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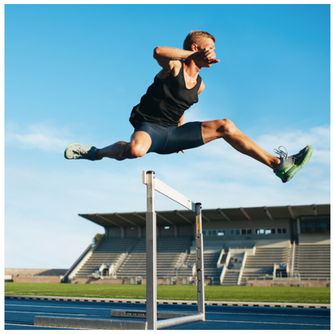

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ORIGINAL ARTICLE
EXERCISE PHYSIOLOGY AND BIOMECHANICS

Effects of two low-volume high-intensity interval training protocols in professional soccer: sprint interval training *versus* small-sided games

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ABSTRACT

BACKGROUND: The programming of training protocols within a high-intensity interval training (HIIT) framework with appropriate analysis of total training load could deliver optimal training adaptations. This study aims to compare the efficiency of two low-volume HIIT protocols integrated with the regular training regime in professional soccer players.

METHODS: Twenty-five participants aged 18.4-29.7 years were randomly assigned to one of two interventions involving straight-line sprint interval training (SIT, N.=13) or small-sided games (SSG, N.=12). Periodization was divided into two 3-week phases concluded by a 7-day taper. SIT first involved two-session·week^{-1} of one set of 10·45-s sprints (at maximal intensity) and then three-session·week^{-1} of two sets of 10·30-s sprints with a 0.75:1 and 1:1 recovery interval (slow running and stretching exercises), respectively. SSG in the first phase involved 5·3-min games of 4 *vs*. 4 and in the second phase 4·4-min games of 2 *vs*. 2 with 3-min recovery (practice drills at 60-70% HR_{max}). Training load was controlled *via* session-RPE and HR-based methods. Pre- and postintervention testing included: countermovement jump height, 5-m and 30-m sprints performance, anaerobic power by the 10-s Wingate Anaerobic Test, maximal oxygen uptake ($\dot{V}O_{2max}$) and blood lactate concentration (BLa^-) determined by incremental exhaustive running test.

RESULTS: Two-way ANOVA showed group×time interaction effects for the 30-m sprint time ($F_{(1,23)}$=3.023; P=0.049; η^2 P=0.116), BLa^- ($F_{(1,23)}$=5.250; P=0.031; η^2 P=0.185), and $\dot{V}O_{2max}$ ($F_{(1,23)}$=4.648, P=0.044; η^2 P=0.157). SIT elicited greater enhancements in anaerobic performance (30-m sprint time and BLa^-), while SSG induced larger improvements in $\dot{V}O_{2max}$.

CONCLUSIONS: Comparable effects of SIT and SSG protocols were noted, however the aerobic capacity benefits provided by SSG warrant this HIIT protocol as a highly recommended training modality in the professional soccer.

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KEY WORDS: Running; Soccer; Sports.

Contemporary professional male soccer players often cover 9 to 12 km per official match, with individual players attaining distances in excess of 14 km.[1, 2] Of the reported distance covered during a 90-min match, it is estimated that 2-3 km involves high-intensity running (>15 km·h^{-1}) and 0.6 km comprises sprinting (≤10 s, >20-25 km·h^{-1}).[2, 3] Global positioning system (GPS) devices and video-based match analyses of professional match play reveal that ~30% of total match time involves high-intensity efforts comprising 150-250 specific game actions including jumps, sprints, accelerations, passing, trapping, shooting, and heading.[2-5] These findings have emphasized the role of anaerobic energy production in meeting the physiological and metabolic demands of elite soccer,[6, 7] particularly during repeated offensive and defensive sprints and one-on-one play[8] as the outcomes of these actions can determine team success.[9] According to Faude *et al.*,[10] straight sprinting is the most frequent action in goal situations in professional soccer. Studies involving professional athletes have supported the use of interval training at near maximal or supramaximal intensity (power output during working periods is above power output at $\dot{V}O_{2max}$) to reach optimal increases in anaerobic performance[11, 12] that cannot be achieved with high-volume, low- to moderate-intensity continuous (steady-state) training.[13, 14] A key training strategy revealed to be particularly effective in soccer is high-intensity interval training (HIIT),[15, 16] a specialized conditioning protocol designed to enhance the high-intensity, intermittent aspects of physical activity.[17] HIIT consists of alternating (work-to-rest ratios of 1:1–4:1) intensive anaerobic exercise (10 s-4 min at ≥85% of peak oxygen uptake [$\dot{V}O_{2peak}$] or 80–100% heart rate maximum [HR_{max}]) with recovery periods (10 s-5 min) of low to moderate intensity aerobic exercise (20-40% $\dot{V}O_{2max}$) or complete rest.[17, 18] While the most common mode of exercise in HIIT is running, the literature strongly supports the use of a sport-specific exercise modality.[8, 16, 19] To date, a variety of uncontrolled and controlled longitudinal approaches,[20-22] with non-randomized[8, 12] and randomized cross-over designs,[23, 24] have been implemented to determine HIIT-induced changes in athletic performance with parallel analysis of physiological/metabolic profiles in professional soccer players. Current soccer-related studies on the enhancement of maximal or supramaximal sprinting performance have suggested the application of a modulated HIIT protocol termed sprint interval training (SIT), which involves all-out <2 min efforts (>100% $\dot{V}O_{2max}$).[25, 26] However, there is still a paucity of semi- or longitudinal experimental studies that have investigated HIIT protocols involving soccer-specific functional tasks and training drills (*e.g.* small-sided games) or compared them with more traditional HIIT exercise modes (*e.g.* straight-line sprinting or high-speed running [HSR]) in professional soccer.[4, 15, 27, 28] Similar in structure to match play but with a smaller number of players and reduced field size, a sport-specific form of HIIT– small-sided games (SSG) – are an important component of soccer training.[29, 30] They have been found to be a highly effective multifactorial training stimulus that simultaneously enhances technical and tactical proficiency while providing the physiological and metabolic benefits of more generic training protocols.[31, 32] Previous research has found SSG to be as effective as a HIIT running protocol in the development of aerobic performance.[33] Moreover, the recent meta-analysis found that HIIT and SSG protocols have equally beneficial impacts on variables related to the endurance, but little influence on neuromuscular performance in young soccer players.[34] While a little less is known on the anaerobic effects of SSG adapted to a HIIT protocol particularly among elite-level soccer players,[4] several studies have indicated that the modulation of various prescriptive variables including game rules, field characteristics, and the number and type of on-field players could be used to elicit a specific exercise intensity that could be beneficial for anaerobic performance.[29-31, 35, 36] The programming of SSG within a HIIT framework with appropriate analysis of total training load could combine the advantages of both training strategies and deliver optimal training adaptations. Therefore, the purposes of this study were: 1) to compare the training load of two low-volume HIIT-based training protocols (SIT and SSG; 2) to investigate and compare the effects of the applied protocols on a range of variables quantifying physiological and metabolic adaptations, perceptual responses, and athletic performance in professional soccer players. It was hypothesized that while both protocols would induce improvements in the above variables, the singular mode of sprint exercise in SIT would have a greater impact on anaerobic performance than SSG, while SSG would induce greater aerobic performance improvements.

