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Research article

Effects of Sprint Interval Training Surface on Physical Fitness Attributes of Collegiate Female Soccer Players: Identifying Individual Responses to Training on Grass, Sand, and Land Surfaces

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Abstract
This study aimed to identify the optimal surface for sprint interval training to maximize transfer effects on physical performance measures on the grass pitch. Using a randomized controlled trial design, 40 collegiate female soccer players were equally assigned to three experimental groups performing short sprint interval training (SSIT: 4 sets of 10 repetitions with 5 seconds all-out running, with a 50-second recovery period between each effort and a 3-minute rest interval between sets) on SAND, GRASS, LAND, and a control group. Before and after a 7-week training period, participants underwent a series of field-based tests to evaluate countermovement jump (CMJ), 20-m linear sprint, Illinois change of direction (CoD) speed, Yo-Yo IR1, 2.4 km time trial, and maximal kicking distance (MKD) performance. A two-way analysis of variance with repeated measures was conducted on the data, along with Bonferroni post hoc testing. After the intervention, the control group did not show any changes, while the SAND, GRASS and LAND training groups demonstrated improvements ($p = 0.001$) in their performance as follows: CMJ (effect size [ES] = 1.21, 0.97, 0.64), 20-m linear sprint (ES = -0.81, -0.55, -0.41), Illinois CoD (ES = -0.72, -0.79, -0.41), Yo-Yo IR1 (ES = 1.86, 1.19, 1.12), 2.4 km time trail (ES = -0.82, -0.62, -0.49), and MKD (ES = 0.60, 0.90, 0.72), respectively. Comparative analysis of SAND, GRASS, and LAND revealed that performing SSIT on SAND results in a significantly greater gain in CMJ than LAND ($p = 0.041$). Analyzing individual responses to training interventions indicated that the training surface had a favorable influence on CMJ (SAND vs. LAND, $p = 0.009$), but on other variables no statistically significant ($p > 0.05$) differences were observed. Considering these findings, it is advised that strength and conditioning coaches use the SAND surface as the initial choice for SSIT sessions regarding greater gains (i.e., ES) in performance. This recommendation aims to facilitate more favorable transfer in physical fitness adaptation on a soccer grass pitch. In case of unavailability of SAND surface, GRASS surface would be a suitable alternative to enhance the physical fitness of collegiate female soccer players.

Key words: Interval training, team sport, aerobic capacity, athletic performance.

Introduction

Soccer is a team sport characterized by intermittent activities demanding numerous explosive movements, such as jumping ability, repeated short-distance sprints, accelerations and decelerations with changes of direction by utilizing an anaerobic metabolic pathway (Asadi et al., 2018; Dai and Xie, 2023). Moreover, aerobic capacity plays a crucial role during low-intensity activities such as walking and running, and elevated aerobic fitness supports faster recovery and plays a key role in sustaining efforts throughout matches (Arazi et al., 2017). Therefore, it is crucial to concentrate on enhancing both anaerobic and aerobic metabolic pathways to elevate the physical performance of soccer players during a match (Arazi et al., 2017).

Numerous training methods have been acknowledged as effective strategies to improve these qualities (Reilly, 1994; Helgerud et al., 2001; Dupont and McCall, 2016; Kunz et al., 2019; Arslan et al., 2020; Clemente et al., 2021). However, short sprint interval training (SSIT) has been reported as an effective training modality to enhance both the physical (i.e., jumping ability, sprinting speed and change of direction ability) and physiological performance (i.e., cardiorespiratory fitness and power output) of soccer players (Arazi et al., 2017; Boullosa et al., 2022; Dai and Xie, 2023). Previous research demonstrated that performing short duration of all-out running (i.e., SSIT < 10 seconds) induced similar adaptive responses to long-duration interval training with better fatigue control and managing motivations through trials (Boullosa et al., 2022; Sheykhlouvand and Gharaat, 2024). As a result, this type of interval training could be recommended for soccer athletes to enhance jumping ability, linear sprint, and change of direction speed as well as aerobic capacity (Arazi et al., 2017).

Although running-based interval training is always performed on land (Arazi et al., 2017; Dai and Xie, 2023), the importance of the training surface as a critical variable that can markedly affect athletes' performance is commonly overlooked (Impellizzeri et al., 2007; Mirzaei et al., 2014; Arazi et al., 2016; Pereira et al., 2023). Therefore, paying attention to the surface used in athletic conditioning schedules is crucial (Pereira et al., 2023). According to Pereira et al. (2023), incorporating sprint-jump training on both sand and grass surfaces can positively improve change of direction ability. Moreover, they suggested that training on sand leads to more significant improvements in linear sprint gains compared to training on grass. Therefore, selecting a suitable training surface is vital for sprint interval training, as it can affect the adaptive outcomes.

Using a sand surface is a viable option in the field of SSIT because the sand surface has the potential to reduce impact on bones and tissues by inducing increased effort from individual muscle fibers and the recruitment of motor units to counteract these properties, resulting in enhanced performance (Pinnington and Dawson, 2001; Arazi et al., 2014). Additionally, running on a sand surface led to

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higher energy expenditure with greater accumulation of H+ during exercise, which is suggested as an essential stimulus for improving muscle buffering capacity, leading to enhancements of aerobic and anaerobic capacities of athletes (Binnie et al., 2013).

