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Research article

Optimal Prescription for Superior Outcomes: A Comparative Analysis of Inter-Individual Variability in Adaptations to Small-Sided Games and Short Sprint Interval Training in Young Basketball Players

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Abstract
This study compared the inter-individual variability in adaptive responses to six weeks of small-sided games (SSG) and short sprint interval training (sSIT) in young basketball players. Thirty well-trained young athletes (age: 16.4 ± 0.6 years; stature: 190 ± 8.4 cm; weight: 84.1 ± 8.2 kg) voluntarily participated and were randomly assigned to SSG (3 sets of 5 min 3v3 on full length (28 m) and half-width (7.5 m) court, with 2 minutes of passive recovery in-between), sSIT (3 sets of 12 × 5 s sprinting with 20 s recovery between efforts and 2 min of rest between sets), or CON (routine basketball-specific technical and tactical drills) groups, each of ten. Before and after the training period, participants underwent a series of laboratory- and field-based measurements to evaluate their maximum oxygen uptake ($\dot{V}O_{2max}$), first and second ventilatory threshold (VT_1 and VT_2), oxygen pulse, peak and average power output (PPO and APO), linear speed, change of direction (COD), countermovement jump (CMJ), and vertical jump (VJ). Both SSG and sSIT sufficiently stimulated adaptive mechanisms involved in enhancement of the mentioned variables ($p < 0.05$). However, sSIT resulted in lower residuals in percent changes in $\dot{V}O_{2max}$ ($p = 0.02$), O_2pulse ($p = 0.005$), VT_1 ($p = 0.001$), PPO ($p = 0.03$), and linear speed ($p = 0.01$) across athletes compared to the SSG. Moreover, sSIT resulted in more responders than SSG in $\dot{V}O_{2max}$ ($p = 0.02$, $\varphi = 0.500$), O_2pulse ($p = 0.003$, $\varphi = 0.655$), VT_1 ($p = 0.003$, $\varphi = 0.655$), VT_2 ($p = 0.05$, $\varphi = 0.436$), and linear speed ($p = 0.05$, $\varphi = 0.420$). Our results indicate that sSIT creates a more consistent level of mechanical and physiological stimulus than SSG, potentially leading to more similar adaptations across team members.

Key words: Team sport, sport-specific intervention, physical conditioning, athletic performance, aerobic fitness, bio-motor abilities.

Introduction

Basketball is court-based team sport characterized by specific movements comprising of repeated sprits, sport-specific change of direction abilities, accelerations, jumps and technical and tactical scenarios (Pernigoni et al., 2021). Attaining peak performance in the repetitive high-intensity actions of basketball games involves a combination of anaerobic and aerobic energy metabolism, neuromuscular and muscular power capabilities (Stojanovic et al., 2018; Song et al., 2023; Zeng et al., 2023). Aerobic energy metabolism also takes precedence on low-intensity activities like jogging, walking, and standing (Stojanovic et al., 2018; Song et al., 2023). Enhancing sport-specific physical fitness enables the execution of basketball-specific technical and tactical maneuvers at a superior level, ensuring consistent performance quality throughout the duration of the game.

Elevating the fitness levels of basketball players strongly relies on incorporating essential physical conditioning into their training strategies (Balčiūnas et al., 2006). Conditioning programs are typically tailored to the game's specific features (Song et al., 2023). Various forms of conditioning methods have been developed to enhance basketball-specific performance. High-intensity interval training (HIIT), defined as repeated bouts at near maximal to maximal intensities interspersed with recovery (Laursen and Buchheit, 2019), is one of the commonly used appropriate interventions for improving aerobic and anaerobic capabilities of basketball players (Balčiūnas et al., 2006; Song et al., 2023; Zeng et al., 2023). Like the nature of HIIT, basketball comprises intermittent maximal efforts interspersed by low-to-moderate-intensity activities (García et al., 2020; Song et al., 2023). Thus, HIIT could be considered a suitable training intervention for basketball athletes (Engel et al., 2018; Song et al., 2023).