Materials and methods

Participants

The number of participants was based on previous studies and sample size calculations using G*Power software (version 3.1.9.4; Heinrich Heine Universität Düsseldorf, Germany). Assuming 80% power of the study at the 5% level of significance, the required sample size for measuring effect was 23 participants. Thus, 25 professional male soccer players (2 extra for possible dropouts) aged 19.4 to 34.0 years were recruited from a Polish first division team (excluding goalkeepers) after meeting the following inclusion criteria: official medical clearance, no recent severe lower extremity injury (>12 months), and no recent use of medication or supplements that could enhance anaerobic or aerobic performance. The sample comprised 8 defenders, 12 midfield players, and 5 forwards with 16.5±4.40 years of competitive soccer experience. Balanced and re-

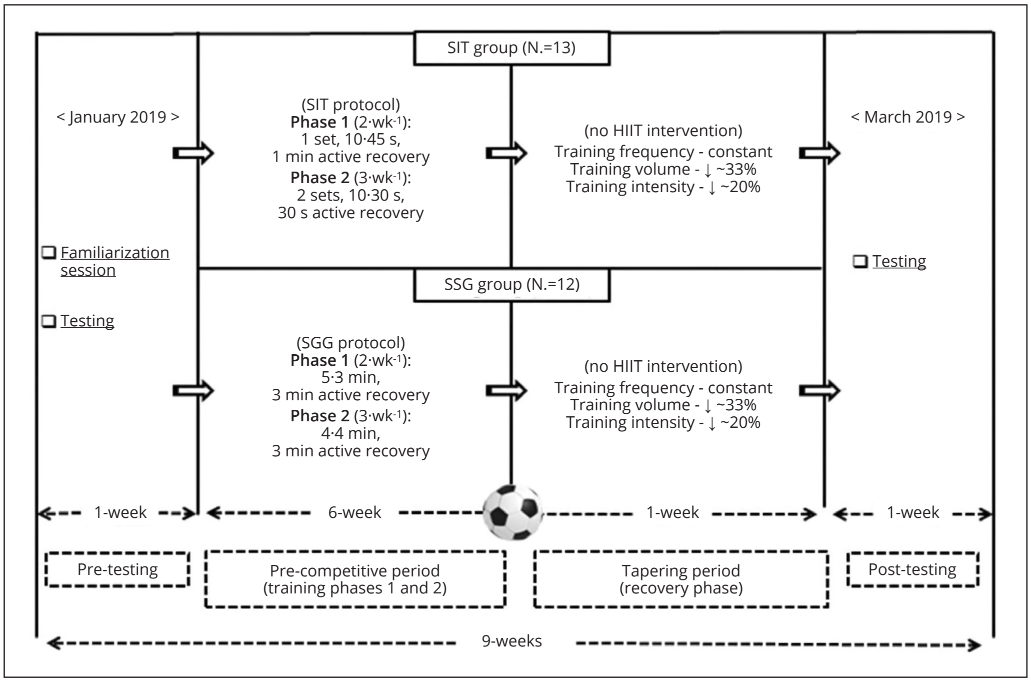

Figure 1.—Schematic representation of the entire study (9-week window).

stricted randomization was used to assign the participant to the SIT or SSG group. The study protocol was approved by the Internal Review Board for Research with Human Subjects of Olsztyn University (No. 4/2018) and was conducted in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki, Fortaleza, Brazil, 2013). The participants provided informed consent and were briefed on the nature of the study without being informed of its specific aims.