Although it was suggested that the friction properties of sand could have detrimental effects on various aspects of training, such as the stretch-shortening cycle and amortization phase, ultimately resulting in a decline in performance adaptations (Arazi et al., 2014; 2016; Pereira et al., 2023), previous research has indicated that not only does sand surface not have negative effects, but it can also have positive effects in enhancing performance adaptations among athletes (Impellizzeri et al., 2007; Mirzaei et al., 2014). Therefore, soft surfaces (i.e., sand) could be one of the best options for producing muscle fiber works to performance enhancements. Expanding on the surface-related impact, it is noteworthy that training on grass or harder surfaces like land may result in lower energy expenditure and better involvement in the stretch-shortening cycle during running and jumping tasks, leading to performance gains (Pereira et al., 2023). These statements suggest that sand training, similar to another solid surface, could be viable for increasing training load and improving physical performance in athletes (Impellizzeri et al., 2007; Mirzaei et al., 2014). However, the influence of soft surface vs. hard surface during SSIT on the adaptive responses of physical performance measures is unknown, and more research is needed to determine the effectiveness of optimal training surface during SSIT, wherein this type of training is viable for soccer athletes.

To the best of our knowledge, no previous study has examined the effects of training surface on the adaptive responses to SSIT. Given the significant impact of SSIT on physical fitness attributes of soccer players including enhancements of jumping ability, sprint performance, change of direction speed and also cardiorespiratory fitness (Arazi et al., 2017; Dai and Xie, 2023; Sheykhlouvand and Gharaat, 2024), it is critical to identify the optimal surface for SSIT to achieve meaningful performance improvements. Therefore, the first objective of this study was to compare the effects of SSIT performed on sand, grass, and land on physical performance adaptations, including vertical jump, 20-m linear sprint, Illinois change of direction speed, Yo-Yo IR1, 2.4 km time trial and maximal kicking distance, in female soccer players, over a 7-week training period. The secondary aim of this study was to assess inter-individual variability in adaptive responses to SSIT conducted on various surfaces, aiming to determine the superior surface for maximizing performance gains. We hypothesized that the utilization of sand surfaces would result in greater changes in the physical performance attributes of female soccer players when compared with other surfaces (Pereira et al., 2023).

Methods

Participants

The sample size for each group was determined using G*Power software (Faul et al., 2007), and with an alpha level of 0.05 and β of 0.8 (Ramirez-Campillo et al., 2014), a minimum of 8 participants was determined for each training group. However, the sample size was later increased to 10 participants per group to accommodate possible participant dropout during data collection. Consequently, 40 collegiate trained (i.e., Tier 2, Mckay et al., 2021) female soccer players who were member of collage team and with the same training habits and loads were included in the study. These players were matched based on their playing positions and then were randomly divided into four groups: SAND (n = 10, age = 21.6 ± 2.3 y, height = 165.3 ± 8.1 cm, weight = 65.8 ± 3.5 kg, soccer experience = 4.5 ± 2.6 y), LAND (n = 10, age = 21.9 ± 2.6 y, height = 163.3 ± 7.5 cm, weight = 64.5 ± 4.3 kg, soccer experience = 4.8 ± 2.1 y), GRASS (n = 10, age = 22.1 ± 2.8 y, height = 166.5 ± 7.3 cm, weight = 67.1 ± 4.2 kg, soccer experience = 5.2 ± 2.9 y), and an active control group (CON; n = 10, age = 22.3 ± 3.1 y, height = 167.2 ± 6.5 cm, weight = 68.6 ± 3.3 kg, soccer experience = 5.5 ± 2.8 y). Similar number of defenders (n = 4), midfielders (n = 3) and forwards (n = 3) were present in each group. All participants were knowledgeable about various types of interval training and also all-out conditions (i.e., maximal and supramaximal efforts), however, they had not engaged in SSIT for a minimum of six months prior to being enrolled in the research. Furthermore, the participants had previous exposure to sand-based soccer training and were accustomed to the sand conditions utilized in the present study. Participants were excluded if they had (1) sustained lower body injuries within the past three months or (2) any medical or orthopedic conditions that could impede their participation or performance, as confirmed by a physician. All participants provided their informed consent, and the study obtained approval from the Ethics Committee of the University of XXX in accordance with the principles outlined in the Declaration of Helsinki.

Study procedure

Using a randomized controlled design, female soccer players underwent a 10-week intervention consisting of various phases (1-week familiarization, 1-week pre-test, 7-week training, and 1-week post-test). During a familiarization session, the researchers performed anthropometric measurements, utilizing a stadiometer (Bodymeter, Germany) for height with a precision of 0.1 cm and a digital scale (Tanita, Tokyo, Japan) for weight with an accuracy of 0.1 kg. One week later, the subjects underwent three days of testing sessions, with a 48-hour rest period between sessions. The testing sessions on Day 1 involved measurements of vertical jumping ability and Illinois change of direction speed. Day 2 included a 20-m linear sprint and Yo-Yo IR1 assessments, while Day 3 focused on the 2.4 km time trial and maximal kicking distance. The identical physical fitness assessment was subsequently administered over 3 separate days in the identical sequence of pre-test following the completion of the training program (Gharaat et al., 2020; Barzegar et al., 2022). All tests were conducted in the afternoon at the same time (i.e., 5 p.m.) to control for the potential influence of circadian rhythm on short-duration exercise performance.

Physical fitness measurements

Throughout the study, participants were advised to maintain regular daily activities and dietary intake to ensure consistency. Participants were also instructed to wear identical footwear for the pre-test and post-test sessions. A standard warm-up routine for soccer players was implemented during each testing session, consisting of 10 minutes of low- to moderate-intensity running, and 5 minutes of static and dynamic stretching (focusing on the lower body as several physical tests were assigned for lower limbs) and 5 minutes of ballistic movements and also repeated short sprint trials (i.e., 10 repetitions). Following the general warm-up, each participant performed a specific warm-up for each test including 2 - 3 trials for familiarization with the testing procedure. All performance tests were conducted on a natural grass field commonly utilized for soccer, as the objective of the study was to elucidate the transfer effects of SSIT on various surface conditions in relation to the physical fitness attributes of soccer players on a grass pitch. The tests were performed in an environment with temperatures ranging from 27 to 29°C, relative humidity between 65 and 70%, and wind velocity of ≤ 9 $km \cdot h^{-1}$.

