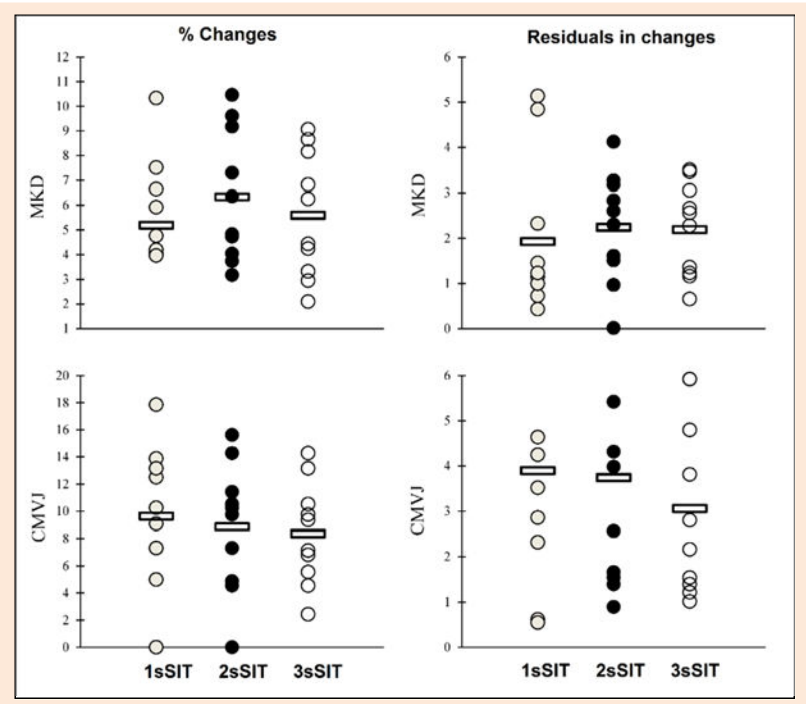

Figure 3. **Individual changes (%) from pre-to post-training and residuals in percent change as the squared root of the squared differences for the 1sSIT, 2sSIT, and 3sSIT groups in maximal kicking distance (MKD) and countermovement vertical jump (CMVJ) performance.**

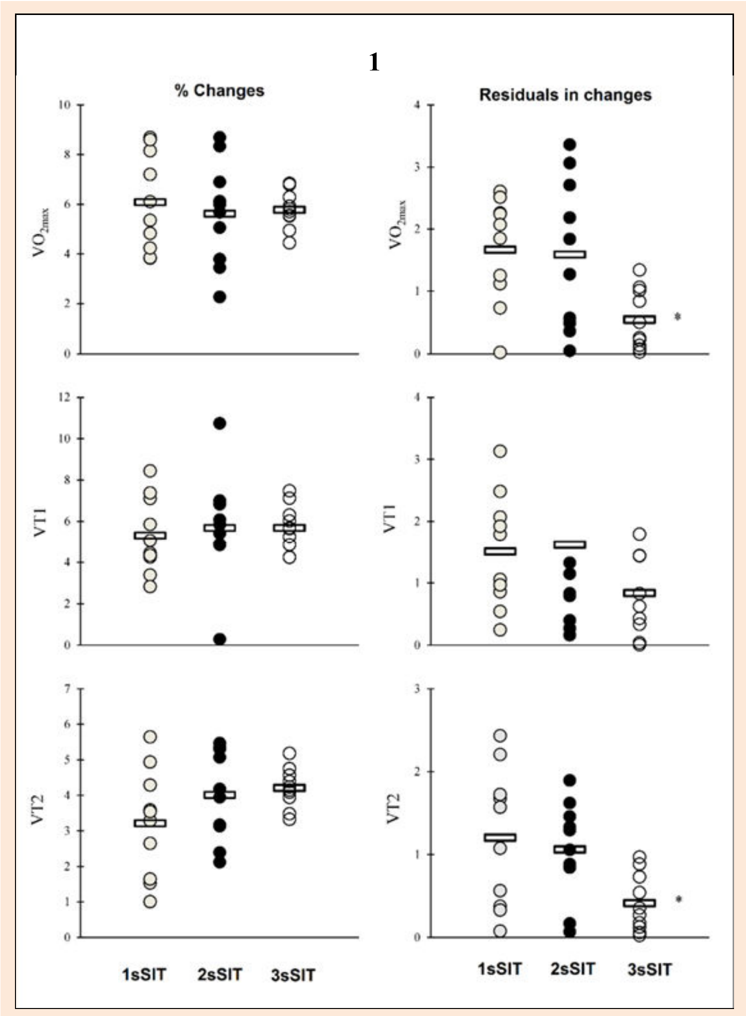

Figure 4. Individual changes (%) from pre-to post-training and residuals in percent change as the squared root of the squared differences for the 1sSIT, 2sSIT, and 3sSIT groups in maximum oxygen uptake ($\dot{V}O_{2max}$), first ventilatory threshold (VT1) and second ventilatory threshold (VT2). *denotes significant differences between 3sSIT and other groups ($p < 0.05$).