Study design

The study utilized a parallel two-group, randomized, and factorial repeated-measures design to compare the effects of two alternative HIIT protocols (SIT *versus* SSG) of a similar training volume. The interventions were integrated with the players' regular soccer training regime but administered during the transition conditioning period (9-week window) before the start of the second round of the 2018/2019 competitive season. The SIT and SSG interventions with controlled training load were compared by analyzing pre- and post-training differences in the physiological, perceptual, and metabolic responses to exercise testing (heart rate [HR], session ratings of perceived exertion [sRPE] and blood lactate concentration [BLa$^-$]), and athletic performance measures (maximal aerobic and anaerobic power and capacity variables) (Figure 1).

Training schedule

The participants attended their regular team practice during the duration of the intervention. Two sessions of 90-min each other were held daily from Monday to Saturday with Sunday serving as a day of rest. Every second Saturday a 90-min control match was scheduled instead of training. Each regular training session began with a 15–20 min warm-up that included dynamic exercises and soccer-specific warm-up drills. The duration of training was 60–70 min and involved drills and exercises targeting agility, flexibility, ball coordination, specialized techniques and skills, or tactics, and included plyometrics and lower-extremity resistance exercise (Table I). The session was concluded with a 10–15 min cool-down. The SIT and SSG interventions were divided into two 3-week phases (Table I). In total, 15 SIT or SSG sessions were performed during the intervention with total training time for SIT~297 min and for SSG ~387 min (135 min and 153 min excluding rest intervals, respectively). After concluding the 6-week intervention, a 1-week taper or recovery phase was completed during which no SIT or SSG sessions were performed. These training sessions were performed at a decreased training volume and intensity (by ~33% and ~20%, respectively) compared with pretaper values (Table I). The legitimacy of performing post-testing after a 7-day

TABLE I.—*Schedules of the SIT and SSG protocols including tapering regime.*

Week		Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Phase 1	Week 1	AG + TE + TA + RE	SIT/SSG FLX + TA	RE + TE + TA+ FLX	SIT/SSG FLX + TA	RE + TE + TA (goal scoring)	90-minute control match	Day off
	Week 2	CO (with balls) + RE + FLX	SIT/SSG FLX + TA	AG + TE + TA + RE	SIT/SSG FLX + TA	RE + TE + TA	PLY + AG + TA	Day off
	Week 3	AG + TE + TA	SIT/SSG FLX + TA	CO (with balls) + RE + FLX	SIT/SSG FLX + TA	RE + TE + TA (goal scoring)	90-minute control match	Day off
Phase 2	Week 4	SIT/SSG FLX + TA	CO (with balls) + TE +AG	SIT/SSG FLX + TA	RE + TE + TA + FLX	SIT/SSG FLX + TA	PLY + AG + TA	Day off
	Week 5	SIT/SSG FLX + TA	RE + TE + TA + FLX	SIT/SSG FLX + TA	RE + TE + TA (goal scoring)	SIT/SSG FLX + TA	90-minute control match	Day off
	Week 6	SIT/SSG FLX + TA	RE + TE + TA (goal scoring)	SIT/SSG FLX + TA	CO (with balls) + TE + AG + FLX	SIT/SSG FLX + TA	PLY + AG + TA	Day off
Tapering period [Vol↓; Int↓]		AG + TE + TA + FLX	RE + TE + TA + FLX	PLY + AG + TA	CO (with balls) + RE + FLX	RE + TE + TA (goal scoring)	60-minute control match	Day off

SIT: sprint interval training; SSG: small-sided games; AG: agility; CO: coordination; FLX: flexibility; PLY: plyometrics; RE: resistance training, TA: tactics, TE: technique.
Vol↓: training volume decreased by 33%; Int↓– training intensity decreased by 20%.

taper was based on meta-analysis showing that maximal performance gains after HIIT are obtained when training volume is reduced by 41-60% of pretaper values.[37] Participants were informed that attendance was required at more than 80% of training sessions to remain in the study.

Intervention protocols

The SIT group executed a traditional sprint interval training protocol that involved one set of 10·45-s sprints in the first phase of training which progressed to two sets of 10·30-s sprints in the second phase of training (Table II). All sprinting was performed in a straight line and began with a stationary start on a synthetic grass field. Sprinting was performed with maximal intensity and with a 0.75:1 recovery interval during which stretching exercises and slow running were performed. In the SSG group, training in the first phase involved a series of five 3-min small-sided games (4 *vs*. 4) on a 50·40 m field. Training intensity was increased in the second phase by playing a series of four 4-min small-sided games (2 *vs*. 2) on a 35·25 m field (Table II). In this format, each game was separated by a 3-min active recovery period involving a series of technical drills (*e.g.*, passing, tackling, shooting) at 60–70% of HR_{max}. This protocol had been previously suggested and administered in the training of elite soccer players.[38]

Determination of training load

We quantified the training load (TL) for each player during each training session by two different methods (subjective and objective): session ratings of perceived exertion (sRPE) method, and HR-based method (Edward's TL). Each player's sRPE was collected in isolation ~30 minutes after each HIIT session using a printout of the modified 10-point category-ratio (CR-10) RPE scale.[39] This ensured the perceived effort reflected the whole session and eliminated bias resulting from the most recent exercise intensity. The RPE training load (RPE-TL) was subsequently calculated by multiplying training duration (min) by the RPE as described by Foster *et al*.[39] The HR-based method proposed by Edwards[40] involved integrating the total volume of the training session with the total intensity of the exercise session, relative to 5 intensity phases.