Countermovement jump assessment

The countermovement jump (CMJ) is commonly utilized in sports environments as an objective measure for assessing lower limb power in soccer athletes (Matsuda et al., 2015). Research also suggests that the ability to perform a CMJ is crucial for executing key skills in soccer, like the header movement, which necessitates strong vertical jumping capabilities (Asadi et al., 2018). The CMJ of female soccer players was assessed by utilizing a wall-mounted VERTEC (Power System, USA). To establish familiarity, the players performed three submaximal jumps before the assessment. Subsequently, they were instructed to perform three maximal jumps, employing countermovement knees until they achieved a 90° angle (i.e., by employing an elastic band in parallel with the land). A one-minute break was given between each jump, and the highest score attained was recorded for subsequent analysis (Arazi et al., 2014).

20-m linear sprint assessment

The 20-m linear sprint test was chosen due to its widespread usage in assessing the sprinting capabilities of soccer players (Asadi et al., 2018). The sprint timing was recorded with a precision of up to 0.01 seconds using single-beam infrared photoelectric cells (Brower Timing Systems, Draper, UT, USA). The standardized starting position involved a stationary split stance, with the toe of the dominant foot positioned behind the starting line. The photoelectric signal was placed at a distance of 20-m and set at a height of approximately 0.7 meters above the floor (i.e., grass pitch), which allowed for the capture of trunk movement and prevented false triggers from limb movement. The players were instructed to perform three maximal runs with a three-minute rest in between, and the best time was recorded for further analysis (Asadi et al., 2018).

Illinois change of direction speed assessment

Successful engagement in soccer requires players to possess the vital skill of changing direction rapidly while sprinting at their maximum speed (Ramirez-Campillo et al., 2014). The Illinois change of direction (CoD) speed test was employed in this research to evaluate the agility of soccer players in terms of their acceleration, deceleration, multidirectional movement, and running at various angles on a grass field. The methodology for this test was previously described in detail by Miller et al. (2006). Following the general warm-up, participants were presented with a diagram (i.e., Illinois test shape) 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 (i.e., 2 trials), participants were directed to perform three maximal effort trials with a three-minute rest period between attempts. The best performance achieved was recorded by photoelectric cells (Brower Timing Systems, Draper, UT, USA) for further analysis.

Yo-Yo Intermittent Recovery Test

The Yo-Yo Intermittent Recovery Test 1 (Yo-Yo IR1) protocol was created to mirror the intermittent nature of soccer, which requires players to engage in bursts of intense physical activity that place demands on both anaerobic and aerobic metabolic systems (Mohr and Krustrup, 2014). The Yo-Yo IR1 procedure followed the detailed instructions provided earlier by Krustrup et al. (2003). Two markers were positioned 20 meters apart to establish a designated running area. Participants were then tasked to complete multiple 20-meter shuttle runs, interspersed with 10 seconds of active recovery between each run. The study encompassed the measurement of the distance covered by the participants in meters (i.e., Yo-Yo IR1 [distance, m] = number of 20-m runs × 20-m distance). After completing a general warm-up, the participants engaged in four self-paced running trials to become familiar with the testing protocol. The participants were given clear instructions to exert their maximum effort during the test, and data from those who did not meet this requirement were excluded from the final analysis.

2.4 km time trial assessment

As suggested in previous research (Coyle, 1995; Assuncao et al., 2017), the 2.4 km time-trial test was selected due to its various requirements (maximal oxygen consumption, lactate threshold, running economy, muscle power), which are expected to impact aerobics performance in soccer. Following an 800-m warm-up run and a 4-minute rest period, the players completed a 2400-m run on the soccer pitch, with timing recorded to the nearest second using a stopwatch.

Maximal kicking distance assessment

The ability to kick the ball is regarded as an essential skill for soccer players' performance as it is utilized in passes, crosses, and clearances as well as plays a pivotal role in determining the success of scoring goals during a match (Rodríguez-Lorenzo et al., 2015). In fact, to evaluate the leg muscles' ability to generate force and achieve the maximum kicking distance (MKD), the researchers employed the MKD test in this study. The primary aim of this test was to assess an individual's capacity to kick the ball as far as possible by utilizing their leg muscles' force production (Rodríguez-Lorenzo et al., 2015). Each player executed a stationary kick using a size 5 football (Nike Seitiro; FIFA certified) to achieve maximum distance. The test adhered to a protocol outlined earlier (Ball, 2009), wherein participants covered a distance of 2 strides (self-determined length) and executed a maximal instep kick with their dominant leg directed toward a goal net. Participants were instructed to concentrate on attaining the maximum possible kicking distance. Two practice trials and three valid maximal trials were conducted for each participant, with the trial that yielded the best performance being utilized for statistical analysis. A rest period of at least 1 minute was allowed between each trial.