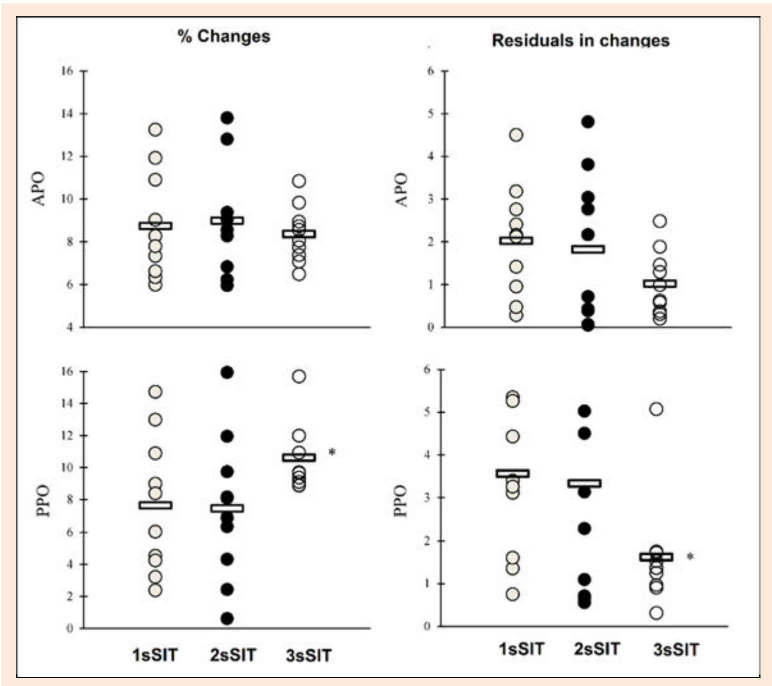

Figure 5. Individual changes (%) from pre-to post-training and residuals in percent change as the squared root of the squared differences for the 1sSIT, 2sSIT, and 3sSIT groups in peak power output (PPO) and average power output (APO). *denotes significant differences between 3sSIT and other groups ($p < 0.05$).

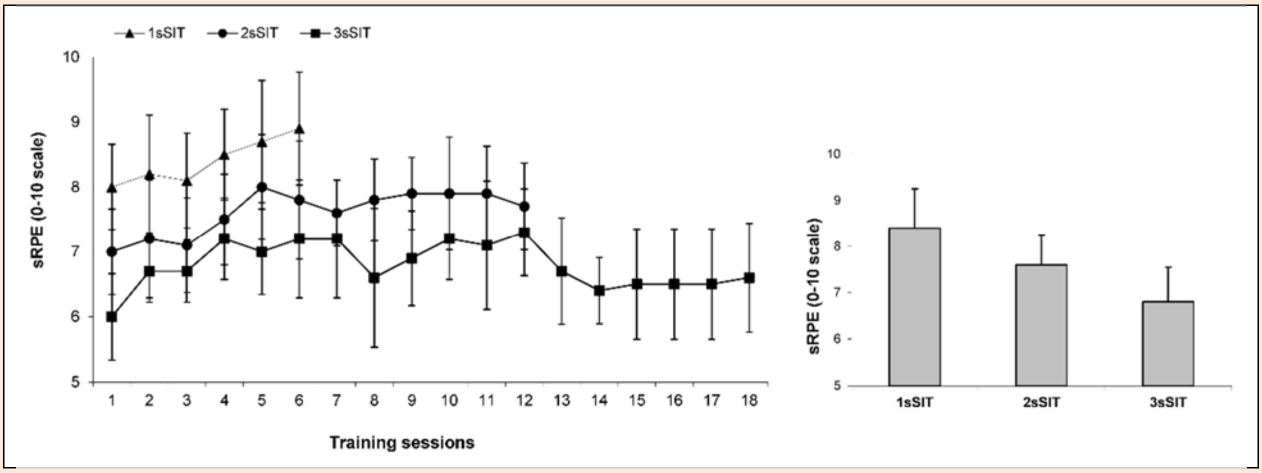

Figure 7. The session RPE for the 1sSIT, 2sSIT, and 3sSIT groups (mean ± SD).