TABLE II.—*Specific characteristics of SIT and SSG training protocols.*

	Intervention phase	Number of sets	Number of bouts per session	Between-set recovery	Exercise intensity	Work duration	Recovery duration	Nature of recovery	Work-to-rest ratio
SIT	Phase 1	1	10	–	maximal	45 seconds	1 minute	Active (slow running)	0.75:1
	Phase 2	2	10	3 minutes	maximal	30 seconds	30 seconds	Active (slow running)	1:1
SSG	Phase 1	–	5	–	85-90% HR_{max}	3 minutes	3 minutes	Active (technical drills)	1:1
	Phase 2	–	4	–	85-90% HR_{max}	4 minutes	3 minutes	Active (technical drills)	1:0.75

SIT: sprint interval training; SSG: small-sided games.

An exercise score for each training bout was calculated by multiplying the accumulated duration in each HR zone by a multiplier allocated to each zone (50-60% HR_{max}=1, 60-70% HR_{max}=2, 70-80% HR_{max}=3, 80-90% HR_{max}=4, and 90-100% HR_{max}=5), and then adding up the results. Exercise intensity during HIIT sessions was supervised by investigators and team coaches using a long-range telemetry system (Polar Team^2 Pro System, Polar Electro Oy, Kempele, Finland) that enabled real-time exercise-intensity checking. HR data (collected every 5 s) were downloaded to a computer. Session-RPE and HR-based TL data were collected for 15 HIIT sessions.

Procedures

Pre- and postintervention testing was performed in controlled laboratory settings (20.2-21.6º C, 33-42% relative humidity, 752-762 mmHg). The participants were familiarized with all testing procedures and informed they were to maintain their diet and abstain prior to testing from caffeine or alcohol (minimum 12 h), avoid any strenuous exercise (minimum 48 h), and not ingest any non-prescription medication or supplements (minimum 24 h). Testing venue, time of the day and order of tests were identical during testing sessions.

Anthropometry

Anthropometry and body composition analysis included measuring standing body height to the nearest 0.1 cm with a stadiometer (WB-150, Tryb-Wag ZPU, Zamość, Poland) and assessing body mass (BM), Body Mass Index (BMI), percent body fat (BF%), and absolute fat-free mass (FFM) with the InBody 720 Tetrapolar 8-Point Tactile Electrode System (Biospace Co., Ltd. Seoul, South Korea).

Countermovement jump test

Following an individual 5-min warm-up (practice jumps and jogging in place, no static stretching exercises) the participants were instructed to complete a maximal countermovement jump (CMJ). They were required to remain in a static position with a 90° knee flexion angle for 2 s before performing an explosive jump as high as possible. The CMJ were executed with the hands fixed on the hips. All jumps were performed on a tensometric platform and analyzed using specialized MVJ v.3.4 software (JBA-Z, Staniak, Poland). Participants were allowed two practice jumps before performing a series of five maximal effort trials interspersed with 10 s of rest. The best attempt was selected for analysis.

Sprint test

Sprint performance was assessed on an indoor synthetic track and simultaneously tested 5-m and 30-m times. Two trials were completed with 3 min of slow walking and rest between each sprinting effort. The test was preceded by a warm-up involving a low-intensity run (~10 $km \cdot h^{-1}$) for 8 min followed by 5 min of sprint starts and dynamic stretching exercises. The participants were instructed to begin from a stationary start position, with their preferred foot forward 0.3 m behind the starting line. The times for the 5-m and 30-m sprint (T5m and T30m, respectively) were measured with the accuracy of 0.001 s using infrared photoelectric cells (The Witty System, Microgate Srl, Bolzano, Italy). The best result was used for analysis.

Wingate anaerobic test

Anaerobic power was assessed using the 10-s variant of the Wingate Anaerobic Test (WAnT)[41] on a calibrated cycle ergometer (874-E, Monark Exercise AB, Vansbro, Sweden). Testing was preceded by a standardized 10-min warm-up performed at a constant workload (1.5–2.0 $W \cdot kg^{-1}$ of BM) and pedaling cadence (60 rotations per min) interspersed with three all-out sprints of 2 to 3 s (~90 rotations per min) to elicit HR between 150 and 160 $beats \cdot min^{-1}$. Participants then rested for 5 min before performing the WAnT. The workload was adjusted to each participant (0.075 $kG \cdot kg^{-1}$ of BM) and standard verbal encouragement was provided by the examiner to perform a maximal effort during the entire test duration. Real-time power output was recorded at a frequency of 1000 Hz. Peak power output (PPO) (the highest PO observed during 1 s during the test) was recorded from the ergometer software. The PPO was also expressed relative to BM (PPO/BM).