Sprint interval training program

All participants in experimental groups including SAND, GRASS, LAND and CON groups engaged in soccer practices for three days a week (i.e., Mondays, Wednesdays, and Fridays) focusing on tactical and technical drills (i.e., passing, dribbling, change of direction with ball), small sided games, and simulated competitive games, which took place on in the afternoon. Each training session lasted approximately 100 to 120 minutes including 15 minutes of warm-up routine (i.e., 10 minutes of low- to moderate-intensity running and 5 minutes of stretching and ballistic movements), 60 - 70-minute main soccer training and 15 minutes of cool-down (i.e., low intensity running and stretching exercises). The players in the CON group only engaged in soccer practices, while the SAND, GRASS and LAND groups performed SSIT (i.e., 4 sets of 10 repetitions with 5 seconds all-out running, with a 50-second recovery period between each effort and a 3-minute rest interval between sets) before their soccer training and after a 15-minute of warm up (Belfry et al., 2020; Boullosa et al., 2022). As a result, the participants in the training groups (i.e., SAND, GRASS, and LAND) carried out each training session in the following manner: a 15-minute warm-up, 50 - 52 minutes of SSIT, 60-70 minutes of soccer training, and a 15-minute cool-down. The SAND training group conducted their training program barefoot on a dry beach sand surface 20 cm deep (i.e., beach soccer court) (Impellizzeri et al., 2007). On the other hand, the GRASS group performed their training program on a natural grass pitch using formal running shoes (Pereira et al., 2023). Similarly, using formal running shoes, the LAND group completed their SSIT program on a tartan track surface located around the soccer grass pitch. Throughout the training period, the strength and conditioning coach closely supervised all players, maintaining a ratio of 1:4 (trainer: player) to provide verbal motivation for the participants to give their maximum effort in each trial. In order to determine the training intensity across different surfaces, the Borg 0-10 rating of perceived exertion (RPE) Scale was employed to measure perceived exertion levels (Borg, 1982). RPE was documented following SSIT sessions and prior to the initiation of soccer training and all players in different training groups (SAND, 8.2 ± 0.9, GRASS, 7.6 ± 0.8, LAND, 7.4 ± 0.5) indicated similar training intensity throughout the training sessions.

Statistical analysis

The mean ± standard deviation (SD) was used to present the data. To determine differences between groups, a two-factor (time [2] × group [4]) repeated-measures analysis of variance (ANOVA) was conducted, followed by a Bonferroni post-hoc test.

Data analysis was carried out using SPSS software version 24 (SPSS Institute, Chicago, IL, USA). The data was presented as mean ± SD values. Shapiro-Wilk test determined the normality of the distribution. A repeated-measures analysis of variance (ANOVA) with a 4 × 2 (group × time) design was performed for each variable to compare the groups. If a significant F value was obtained, the Bonferroni post-hoc test was used to identify specific differences between the groups. The effect size (ES) with a 95% confidence interval (CI) was employed to assess the magnitude of training effects. Hedge's g was utilized to calculate an ES for all measures. Based on 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. To assess inter-individual variability over time, the coefficient of variation (CV) was computed. Individual percent changes from pre-training to post-training were calculated ($\Delta\% = (\text{post} - \text{pre}) / \text{pre} \times 100$) for each variable, and the mean (SD) of these changes was determined. The CV (ratio of SD to the mean) of percent changes was then calculated for each variable. Additionally, individual residuals (IRs) were computed as the square root of the squared difference between individual and mean values for each tested variable. Ultimately, the impact of interventions on inter-subject variability in variables was evaluated by comparing between-group mean residuals for each variable. The one-way ANOVA was used to identify significant differences among groups in the magnitude of changes and also IRs in percent changes in soccer players. The significance level was set at 0.05.

Results

No between-group difference was observed for the measured variables at the baseline. Furthermore, the CON group exhibited no significant changes in their physical fitness measures from pre- to post-training.

Following the 7-week training intervention, significant improvements ($p = 0.001$) in physical fitness attributes of female soccer players were observed with ES ranging from small to very large (Table 1). All training groups demonstrated a significant group × time interaction ($p < 0.05$), indicating greater adaptive changes in physical fitness attributes than the CON group. In addition, the SAND group displayed significant differences ($p = 0.041$) from the LAND group in the CMJ following the intervention period. However, on other physical fitness variables, no significant differences were observed among groups ($p > 0.05$).

Comparison of group changes indicated that the SAND group resulted in a significantly greater change (9.6% vs. 5.2%, $p = 0.009$) in CMJ compared to the LAND group (Figure 1, A). Although the changes in other variables did not reach statistically significant ($p > 0.05$), the magnitude of changes was different among the groups as follows: 20-m linear sprint (SAND > GRASS = LAND, -4.1% vs. -3.0% vs. -2.9%, p = 0.314) (Figure 1, B), Illinois CoD (SAND = GRASS > LAND, -3.2% vs. -3.4% vs. -2.3 %, p = 0.327) (Figure 1, C), Yo-Yo IR1 (SAND > GRASS = LAND, 14.0% vs. 11.0% vs. 11.1%, p = 0.228) (Figure 1, D), 2.4 km time trail (SAND > GRASS > LAND, -7.5% vs. -6.0% vs. 4.8%, p = 0.148) (Figure 1, E), and MKD (SAND = GRASS > LAND, 9.3% vs. 9.5% vs. 8.5%, p = 0.471) (Figure 1, F).

Upon analyzing IRs in percent changes, there were no significant differences among the groups in CMJ (p = 0.775), 20-m linear sprint (p = 0.907), Illinois CoD (p = 0.194), Yo-Yo IR1 (p = 0.671), 2.4 km time trial (p = 0.876), and MKD (p = 0.629); however, the SAND and GRASS groups indicated lower IRs than the LAND group (Figure 2). The CV in the physical fitness tests were as follows SAND < GRASS < LAND, which indicates lower inter-subject variability for the SAND group versus GRASS and LAND groups, as well as GRASS group versus LAND group (Figure 2).