When designing sessions, coaches and sports scientist attempt to adopt drills that emphasize the movements and individual and collective interactions that the players face during the competition (Bourbousson et al., 2010a; 2010b). Given basketball's technical and tactical demands and following the important principle of training specificity, there has been a notable growth in interest in small-sided games (SSG), commonly referred to as game-based conditioning or skilled-based conditioning (Hill-Haas et al., 2011; Laursen and Buchheit, 2019). The popularity of SSG is attributed to its ability to mimic the mechanical stress, physiological demands, and technical requirements seen in competitive match play, while demanding that players make decisions under pressure and fatigue (Conte et al., 2015; Figueira et al., 2022; Sansone et al., 2023). SSGs are recognized for their time efficiency, allowing the simultaneous development of physical performance, technical skills, and tactical awareness (Hill-Haas et al., 2011; Corvino et al., 2014). Several studies have shown SSG's positive effects in improving basketball players' aerobic and anaerobic capacities (Delextrat and Martinez, 2014; Delextrat et al., 2018). However, despite its training effectiveness, SSGs have limitations. Differences in the quantity of high-intensity activities executed in SSG interventions lead to individual differences in workload, preventing ho-

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mogenized adaptations to the training across team members (Ben Abdelkrim et al., 2007; Matthew and Delextrat, 2009; Castagna et al., 2011). SSGs result in highly variable within-player responses in cardiovascular and high-intensity running responses in comparison to more-specific run-based HIIT (Hill-Hass et al., 2008a; 2008b; 2009).

A match constitutes a dynamic system formed by the interaction of two teams amidst various contextual factors (Gréhaigne et al., 1997). Consequently, all training scenarios involve a level of unpredictability, and this inherent unpredictability inherently amplifies the variability of stimuli. This resultant variability in physiological demands may result in varying degrees of adaptations (Clemente, 2020). These limitations support the use of less-specific [i.e., running-based repeated sprints (RST)] but more controlled HIIT format (Laursen and Buchheit, 2019). These interventions could compensate for the limitations of SSG training. Since such intervention are executed *all-out*, it could be prescribed without evaluation of the individual's physiological ceilings (e.g., $\dot{V}O_{2max}$) to calibrate the exercise intensity (Laursen and Buchheit, 2019). Traditional repeated sprint training (30 - 45 s *all-out* sprints) demands a considerable degree of motivation and may lead to sensations of nausea and discomfort because of the extreme physical exertion (Little et al., 2010). This could result in some young athletes' lower physical tolerability and lead to undergo different relative workloads. Such variability may cause varied mechanical stress, unequal physiological demands, and non-homogenized adaptations among team members (Sandford et al., 2021).

Recent studies have indicated shorter duration sprints, referred to as short sprint interval training [sSIT (3-10 s efforts)], could be considered a potential alternative to traditional repeated sprint training as it has the potential to induce similar adaptive responses, simultaneously enhancing enjoyment and lowering the perceived exertion rate (Benítez-Flores et al., 2018; McKie et al., 2018). In addition, observational data indicate sprint running duration throughout a basketball match ranges between 2-6 seconds for young basketball players (Figueira et al., 2022), making sSIT more specialized intervention for this category. Positive effects of sSIT on basketball-specific physical and physiological parameters have recently been well elucidated (Fang and Jiang, 2024). Therefore, this study aimed to compare the inter-individual difference in the adapta tions in physiological parameters and bio-motor abilities to SSG and sSIT in young basketball players. According to the more controllable quantification of sSIT and calibrated exercise intensity through *all-out* efforts, we hypothesized sSIT will result in more homogenized and lower inter-subject variability in the adaptations among the team members than SSG.