Incremental exhaustive running test

On a separate testing day, following a 10-min warm-up consisting of low-intensity running (at ~6 $km \cdot h^{-1}$) and self-selected stretching exercises, each participant performed an incremental exhaustive running test on a motorized treadmill (Pulsar 4.0, h/p/Cosmos Sports & Medical GmbH, Nussdorf-Traunstein, Germany). The protocol consisted of continuous 3-minute running stages (at 1% gradient) with initial speed set at 9 $km \cdot h^{-1}$ increased by 1 $km \cdot h^{-1}$ per stage until volitional exhaustion (failure) was reached.[42] Flow, volume, and gas concentrations were calibrated before the test according to the manufacturer's procedures. Oxygen uptake was measured on a breath-by-breath basis using an automated gas analysis system (ZAN

680; Oberthulba, Germany) and the data averaged over 30 s periods. A plateau in $\dot{V}O_2$, defined as an increase in oxygen uptake of less than 2 $mL \cdot kg^{-1} \cdot min^{-1}$ with increasing exercise intensity, was used as our criterion for $\dot{V}O_{2max}$. HR was recorded in 5-s intervals during the entire test with a Polar T-31 portable transmitter (Polar Electro OY). Individual HR_{max} was determined as the peak value reached in a 5-s window during the final stage of the incremental exercise test. A capillary blood samples were obtained at rest, 15 s before the end of each stage, and 3 min after the end of the exercise test from the fingertip by pin prick and collected in 25-µL heparinized capillary tubes for lactate analysis. Blood samples were analyzed in duplicate on the same day using the spectrophotometric method (Dr Lange, GmbH, Berlin, Germany). The mean of the two measures was used for analysis.

Test-retest reproducibility

We estimated reliability statistical analyses of all performance variables using a test-retest procedure with a random sub-sample of 16 participants. To determine absolute and relative reliability the typical error expressed as a coefficient of variation (CV%) and the intra-class correlation coefficient (ICC) were calculated.[43] A CV of ≤5% and an ICC of >0.75 were considered excellent reliability, whereas a CV of 5-10% and ICC 0.60-0.70 were considered good reliability.[44] All performance tests used in this research presented very high levels of absolute and relative reliability (the ranges of CVs and ICCs were 1.9-4.8% and 0.77-0.89, respectively).

Statistical analysis

The experimental data for the total sample are expressed as means and standard deviations (mean±SD). Statistical analysis was initially performed using the Shapiro-Wilk normality test and the homoscedasticity test (Bartlett criterion). The independent *t*-test was used for between-group comparison of the baseline values. A two-way mixed model analysis of variance (ANOVA) for repeated measures was used to test for main and interaction effects of group (levels: SIT, SSG) and timing of measurement (levels: preintervention, postintervention) for each outcome variable independently. Where appropriate, Tukey's test was applied *post-hoc* to the data. In the presence of significant main and interaction effects, the effect size (ES) was estimated by partial eta square (η^2_p). The interpretation of ES was based on benchmarks established by Cohen[45] where d=0.01 indicates a small effect, 0.06 a medium effect, and 0.14 a large effect. Pearson's product-moment correlation was used to analyze the relationship between different measures of training load. The level of significance was set at P<0.05. All statistical calculations were performed using the Statistica v. 10.1 software package (StatSoft Inc., College Station, TX, USA) and Office Excel 2010 (Microsoft Corp., Redmond, WA, USA).

TABLE III.—*Baseline characteristics and differences between SIT and SSG groups.*

Variables	SIT (N.=13)	SSG (N.=12)	Relevance level (P value)
Age (years)	25.6±3.98	24.3±5.16	0.556
Soccer experience (years)	15.4±1.46	17.3±2.38	0.092
Body height (cm)	180.3±6.45	181.0±4.37	0.277
Body mass (kg)	75.4±6.15	75.0±5.94	0.609
Body Mass Index (kg/m²)	23.2±0.84	22.9±0.97	0.487
Body fat (%)	14.1±2.67	14.0±4.30	0.722
Fat-free mass (kg)	64.8±4.42	64.9±4.55	0.641

Values are expressed as mean±SD.
SIT: sprint interval training; SSG: small-sided games.

Results

Baseline status

The data presented normal distribution. Baseline characteristics of the study participants are presented in Table III. There were no significant differences between the groups for any variable at baseline (Table III).

Compliance with training

Participants showed a high degree of compliance with training. All 25 players met the minimum attendance re-

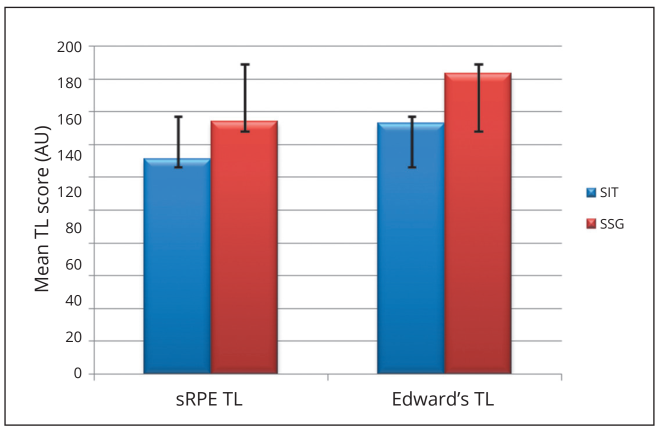

Figure 2.—Mean sRPE and HR-based training load scores during the intervention period in SIT and SSG groups.