Discussion

The present study, to the best of the authors' knowledge, is the first investigation to explore the impact of SSIT on different surfaces in relation to the physical fitness attributes of female soccer players. Our results indicated that all training surfaces were effective in inducing significant adaptive changes to enhance the physical fitness of female soccer players following the 7-week intervention. Comparative analysis of the interventions revealed that the SAND group exhibited significantly greater improvements in CMJ compared to the LAND group. Although the changes in other variables did not reach statistical significance, there were differences in the magnitude of changes among the groups. Notably, the SAND group demonstrated greater gains in percent changes for the 20-m linear sprint and Yo-Yo IR1 compared to the GRASS and LAND groups. Additionally, the SAND and GRASS groups displayed greater adaptations in the Illinois CoD and MKD compared to the LAND group. However, in the 2.4 km time trial, the training effects were observed to follow the order of SAND > GRASS > LAND.

The CMJ is one of the most influencing abilities on soccer performance particularly in crucial skills like heading (Paoli et al., 2012). Our results regarding the positive effects of SSIT on CMJ corroborate previous studies (Kunz et al., 2019; Arslan et al., 2020; Boullosa et al., 2022; Clemente et al., 2021; Dai and Xie, 2023) reporting significant effects of SSIT on CMJ performance by targeting specific mechanisms such as enhancing muscle-tendon properties, improving intermuscular coordination, and increasing alpha motor-neuron firing rate (Wahl et al., 2014; Song and Deng, 2023). Buchheit and Laursen (2013) suggested that short duration and high intensity interval training is an effective training modality for improving neuromuscular systems by enhancing force development and firing rates. Additionally, the short foot contact time during SSIT is similar to the stretch-shortening cycle involved in jump training, which leads to adaptive changes in the neuromuscular systems and subsequent improvements in VJ performance.

Table 1. Changes in physical fitness attributes from pre to post-intervention for the experimental groups (mean ± SD).

Variables	Variables	Pre-intervention	Post-intervention	Main effect	Interaction effect	Hedge's g (95% CI)		n^2p
CMJ (cm)	SAND	35.6 ± 2.7	39.0 ± 2.7*†	F = 83.9, p = 0.001	Group × Time	1.21 (0.25 to 2.15)	Large ↑	0.90
	GRASS	34.7 ± 2.7	37.3 ± 2.4*	F = 138.2, p = 0.001	F = 7.9	0.97 (0.05 to 1.90)	Moderate ↑	0.93
	LAND	34.6 ± 2.8	36.4 ± 2.6*	F = 52.0, p = 0.001	p = 0.008	0.64 (-0.26 to 1.54)	Moderate ↑	0.85
	CON	34.8 ± 2.9	35.1 ± 2.8	NA	N = 80			
20-m linear sprint (sec)	SAND	3.87 ± 0.18	3.71 ± 0.20*	F = 36.5, p = 0.001	Group × Time	-0.81 (-1.72 to 0.11)	Moderate ↓	0.80
	GRASS	3.86 ± 0.21	3.74 ± 0.21*	F = 27.2, p = 0.001	F = 10.7	-0.55 (-1.44 to 0.35)	Small ↓	0.75
	LAND	3.82 ± 0.27	3.70 ± 0.29*	F = 23.9, p = 0.001	p = 0.014	-0.41 (-1.30 to 0.48)	Small ↓	0.72
	CON	3.84 ± 0.26	3.87 ± 0.28	NA	N = 80			
Illinois CoD (sec)	SAND	18.46 ± 0.70	17.87 ± 0.87*	F = 55.6, p = 0.001	Group × Time	-0.72 (-1.72 to 0.19)	Moderate ↓	0.86
	GRASS	18.56 ± 0.67	17.93 ± 0.84*	F = 42.0, p = 0.001	F = 11.1	-0.79 (-1.70 to 0.12)	Moderate ↓	0.82
	LAND	18.47 ± 1.01	18.03 ± 1.04*	F = 13.7, p = 0.005	p = 0.033	-0.41 (-1.30 to 0.47)	Small ↓	0.60
	CON	18.49 ± 0.91	18.52 ± 0.98	NA	N = 80			
Yo-Yo IR1 (distance, m)	SAND	1300.0 ± 78.3	1482.2 ± 106.8*	F = 73.8, p = 0.001	Group × Time	1.86 (0.81 to 2.91)	Large ↑	0.89
	GRASS	1326.0 ± 117.0	1470.0 ± 114.7*	F = 42.0, p = 0.001	F = 18.6	1.19 (0.24 to 2.15)	Moderate ↑	0.86
	LAND	1338.0 ± 109.7	1486.0 ± 140.8*	F = 29.2, p = 0.001	p = 0.002	1.12 (0.18 to 2.07)	Moderate ↑	0.76
	CON	1320.0 ± 91.1	1340.0 ± 98.8	NA	N = 80			
2.4 km time trail (min)	SAND	14.54 ± 1.22	13.44 ± 1.35*	F = 58.4, p = 0.001	Group × Time	-0.82 (-1.73 to 0.09)	Moderate ↓	0.86
	GRASS	14.50 ± 1.33	13.62 ± 1.39*	F = 57.5, p = 0.001	F = 13.9	-0.62 (-1.52 to 0.28)	Moderate ↓	0.86
	LAND	14.44 ± 1.33	13.73 ± 1.45*	F = 27.6, p = 0.001	p = 0.026	-0.49 (-1.38 to 0.40)	Small ↓	0.75
	CON	14.67 ± 1.42	14.58 ± 1.51	NA	N = 80			
MKD (m)	SAND	37.8 ± 5.5	41.2 ± 5.3*	F = 60.4, p = 0.001	Group × Time	0.60 (-0.29 to 1.50)	Moderate ↑	0.87
	GRASS	35.7 ± 3.9	39.1 ± 3.3*	F = 90.1, p = 0.001	F = 10.9	0.90 (-0.02 to 1.82)	Moderate ↑	0.95
	LAND	36.6 ± 4.2	39.7 ± 4.1*	F = 54.6, p = 0.001	p = 0.002	0.72 (-0.19 to 1.62)	Moderate ↑	0.93
	CON	36.4 ± 5.3	36.7 ± 6.1	NA	N = 80			

* Denotes significant differences versus pre-intervention value and CON group (p ≤ 0.05). † Denotes significant differences compared with LAND group (p ≤ 0.05). NA: not applicable.