Methods

Participants

Thirty young, well-trained national-level basketball players (basketball experience: ~6 years) provided their written informed consent and volunteered to participate in this study. According to a classification framework provided by McKay and colleagues (2022), our participants are considered as well-trained athletes. Participants were members of a national-level club and familiar with high-intensity interventions. To be eligible for the study, subjects needed to meet specific inclusion criteria, outlined as follows: a) absence of lower body injuries that could impact testing and training sessions, b) no participation in sprint interval training during the study period and the preceding 3 months, and c) no consumption of any supplements three months prior to the study. Following a medical screening, completing a questionnaire examining their medical history, injury background, and performance levels, and elaborating on the testing procedure and training protocols, they were matched based on the playing position (i.e., guard, forward, and center) and randomly assigned to three groups of SSG (age: 16.9 ± 0.3 years; stature: 189.0 ± 7.1 cm; weight: 81.3 ± 6.8 kg), sSIT (age: 16.1 ± 0.9 years; stature: 192 ± 6.6 cm; weight: 86.8 ± 5.3 kg), and control [CON (age: 16.2 ± 0.6 years; stature: 189.0 ± 8.4 cm; weight: 84.2 ± 8.2 kg)], each of 10. All procedures adhered to the principles delineated in the Declaration of Helsinki and approved by the ethical committee of the Guangzhou Sport University.

Study design

Figure 1 indicates overview of experimental protocol. Using a randomized controlled trial with two experimental groups and one control group, this study was conducted over a 6-week training period during the pre-season phase of the athletes' annual training cycle. Before and after the training period, basketball players underwent a graded exercise test to evaluate maximum oxygen uptake ($\dot{V}O_{2max}$) and related physiological parameters. On the other occasion, 24 hours apart, they completed a Wingate-based anaerobic power test to evaluate their peak power output (PPO) and average power output (APO). Bio-motor abilities including linear speed, change of direction (COD), and

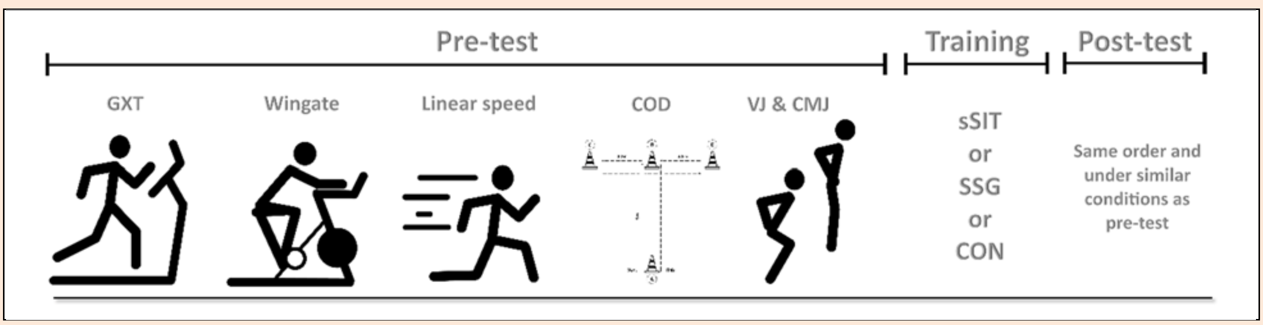

Figure 1. Overview of the experimental protocol. GXT, graded exercise test; COD, change of direction; VJ, vertical jump; CMJ, countermovement jump; sSIT, short sprint interval training; SSG, small-sided games; CON, control.

jumping abilities were measured in other testing sessions separated by 24 hours of relief between visits. Forty-eight hours after the baseline measurements, participants completed three sessions per week of SSG, sSIT, and CON in conjunction with their regular basketball sessions as outlined in section "training interventions". Forty-eight hours after completion of the training period, the participants repeated the same tests under the same conditions and in the same order as pre-training. The participants were asked to refrain from caffeine and alcohol and not to engage in vigorous physical activity the day preceding testing sessions (Gharaat et al., 2020; Barzegar et al., 2021).