Table IV.—*Effects of 6-week intervention and a 7-day taper on physiological and performance variables in soccer players (N.=25).*

Variables	Group	Preintervention	Postintervention	Δ%	Main and Interaction effects Snedecor F value/P value/effect size (η^2_p)/descriptor
CMJ_{height} (m)					Interaction: $F_{(1,23)}$=0.109; P=0.745; $\eta^2_{P=}$0.005 [small]
	SIT	0.456±0.048	0.472±0.049	+3.5%	Group: $F_{(1,23)}$=0.122; P=0.731; $\eta^2_{P=}$0.006 [small]
	SSG	0.464±0.046	0.477±0.051	+2.9%	Time: $F_{(1,23)}$=19.617; P<0.001; $\eta^2_{P=}$0.460 [large]
T5m (s)					Interaction: $F_{(1,23)}$=0.049; P=0.827; $\eta^2_{P=}$0.002 [small]
	SIT	1.04±0.02	1.02±0.03	-2.2%	Group: $F_{(1,23)}$=1.217; P=0.281; $\eta^2_{P=}$0.050 [small]
	SSG	1.05±0.03	1.03±0.04	-2.1%	Time: $F_{(1,23)}$=49.169; P<0.001; $\eta^2_{P=}$0.681 [large]
T30m (s)					Interaction: $F_{(1,23)}$=3.023; P=0.049; $\eta^2_{P=}$0.116[medium]
	SIT	4.20±0.11	4.10±0.10	-2.4%	Group: $F_{(1,23)}$=2.373; P=0.137; $\eta^2_{P=}$0.094 [medium]
	SSG	4.24±0.13	4.18±0.08	-1.5%	Time: $F_{(1,23)}$=55.033; P<0.001; $\eta^2_{P=}$0.116 [medium]
WAnT PPO (W)					Interaction: $F_{(1,23)}$=1.339; P=0.259; $\eta^2_{P=}$0.055[medium]
	SIT	889.8±88.5	929.8±89.7	+4.5%	Group: $F_{(1,23)}$=0.053; P=0.820; $\eta^2_{P=}$0.002 [small]
	SSG	904.3±83.5	931.4±91.1	+3.0%	Time: $F_{(1,23)}$=37.039; P<0.001; $\eta^2_{P=}$0.617 [large]
WAnT PPO (W/kg)					Interaction: $F_{(1,23)}$=3.758; P=0.064; $\eta^2_{P=}$0.140 [large]
	SIT	11.78±0.71	12.43±0.68	+5.5%	Group: $F_{(1,23)}$=0.262; P=0.614; $\eta^2_{P=}$0.011 [small]
	SSG	12.07±0.80	12.42±0.66	+2.9%	Time: $F_{(1,23)}$=45.004; P<0.001; $\eta^2_{P=}$0.662 [large]
VO_{2max} ($mL \cdot min^{-1} \cdot kg^{-1}$)					Interaction: $F_{(1,23)=}$4.648, P=0.044; η2P=0.157 [large]
	SIT	54.5±4.96	55.9±5.97	+2.6%	Group: $F_{(1,23)}$=0.384; P=0.527; $\eta^2_{P=}$0.017 [small]
	SSG	56.3±5.62	59.2±7.64	+5.2%	Time: $F_{(1,23)}$=31.207; P<0.001; $\eta^2_{P=}$0.429 [large]
BLa^- ($mmol \cdot L^{-1}$)					Interaction: $F_{(1,23)}$=5.250; P=0.031; $\eta^2_{P=}$0.186 [large]
	SIT	10.53±1.29	11.67±1.43	+10.8%	Group: $F_{(1,23)}$=8.212; P=0.009; $\eta^2_{P=}$0.263 [large]
	SSG	9.27±1.32	9.92±1.56	+7.0%	Time: $F_{(1,23)}$=71.054; P<0.001; $\eta^2_{P=}$0.755 [large]

The data are presented as mean±SD.
CMJ_{height}: countermovement jump height; T5m: 5-m sprint time; T30m: 30-m sprint time; WAnT: Wingate Anaerobic Test; PPO: Peak power output; $\dot{V}O_{2max}$: Maximum oxygen uptake; BLa^-: Blood lactate concentration; SIT: Sprint interval training; SSG: Small-sided games.

quirements of 80%. The SIT and SSG groups completed 86.4±5.3% and 88.2±6.4% of the training sessions, respectively. The reasons for the absences were lower extremity injuries or upper respiratory tract infections.

Training load analysis

The mean physiological intensity of HIIT sessions in SIT and SSG was 83.9±8.1% and 79.7±6.8% of individual HR_{max}, respectively. No differences were observed in $\%HR_{max}$ between the groups (P>0.05). Variation of TL calculated with RPE-TL and Edwards' TL methods was comparable in the groups. For instance, the average CV% for total TL for SIT and SSG determined over the 6 weeks was 11% (95% CI: 5% to 15%) and 13% (95% CI: 7% to 18%) for the sRPE method, respectively. For Edward's TL method it was 9% (95% CI: 6% to 14%) and 12% (95% CI: 8% to 17%), respectively. Mean TL scores of HIIT sessions derived from Edwards' TL in SIT and SSG were 152.7±44.5 arbitrary units (AU; range 107.9–183.7 AU) and 183.2±54.1 AU (range 132.4–232.6 AU), respectively (Figure 2). Perceptual intensity of HIIT sessions corresponded to mean sRPE scores of 5.8±1.5 AU (range 4–8 AU) in SIT and 6.4±1.8 AU (range 3–8 AU) in SSG. Mean TL of HIIT sessions calculated using the sRPE method in SIT and SSG was 131±24 AU (range 102–159 AU) and 154±76 AU (range 116–197 AU), respectively (Figure 2). A strong relationship was found between measures of TL (r=0.729).