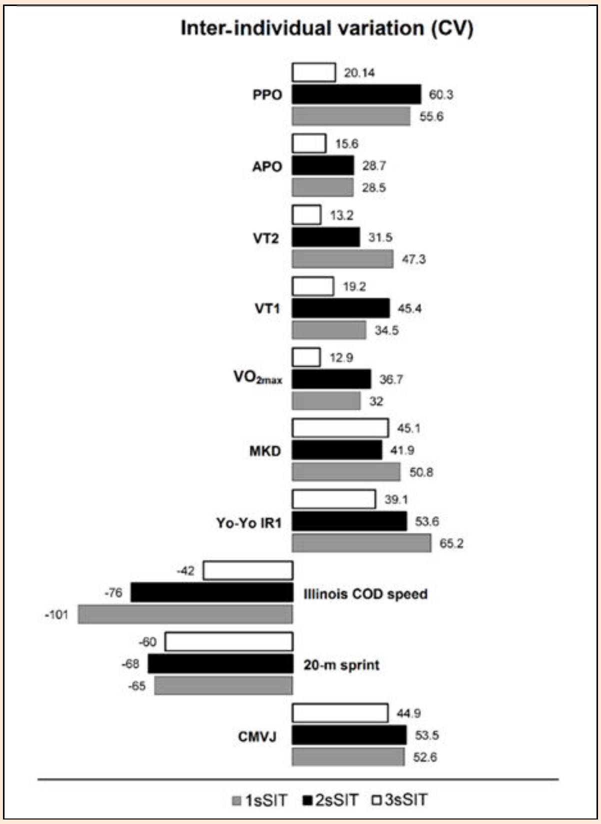

Figure 6. The inter-individual variation (CV) of percent changes in both the sport-related performance and physiological variables for the 1sSIT, 2sSIT, and 3sSIT groups.

Discussion

This study investigated the impact of different weekly sSIT frequencies under a volume-matched condition on cardiorespiratory fitness, anaerobic power, and physical performance of male soccer players. The results indicated that one, two, or three weekly sessions of sSIT performed over a 6-week training period led to a significant enhancement in measures of aerobic and anaerobic performance. More importantly, analyzing individual adaptations reviled higher training frequencies results in more homogenized adaptations among team members by reducing inter-individual variability in the magnitude of the adaptive responses.

Physical performance

The significant improvements observed in the CMVJ, 20-m sprint, Illinois COD, Yo-Yo IR1, and MKD across all training groups after 6 weeks were in accordance with previous research demonstrating the notable effects of various forms of sprint interval training on performance adaptations in soccer players (Arazi et al., 2017; Kunz et al., 2019; Lee et al., 2020; Boullosa et al., 2022; Arslan et al., 2020; Clemente et al., 2021; Yan et al., 2022; Li and Xue, 2024) by improvements in neuromuscular properties (Rimmer and Sleivert, 2000; Markovic et al., 2007), including intermuscular coordination and firing rate of alpha motor neuron (Zhang et al., 2024). Additionally, gains in muscle-tendon mechanical properties (Clemente et al., 2021), activation of fast-twitch muscle fibers (Arslan et al., 2020), and improvements in vertical and horizontal acceleration (Markovic et al., 2007) likely contribute to the observed improvements in CMVJ, 20-m sprint, and Illinois COD performance. The observed increase in running economy and musculotendinous stiffness (Yan et al., 2022), promoting enhanced recovery during sSIT, may lead to adaptive changes in Yo-Yo IR1. Moreover, sSIT intervention has been shown to induce neuromuscular adaptations that improve biomechanical parameters related to MKD, such as leg maximum linear speed (Lees et al., 2010; Wong et al., 2010).

While the percent change and residuals in physical performance variables did not show statistically significant differences among the groups, the 3sSIT group demonstrated lower residuals and CVs in the magnitude of these changes. This indicates that, although all sSIT frequencies are effective in enhancing physical performance adaptations, the 3sSIT group achieved more consistent results compared to the other groups.

Physiological variables

After six weeks of training, all training groups exhibited significant improvements in $\dot{V}O_{2max}$, VT_1, VT_2, PPO and APO. These findings align with prior research, highlighting the significant effects of various sprint interval training approaches on physiological variables (Helgerud et al., 2001; Mohr et al., 2003; Arazi et al., 2017; Kunz et al., 2019; Lee et al., 2020; Boullosa et al., 2022; Sheykhlouvand and Gharaat, 2024). The improvements in cardiorespiratory fitness could be attributed to enhancements in both the central aspect (Song and Sheykhlouvand, 2024; Sayevand et al., 2022), involving the delivery of more oxygen to the working muscles (Buchheit and Laursen, 2013), and the peripheral aspect, oxygen utilization by active muscles (Yan et al., 2022; Gharaat et al., 2024; Rasouli Mojez et al., 2021). Enhanced anaerobic performance (i.e., APO and PPO) could be associated with factors such as an elevation in the discharge rate and recruitment of high-threshold motor units (Tønnessen et al., 2020), an increase in the total creatine content in active muscles (Li and Xue, 2024), and an improvement in the muscle's buffering capacity (Kunz et al., 2019).