Graded exercise test

Following a warm-up consisting of 5 minutes of jogging, followed by dynamic stretching and upper- and lower-body join mobilization exercises, participants completed a graded exercise test on a treadmill to test their cardiorespiratory fitness. The test initiated at 8 km·hr^{-1} and the workload increased 1 km·hr^{-1} every 3 minutes with a 30-seconds rest interval between stages for blood sampling to determine blood lactate concentrations (BLa) from the earlobe using blood lactate measurement device (Lactate Pro 2 LT-1730, Arkray, Japan). Gas exchange was continuously measured using a breath-by-breath gas collection device (2700 series; Hans Rudolph Inc., Shawnee, KS, USA). The $\dot{V}O_{2max}$ was established as the highest 30-seconds value in the test and the following end criteria were used to determine if the athlete reached $\dot{V}O_{2max}$: I) a $\dot{V}O_2$ leveling off despite increase in workload; II) respiratory exchange ratio > 1.1; III) BLa $\geq$ 8 mmol·L^{-1}; IV) $HR_{max} \geq 95\%$ age-predicted maximum (220 - age); V) volitional exhaustion (Eston and Reilly, 2009; Sheykhlouvand et al., 2015; Sheykhlouvand and Forbes, 2017). First and second ventilatory thresholds (VT_1 and VT_2) were determined using the previously standardized criteria (Alejo et al., 2022).

Wingate test

A 30-second maximal Wingate test measured lower-body peak power output (PPO) and average power output (APO). Using a mechanically braked cycle ergometer (model 894E, Monark, Sweden), participants pedaled against a resistance equivalent to 0.075 kg·kg^{-1} of their body mass. At the beginning of the test, participants started pedaling as fast as possible against the device's inertial resistance, and then the individualized load was applied. Athletes were verbally encouraged to pedal as fast as they could for 30 seconds, and the maximal power attained at the 5-second and the average power throughout the test was defined as PPO and APO (Delextrat and Cohen, 2008).

Maximal sprint speed

Following a general warm-up, participants completed two maximal 20-m sprinting between photocells at the hip level (Freelap BLE 424, USA). The participants were instructed to commence the test with a standing position and front foot at least 0.5 m behind the starting gate. The test began with a self-selected start time, and the 20-m sprinting time was measured to the nearest 0.01 s. Efforts were separated with three-minute relief intervals, and the athlete's best performance was considered for subsequent analyses (Song et al., 2023).

Change of direction test

Change of direction (COD) performance was determined by measuring multi-directional running speed including linear sprinting, shuffling to right and left, as well as backpedaling using the MAT-test (Sassi et al., 2009). Briefly, according to the Figure 2, the players started the test by forward sprinting from cone A towards cone B and touched its base. Then, shuffled to the C cone while facing forward without crossing their feet, and then shuffled right towards cone C and touched it. Then shuffled back to the cone B and ran backward to the starting point (cone A).

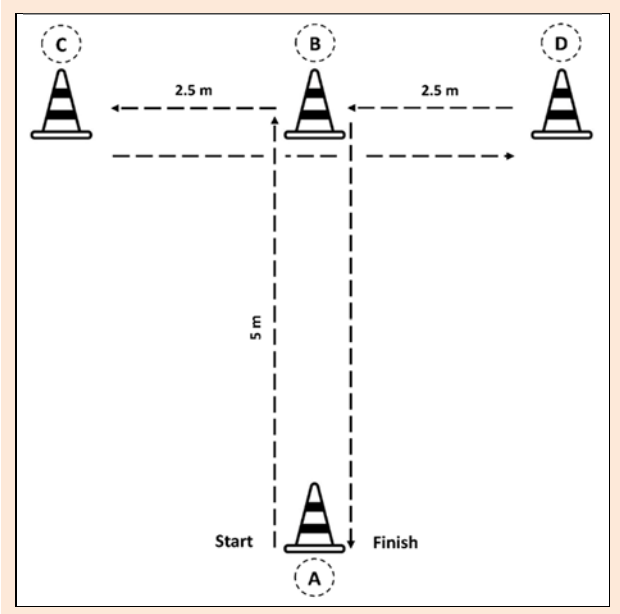

Figure 2. MAT-test for evaluation of change of direction ability.