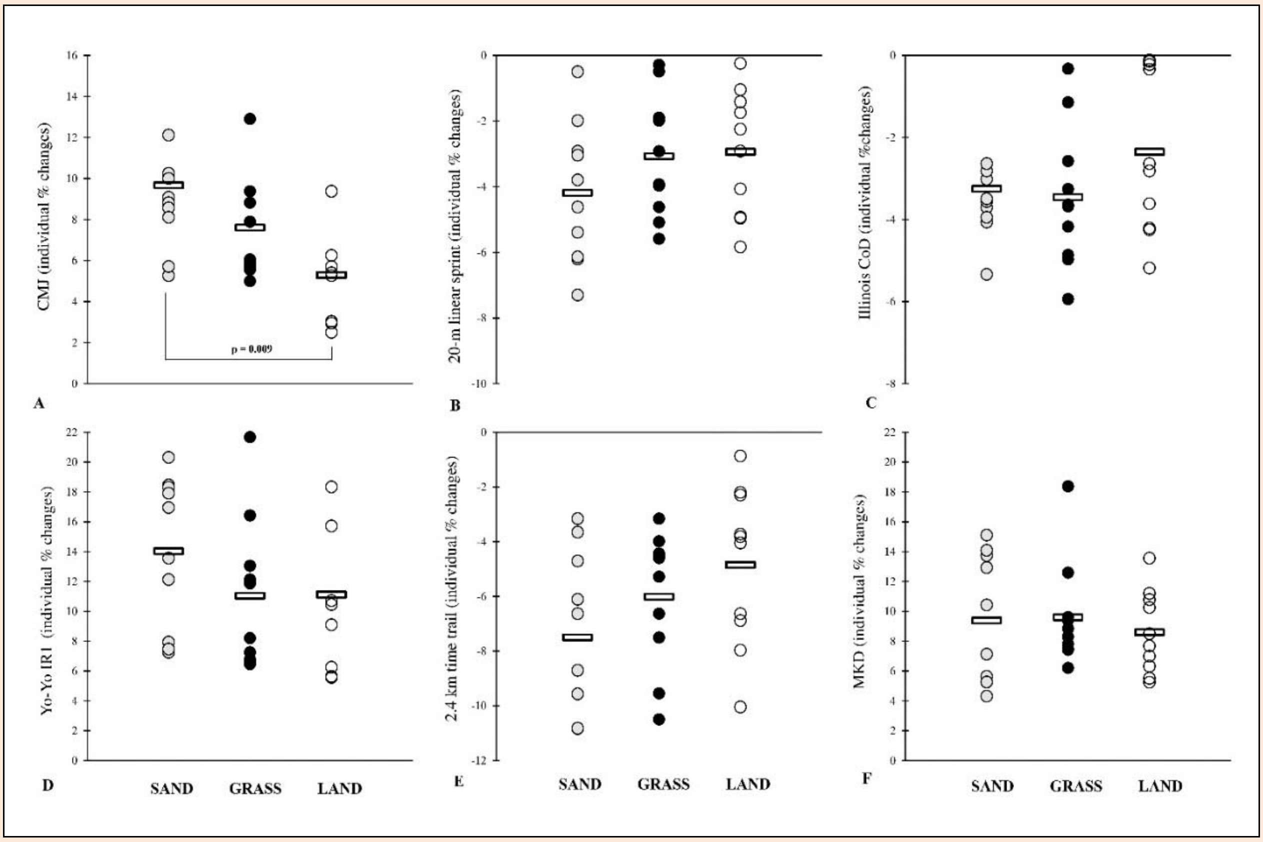

Figure 1. **Individual percent changes (%Δ) for the SAND, GRASS and LAND groups from pre to post a 7-week intervention in the CMJ (A), 20-m sprint (B), Illinois CoD (C), Yo-Yo IR1 (D), 2.4 km time trail, and MKD (F).**

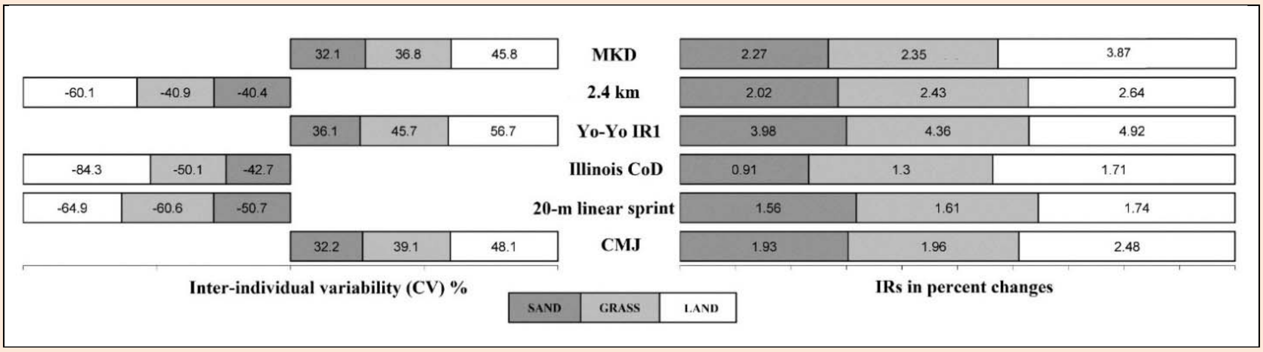

Figure 2. **Inter-individual variability (CV) and individual residuals (IRs) in percent changes in the training groups following the 7-week SSIT intervention.**