Physiological responses and athletic performance

Summary statistics for the effects of SIT and SSG groups by timing of measurements are shown in Table IV. From the two-way ANOVA there were observed group×time interaction effects for T30m ($F_{(1,23)}$=3.023; P=0.049; η^2_P=0.116 [medium]), BLa^- ($F_{(1,23)}$=5.250; P=0.031; η^2_P=0.185 [large]), and $\dot{V}O_{2max}$ ($F_{1,23=}$4.648, P=0.044; η^2_P=0.157 [large]). In the absence of statistical evidence for interaction effects, significant main effects of time were observed for the following: CMJ_{height} ($F_{(1,23)}$=19.617; P<0.001; η^2_P=0.460 [large]) – the pre- to postintervention increase in SIT and SSG was 3.5% and 2.9%, respectively; T5m ($F_{(1,23)}$=49.169; P<0.001; η^2_P=0.681 [large]) – pre- to postintervention increase in SIT and SSG was 2.2% and 2.1%, respectively; absolute and relative PPO ($F_{(1,23)}$=37.039; P<0.001; η^2_P=0.617 [large] and $F_{(1,23)}$=45.004; P<0.001; η^2_P=0.662 [large], respectively) – pre- to postintervention increases in SIT and SSG were 4.5% and 3.0%/5.5% and 2.9%, respectively. Conversely, we did not observe a significant main effect of group on any variable tested.

Discussion

This study compared the effects of SIT *vs*. SSG protocols in physiological, perceptual, and athletic performance parameters in elite soccer players during the transition conditioning period. Generally, the results show that both the lack of interaction effects and magnitude of percent change in T5m, CMJ_{height}, and WAnT-determined peak power variables were comparable between SIT and SSG, indicating similar adaptations induced by the two different methods of programming HIIT. We established that SIT appears to be superior for enhancing glycolytic capacity as expressed by elevated postintervention BLa^- (large effect size) and T30m (medium effect size), while the SSG protocol is more effective in $\dot{V}O_{2max}$ improvements. These findings partly support our hypothesis that a reduced SIT volume with a higher number of shorter runs/bouts will have a greater impact on maximal anaerobic performance expressed as CMJ_{height}, 5-m and 30-m sprint tests, WAnT-determined peak power variables or on BLa^- concentration compared to the SSG protocol. The quantification and analysis of the players' training load data demonstrate that the HIIT sessions were indeed a high-intensity training stimulus applied consistently across both interventions. The reduced training volume per session in SIT was compensated by higher mean exercise intensity; thus, the protocols were comparable in terms of total TL (P>0.05). Due to critical statements regarding the use of heart rate data in weight training, HIIT, plyometric training and match related SSG,[9] we supplemented internal TL analysis by sRPE method. Subjective sRPE is considered to be a simple and valid quantifier of training intensity in resistance exercise and various HIIT modalities (SSG, plyometrics, or speed, and aerobic conditioning).[31] In this study, the absolute sRPE values measured during the SIT or SSG protocol were higher than previously reported values.[31, 35, 46] While both groups in our study experienced perceptual improvements in sRPE and $\%HR_{max}$ across the training phases, on this basis it is hard to objectively discuss the intervention fidelity. However, our observations are in line with the results obtained by Dellal *et al*.,[27] who reported no significant differences (P>0.05) in sRPE and HR_{max} between two groups (SSG, [2 *vs*. 2, 5·2-min 30 s; 2-min recovery and 1 *vs*. 1, 5·1-min 30 s, 1-min 30 s recovery; HIIT, 40-m shuttles, with 30 s-30 s, 15 s-15 s, or 10 s-10 s intermittent runs) both before and after the training interventions. Obviously, various factors could influence sRPE or HR during SSG training, including, *e.g.*, the duration of play, the intermittent design, and frequency of repeated sprint efforts and that many previous soccer-specific studies have shown that SSG formats with fewer players elicit greater sRPE than larger playing formats.[31, 33, 46, 47] For example, Sampaio *et al*.[35] reported no significant differences in HR responses but higher sRPE values in 3 *vs*. 3 SSG compared with 4 *vs*. 4 SSG (16.5±0.5 *vs*. 14.4±0.5, Borg 6-20 scale, respectively) in a 4·4-min format with 3 min of recovery between games. Given the duration of the soccer match and the importance of quick recovery from anaerobic bouts of activity, the aerobic contribution is significant with an estimated average intensity of 70-75% of $\dot{V}O_{2max}$.[6, 7] A recent meta-analysis of randomized controlled trials conducted by Wen *et al*.[48] reviewed the effects of different HIIT protocols for $\dot{V}O_{2max}$ improvements in different populations, including athletes. The authors found that most HIIT protocols (moderate to long-interval, moderate to high-volume and short to moderate-term HIIT) elicited significant beneficial effects (standardized mean difference = 0.50–1.01, P<0.05) on $\dot{V}O_{2max}$ values in professional athletes. They also showed that long-interval (≥2 min), high-volume (≥15 min) and moderate to long-term (≥4-12 weeks) HIIT protocols should be adopted if the goal is to maximize the training effects on $\dot{V}O_{2max}$. Indeed, one of the most evident outcomes of our study was an interaction effect observed for aerobic power expressed as $\dot{V}O_{2max}$ [a large ES (0.157)]. In comparison to SSG, SIT exerted a small positive effect on $\dot{V}O_{2max}$ (5.2% *vs*. 2.6%, respectively), as shown by two previous studies, one demonstrating a trivial positive effect[33] and the other a small positive effect.[31] Overall, these improvements are satisfactory as it is unlikely that large improvements in $\dot{V}O_{2max}$ could occur following HIIT in already highly trained athletes. Many different components of HIIT such as work intensity, bout duration, number of repetitions, and training periodization have been shown to have a substantial influence on $\dot{V}O_{2max}$.[18] Based on the specific characteristics of applied HIIT protocols we suppose that the exercise volume as determined by work intervals and repetitions together was a key factor that influenced $\dot{V}O_{2max}$ improvements. This means that although SIT was more time-efficient and highlighted peak power generation as an important metabolic stimulus, SSG could be an alternative approach when considering the parallel use of soccer-specific activities and feasibility issues regarding the application of HIIT in soccer.[49] In the present study peak BLa^- measured *via* the incremental exhaustive running test increased by 10.8% in SIT (from 10.53±1.29 to