Jumping ability

The participants' jumping ability was tested using squat jump (SJ) and countermovement jump (CMJ) tests and a Globus electronic contact mat system (Codognè, Italy) measured the maximum height reached with a precision of 0.01 meters. SJ was conducted by placing hands on hips and keeping shoulders wide apart, followed by flexing knees to about a 90-degree angle for a duration of 3-sec, and executing a vertical jump with maximum effort (Ramírez-Campillo et al., 2013). During the CMJ, individuals were instructed to position their hands on their hips, adopt a wide stance with feet and shoulders apart, and perform a descending motion (without restricting the angle of the knees) before propelling themselves into a vertical jump with maximum effort. The players were asked to land in an upright position (Stevanovic et al., 2019). Three consecutive jumps were executed with 2-minutes resting intervals between trials and the best performance was considered for the subsequent analyses.

Training interventions

Three sessions per week of sSIT and SSG were added to the typical basketball-specific training of the participants during the off-season phase of the preparatory period.

Players completed five sessions per week of basketball-specific training consisting of general warm-up including jogging, dynamic movements with and without ball, static and ballistic stretches, reviewing technical drills and tactical strategies, and cool down. Each session lasted between 60 to 90 minutes. sSIT or SSG were completed prior to their training sessions on Saturday, Monday, and Wednesday. Participants initiated their training sessions with ten minutes of warm-up, including low-intensity running, dynamic stretching, and sprinting with the integration of self-selected common basketball-specific technical actions with the ball. Following the warm-up, players performed either SSG or a HIIT session with the same total training time during each training session (Arslan et al., 2022). sSIT consisted of 3 sets of 12 × 5 s sprinting with 20 s recovery between efforts and 2 min of relief between sets, and SSG comprised of 3 sets of 5 min 3v3 on full length (28 m) and half-width (7.5 m) court, with 2 minutes of passive recovery in-between. Drills were played with only man-to-man defense and without free throws or time-outs. Players were randomly allocated to pairs (a guard and either a forward or a center), and new pairs were created for each training session (Delextrat et al., 2018). Participants were advised to refrain from committing fouls in order to maintain the flow of the game, and if a foul occurred, the game continued without interruption. Participants of the CON group performed basketball-specific technical and tactical drills throughout the training session. An experienced coach with at least 10 years of coaching in national-level clubs supervised all sessions. Also, two coaches encouraged players and supplied new balls to maintain the game's flow.

Statistical analysis

Statistical analyses were conducted using SPSS software version 25.0 (IBM Corp., Chicago, IL) and sample size was estimated using G*Power software (Faul et al., 2017). For this study design, a total of 12 participants were estimated for each group with the effect size of 0.8, alpha level of 0.05 and power of 0.95. However, anticipating potential participant dropout during the data collection phase, the total sample size was expanded to encompass 30 participants. Descriptive reports were provided a Mean ± SD. The Shapiro-Wilk test examined normality of distribution and the homogeneity of variances was assessed through Levene's test. A two-factor mixed analysis of variance (ANOVA) with the between factor [groups (sSIT, SSG, and CON)] and repeated factor [time (pre-training *vs.* post-training)] analyzed the significant interactions or main effects with the Tukey *post-hoc* test when a significant F-ratio was observed. Moreover, the individual residuals in the percent changes were calculated for each variable and were compare using one-was ANOVA to determine inter-individual variability in the adaptive changes over the training period. Moreover, responders (Rs) and non-responders (NRs) to the interventions were determined through calculating two-technical error (TE) using the equation ($TE = SD_{diff} / \sqrt{2}$) provided by Hopkins (2000). In accordance with Hopkins (2000), a change exceeding 2 × TE strongly implies a significant likelihood (with odds of 12 to 1) that this response reflects a genuine physiological adaptation, going beyond what could reasonably be attributed to technical or biological fluctuations. Non-responders were characterized as individuals who couldn't exhibit an increase or decrease (favoring beneficial changes) in the measured variables greater than twice the two-technical error away from zero. 2TEs were determined as follows: $\dot{V}O_{2max}$: 0.742 $ml\cdot kg^{-1}\cdot min^{-1}$, O_2pulse: 0.588 $ml\cdot b^{-1}\cdot min^{-1}$, VT_1: 2.904 %, VT_2: 2.314 %, PPO: 21.134 W, APO: 18.902 W, linear speed: 0.032 s, COD: 0.462 s, SJ: 0.508 cm, and CMJ: 0.181 cm, respectively. The Chi-Square test (χ^2) with Phi (φ) effect size was employed to compare groups of participants falling within the 2 × TE range calculated for each outcome (non-responders or NRs) or surpassing TE more than two times the TE (responders or Rs). α level was set at 0.05.