The analysis of residuals in individual adaptive responses indicated that the 3sSIT method effectively reduces inter-individual variability in the changes observed in $\dot{V}O_{2max}$, VT2, and PPO. Furthermore, the 3sSIT group exhibited lower CVs, suggesting a more uniform physiological adaptation among participants. The findings underscore the potential of this training approach to enhance the consistency of adaptations within a team setting with reduced fatigue and RPE. This, in turn, results in more substantial adaptive changes in the contractile ability of muscles (Sheykhlouvand and Gharaat, 2024; Zhang et al., 2024) and gains in PPO. Therefore, it is recommended for coaches and athletes who prefer a segmented approach to sSIT as it elicits more favorable adaptive responses in the PPO of soccer players, characterized by lower residuals in changes and homogeneous adaptations.

The results suggest that the interval between training sessions significantly influences physiological improvements more than the total number of sessions completed. Hatle et al. (2014) conducted a study comparing the effects of a 24-session high-intensity interval training (HIIT) program over eight weeks at a moderate frequency of three sessions per week versus a high frequency of eight sessions over three weeks. Their findings revealed that cardiovascular adaptations were delayed in the high-frequency training group compared to those in the moderate frequency group. Although the total workload was consistent across both groups, the differing training durations complicate direct comparisons with our results. In a study aligned with our methodology, Tønnessen et al. (2020) evaluated two groups with matched total weekly training volumes, one performing two sessions per week of longer HIIT and the other four sessions per week of shorter HIIT. The outcomes indicated that despite equivalent workloads, the concentrated exercise stimulus in the low-frequency group led to more favorable adaptations, supporting our findings. The observed small to very large training effects after single, double, and triple sprints indicate an optimal workload and recovery period between sessions. Overall, the interpretation of these studies, along with our results, suggests that the ideal stress from training interventions and appropriate recovery intervals enhance athletes' recovery and training responses. For sSIT, performing two sets of 6×5 sec with 15 sec of recovery between repetitions and a three-minute recovery between sets, three times per week, appears to be more effective than longer, low-frequency sessions.

Another aspect of this study involved assessing sRPE after each sSIT session. The findings revealed a decrease in sRPE with an increase in the number of training sessions (1sSIT > 2sSIT > 3sSIT). When considering these results in conjunction with existing literature (Marzouki et al., 2021; Boullosa et al., 2022), it is reasonable to suggest that sRPE serves as a suitable marker for monitoring training load and providing insights into soccer players' perceived exertion. The study's primary outcome emphasizes the significance of monitoring RPE during interval training sessions. In this context, increasing training frequencies led to lower sRPE, potentially enhancing the enjoyment of athletes who perceived lower effort during the training programs.

The present study has several limitations that should be acknowledged. Firstly, the relatively small number of participants, with only 10 soccer players in each group, may limit the overall power of the findings. However, a priori power analysis was performed, suggesting that this sample size is adequate for achieving the necessary statistical power. Another limitation is the authors' failure to monitor the intensity and running distance of each training session for individual subjects using global positioning system (GPS) technology. Future studies are encouraged to utilize laboratory measurements to identify the specific adaptations that facilitate the mechanisms underlying SIT. Moreover, the authors did not sufficiently account for soccer practice by monitoring psycho-physiological variables and nutritional status, which should be taken into consideration in future research. Additionally, controlling for other soccer training variables, such as short sprints during small-sided games, should be a focus of future investigations.

Conclusion

In summary, redistributing a given training volume (36 trials of 5 sec) across 1, 2, or 3 sessions per week does not yield statistically significant differences in CMVJ, 20-m sprint, Illinois COD, Yo-Yo IR1, cardiorespiratory fitness, power output, and MKD after a 6-week training period. However, our findings suggest that a higher frequency of sSIT diminishes effect on residual changes in male soccer players while maintaining consistency in adaptation during the 6-week training period. Therefore, strength and conditioning coaches may consider incorporating more sessions with shorter training durations to enhance athletic performance with reduced perceived exertion and consistent adaptations. From a practical perspective, executing fewer repetitions of sSIT during each training session may prove to be more advantageous than conducting a higher number of repetitions in a single training session, as this approach promotes improved uniformity in adaptations.

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The experiments comply with the current laws of the country in which they were performed. The authors have no conflict of interest to declare. The datasets generated during and/or 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

- Incorporating sSIT not only induces meaningful gains in physical performance but also produces adaptations in physiological parameters of soccer players.
- Although the changes in the variables from pre- to post-intervention were the same among the groups, the 3 sSIT group indicated lower inter-subject variability than other groups.
- From a practical perspective, it is advisable to incorporate brief sSIT sessions prior to each soccer training for players who experience lower perceived exertion, as increased homogeneity in adaptations has been observed with a higher frequency of weekly sSIT sessions.

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