11.67±1.43 mmol·L^{-1}) and by 7.0% in SSG (from 9.27±1.32 to 9.92±1.56 mmol·L^{-1}). The significant main effects of group, time and interaction suggest that the SIT protocol provides a stronger stimulus towards engaging the glycolytic pathway. It is possible that the low-intensity active recovery component in SSG (3 min, 60–70% HR_{max}) may have decreased muscle acidosis, as previous studies have suggested that the use of active recovery (at 65–70% $\dot{V}O_{2max}$) could be more efficient than passive recovery in reducing BLa^- concentration.[50] However, as biochemical responses (*e.g.* muscle buffering capacity) were not controlled in the present study, this remains to be confirmed and warrants further investigation. Other studies have reported similar changes in peak BLa^- concentrations,[12, 51] although one study[52] that analyzed BLa^- measured 1 min after SSG (three 4-min bouts separated with 3-min active recovery) showed substantially lower values (5.59±1.78 mmol·L^{-1}) than what was observed herein. This aforementioned study[52] also demonstrated that RPE measures were significantly correlated with BLa^- (r=0.63, P<0.05) and $\%HR_{peak}$ (r=0.60, P<0.05) and concluded that sRPE and HR measures are independent and reliable markers of training load. Although T30m significantly decreased in both SIT and SSG (by 0.1 s or 2.4% and 0.06 s or 1.5%, respectively), the interaction effect we observed in SIT highlights this protocol as more effective in improving sprint performance at this distance. The exact mechanisms responsible for the decrease in T30m are difficult to ascertain as anaerobic performance improvements could be related to many different physiological or morphological factors. Conversely, we did not observe a SIT-induced effect on T5m, with comparable decreases in both groups (2.2% *versus* 2.1%), suggesting that both applied protocols have similar potential in decreasing short-distance sprint times. Contrary to our outcomes, Radzimiński *et al.*[28] observed significant changes in 5-m sprint time but not in 10-m and 30-m sprint times after an 8-week training intervention of either running (5·4-min running with an active recovery period of 3 min) or small-sided games (5·4-min 3 *vs.* 3 games with an active recovery period of 3 min). In designing this study, we adopted the non-soccer specific WAnT in parallel with the sprint tests to assess anaerobic power as well as lower limb performance. Although SIT and SSG showed improvements in relative PPO (by 0.65 W·kg^{-1} or 5.5% and 0.35 W·kg^{-1} or 3.0%, respectively), no significant between-group differences were observed at postintervention with relative PPO. This was an unexpected outcome as strong correlations have been found between especially WAnT relative PPO and sprint performance.[53] Similarly, vertical jump heights (CMJ_{height}) increased after the intervention in both SIT and SSG (16 mm or 3.5% and 14 mm or 2.9%, respectively), but a lack of significant difference in the magnitude of training-induced improvements between the groups suggests that neither of the proposed protocols is superior in enhancing vertical jump performance. There is evidence that jump performance (countermovement and drop jump height) deteriorates after high-volume training or high-intensity training. These observations indicate that jump interval training,[54] HIIT supplemented by resistive/strength training,[21] or specific plyometric training[55] is essential to produce significant improvements in vertical jumping performance critical in soccer players.

Limitations of the study

As with many investigations performed with elite soccer players during their professional training regimes, this study is limited by several factors, such as the relatively small sample size, absence of a control group (following a standard training routine), no access to valid tools like GPS to better analyze performance (especially the different runs) and the impossibility of controlling all variables associated with the total training content. Nevertheless, it is critical to emphasize that both applied HIIT protocols were effective in increasing the anaerobic and aerobic components of performance in professional soccer players during a 6-week transition conditioning period. Future research is needed to examine the optimal periodization strategies of these HIIT-based protocols for the long-term development of physiological, perceptual, and metabolic responses, and athletic performance.

Conclusions

In conclusion, the results of this study showed that multiple performance variables were enhanced during the transition conditioning period by integrating two specific HIIT protocols involving either intermittent straight-line sprinting at maximal intensity or SSG performed in different field areas and playing formats (4 *vs.* 4 on 50·40 m field and 2 *vs.* 2 on 35·25 m field). Performance was similarly improved by both protocols although there were differences in total training time (SIT: ~294 min *vs.* SSG: ~387 min). While SIT appears to represent a more time-efficient stimulus due to the greater improvements in 30-m sprint time and glycolytic capacity (expressed by postintervention BLa^-), SSG are more effective in $\dot{V}O_{2max}$ improvement and represent an essential component of soccer training as the replication of match play provides multifactorial training benefits with concomitant improvements in technical and tactical skills.

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