Interestingly, the type of surface used during training plays a significant role in individual responses to training. The SAND group (9.6%) showed greater improvements than the GRASS (7.6%) and LAND (5.2%) groups, while the GRASS group showed more gains than the LAND group. Research indicates SSIT on SAND results in higher activation of muscle fibers due to sand's shock-absorbing and friction qualities (Impellizzeri et al., 2007). SAND may require more effort from the muscles to overcome the instability of the ground, leading to increased work in the muscles and tendons during short runs in SSIT. This, in turn, enhances the contractile properties of the muscle fibers and allows the leg muscles to reach an active state, resulting in greater gains in CMJ (Pinnington and Dawson, 2001). In fact, it is possible that undergoing training on SAND, given its inherent instability, may cause a change in the force vectors exerted while running, resulting in adaptations that improve the ability to generate vertical force (Pereira et al., 2023). This improvement can be attributed to the requirement for increased stabilization and force generation to maneuver on the unstable surface (Mirzaei et al., 2014), ultimately leading to enhancements in CMJ. Conducting further research on the biomechanical mechanisms that underlie this phenomenon could offer valuable insights into the effectiveness of SAND training in enhancing CMJ performance. Furthermore, performing SSIT on GRASS may adhere to the principle of training specificity. Conversely, SSIT on GRASS led to more adaptive changes compared to LAND, making it a recommended training strategy. Overall, conducting SSIT on different surfaces elicits different responses, and the SAND and GRASS surface could be a suitable training surface for inducing better adaptations than LAND; however, for greater gains in CMJ the SAND surface is better than others. If a SAND surface is unavailable, it is advisable to choose a GRASS pitch. Performing SSIT on a GRASS surface tends to result in greater gains compared to LAND. With regards to inter-subject variability in response to SSIT intervention, the SAND group exhibited lower IRs in current changes and CV compared to other groups, as well as GRASS in contrast to LAND. This highlights the significance of selecting the most suitable surface for promoting uniformity in adaptations for female soccer players. Thus, SAND is recommended over GRASS and LAND, and GRASS is also preferred over LAND.

Our findings indicate that a 7-week SSIT program is an effective training method for reducing 20-m sprint (SAND, -4.1%, GRASS, -3.0%, and LAND -2.9%) and Illinois CoD (SAND, -3.2%, GRASS, -3.4%, and LAND -2.3%) times in female soccer players. These findings are in accordance with previous studies that have shown positive transfer of SSIT to sprint and CoD ability gains in athletes (Arazi et al., 2017; Lee et al., 2020; Dai and Xie, 2023). SSIT facilitates maximal horizontal acceleration, which is crucial for sprinting and CoD tasks. A quick change of direction may stem from rapid force development and high power generation in the lower extremities (Miller et al., 2006). The improved linear speed could be linked to advancements in the acceleration component of maximal sprint and enhancements in stride length, leading to gains in sprint performance (Lee et al., 2020; Clemente et al., 2021). Furthermore, it seems that engaging in SSIT may impact the improvements in maximum strength, power, and speed necessary for adaptive enhancements in the CoD ability. The findings from Boullosa et al. (2022) and Song and Deng (2023) suggest that SSIT induced adaptive alterations in the CMJ and linear sprint, leading to a positive transfer to the CoD ability gains in female soccer players as highlighted by Arazi et al. (2017).

Results of a comparative analysis could be supportive of the fact that the unstable and shock absorbance nature of the SAND and GRASS surfaces and may require more effort from the muscles, resulting in increased work in the muscle fibers in short runs during SSIT, leading to improve contractile properties of the leg muscles to reach an active state, resulting in greater achievements in 20-m sprint and Illinois CoD speed (Pinnington and Dawson, 2001; Impellizzeri et al., 2007) than LAND surface. Furthermore, the recruitment of fast-twitch muscle fibers and involvement of eccentric to concentric muscle actions during SSIT could be another mechanism in enhancing sprint and CoD ability (Clemente et al., 2021).

In addition, the IRs in percent changes and CV were lower for SAND and also GRASS compared with LAND which indicates better adaptive responses in players with greater uniformity in adaptions. Therefore, it is recommended to perform SSIT on different surfaces to elicit different responses. The SAND surface could be a suitable option for training to improve sprint gains, while both SAND and GRASS surfaces are optimal for enhancing CoD ability. However, if a SAND surface is unavailable, it is better to use a GRASS pitch for SSIT as it yields greater gains than LAND, with greater homogeneity in adaptations.

Our results indicate SSIT performed on different surfaces is an effective method for improving Yo-Yo IR1 (SAND, 14.0%, GRASS, 11.0%, and LAND 11.1%) and 2.4 km time trial performance (SAND, -7.5%, GRASS, -6.0%, and LAND -4.8%), regarding the relationship between repeated sprint ability, aerobic capacity, intermittent endurance, and heart rate recovery in youth soccer players, which corroborates previous studies (Arazi et al., 2017; Arslan et al., 2020; Boullosa et al., 2022; Clemente et al., 2021). The enhanced aerobic performance could be attributed to improved oxygen delivery (Fereshtian et al., 2017; Sheykhlouvand et al., 2016a; 2016b) and utilization by the active muscles (Sheykhlouvand et al., 2022). Research indicates SSIT leads to adaptations in both the central and peripheral components of aerobic activities (Sheykhlouvand et al., 2018a; 2018b; Rasouli Mojez et al., 2021; Sayevand et al., 2022), as well as optimize the resynthesis of high-energy phosphates and recruitment of fast-twitch motor unites (Sanchez-Sanchez et al., 2019), resulting in improved performance in Yo-Yo IR1 and 2.4 km time trials. On the other hand, the SAND group demonstrated a 14% (Large ES) improvement in Yo-Yo IR1, surpassing the 11% (Moderate ES) improvements shown by the GRASS and LAND groups. This highlights the clear advantage of engaging in intermittent sprint training on SAND compared to other surfaces via greater enhancements in energy expenditure alongside a greater accumulation of H^+ during exercise which could be a key element in enhancing muscle buffering capacity (Binnie et al., 2013). Consequently, this leads to advancements in the aerobic and anaerobic capabilities of athletes, leading to more adaptations in Yo-Yo IR1 for the SAND training group.

It is widely documented that running on SAND requires significantly more energy than on a firm surface like GRASS (Pinnington and Dawson, 2001). Furthermore, training on SAND results in higher average heart rate and blood lactate accumulation during a conditioning session for team sport athletes, surpassing the effects of training on GRASS surfaces (Binnie et al., 2013). Typically, interval training on SAND, as opposed to a firm surface, can result in higher training intensity, leading to greater aerobic adaptations resulting in more enhancements of aerobic capacity, oxygen uptake kinetics, exercise economy, and lactate threshold (Wahl et al., 2014; Song and Deng, 2023). A high level of aerobic fitness is crucial for recovering and maintaining high-intensity efforts throughout a soccer game. Reduced H^+ accumulation and elevated buffering capacity could be another explanation for enhancing Yo-Yo IR1 and 2.4 km time trial performance (Kunz et al., 2019; Dai and Xie, 2023). Training on SAND may also lead to greater gains in running economy, further enhancing running performance. Furthermore, SAND and GRASS exhibited lower IRs in percent changes and CV compared to LAND, suggesting superior adaptive responses in players with more consistent adaptations. Therefore, it is recommended to incorporate SSIT on different surfaces to elicit varied responses. If a SAND surface is unavailable, a GRASS pitch is a suitable alternative for SSIT in female soccer players.

Based on the study's findings, the effectiveness of a 7-week SSIT training method in enhancing MKD has been established, as all training groups (SAND, 9.3%, GRASS, 9.5%, and LAND 8.5%), displayed significant improvements after the training period. These results are consistent with previous research that suggests interval training has a positive impact on soccer players' KD (Lees et al., 2010; Rodríguez-Lorenzo et al., 2016), possibly due to enhancements in biomechanical factors involved in achieving maximum kicking distance, such as increased leg linear speed resulting from neuromuscular adaptations following the SSIT regime (Lees et al., 2010). Upon analyzing individual responses to the training, it was observed that the type of training surface had influence on the adaptations in MKD indicating more adaptive responses for the GRASS than the SAND and LAND. Moreover, SAND and GRASS demonstrated lower IRs in percentage changes and CV in contrast to LAND, implying more effective adaptive responses in players with greater consistency in their adaptations.

A limitation of this study is its exclusive focus on female participants, limiting the generalizability of the findings to females only, not males. Moreover, the players involved in the study were adults, therefore it is necessary to be careful when extrapolating these results to other age categories such as prepubertal. It is crucial to emphasize that our results specifically pertain to interval protocols conducted within the conditions of this study. The potential for comparable outcomes with different reference intensities or training volumes remains to be determined.

Conclusion

Our results indicate that performing a 7-week of SSIT on SAND, GRASS and LAND surface before soccer training is an appropriate way for improving physical fitness attributes of female collegiate soccer players. SSIT on SAND appears to be more effective in eliciting positive changes in CMJ than the LAND. Although the changes in other physical fitness variables did not reach statistical significance, there were differences in the magnitude of changes among the groups, indicating greater gains in the SAND group for the 20-m linear sprint and Yo-Yo IR1 compared to the GRASS and LAND groups. Additionally, the SAND and GRASS groups displayed greater adaptations in the Illinois CoD and MKD compared to the LAND group. However, in the 2.4 km time trial, the training effects were observed to follow the order of SAND > GRASS > LAND. Considering these findings, it is advised that strength and conditioning coaches use the SAND surface as the initial choice for SSIT sessions. This recommendation aims to facilitate more favorable transfer in physical fitness adaptation on a soccer grass pitch. In case of unavailability of SAND surface, GRASS surface would be a suitable alternative to enhance the physical fitness of collegiate female soccer players. Our findings provide support for incorporating SSIT on different surfaces before soccer technical and technical training to induce physical fitness adaptations. Nevertheless, players have the option to utilize these training modalities on alternate days when they are not engaged in soccer training, with the aim of enhancing their physical fitness.

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The authors declare no potential or actual conflicts of interest. 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. The experiments comply with the current laws of the country where they were performed.

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Key points

- All types of surfaces can be utilized to induce sufficient stimulation for enhancing mechanisms responsible for physical fitness adaptations in female soccer players.
- The SAND group indicated greater training effects than the LAND group in CMJ performance.
- Although there were no statistically significant changes in other physical fitness variables, the SAND and GRASS groups indicated lower IRs in percent changes and CV than the LAND group which indicates better adaptive responses in players with lower inter-individual variability as well as greater uniformity in adaptions.

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