Results

Table 1 and Figure 3 indicate the within-group changes and residuals in individual percent changes in cardiorespiratory fitness measures, respectively. Table 2 and Figure 4 also present within-group changes and residuals in individual percent changes in bio-motor abilities over time.

Results indicated no between-group difference for the measured variables at the baseline. Both SSG and sSIT groups had a significant main effect on all measured variables (Table 1 and Table 2). A significant time-regimen interaction was also found in $\dot{V}O_{2max}$, O_2pulse, VT_1, VT_2, APO, and change of direction. As shown in Tables 1 & 2, SSG and sSIT groups resulted in significantly greater changes (except as indicated) in $\dot{V}O_{2max}$ ($p = 0.03$ and 0.05, respectively), O_2pulse ($p = 0.03$ and 0.09), VT_1 ($p = 0.86$ and 0.03), VT_2 ($p = 0.01$ and 0.01), APO ($p = 0.71$ and 0.05), and change of direction ($p = 0.02$ and 0.07) than the CON group. The magnitude of the change in VT_1 in the sSIT group was significantly greater ($p = 0.02$) than that of the SSG group. SSG also resulted in a significantly greater decrease in COD time than sSIT ($p = 0.02$).

Participants of the sSIT group exhibited significantly lower residuals (Figure 3, Figure 4 and Figure 5) in the percent changes in $\dot{V}O_{2max}$ ($p = 0.02$), O_2pulse ($p = 0.05$), VT_1 ($p = 0.01$), PPO ($p = 0.03$) and linear speed ($p = 0.01$) than SSG group. The coefficient of variations (CV) in the adaptive changes in $\dot{V}O_{2max}$, O_2pulse, VT_1, VT_2, linear speed, PPO, and APO in response to sSIT was lower than those of the SSG group who showed lower CVs in COD, SJ, and CMJ compared to sSIT group (Table 1 and Table 2).

Figure 6 shows the percentage of NRs to the training interventions. Overall, the SSG group showed 40%, 60%, 60%, 10%, 10%, 50%, and 30% of NRs in $\dot{V}O_{2max}$, O_2pulse, VT_1, VT_2, PPO, APO, and linear speed, respectively. sSIT group only resulted in 20% non-responders in VT_2. χ^2 test indicated more responders to sSIT in $\dot{V}O_{2max}$ ($p = 0.02$, $\varphi = 0.500$), O_2pulse ($p = 0.03$, $\varphi = 0.655$), VT_1 ($p = 0.03$, $\varphi = 0.655$), VT_2 ($p = 0.05$, $\varphi = 0.436$), and linear speed ($p = 0.05$, $\varphi = 0.420$) than SSG.

Table 1. Pre-training vs. post-training values for indicators of cardiorespiratory fitness.

	SSG		sSIT		CON	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**
$\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	50.77 ± 2.53	52.56 ± 3.06	50.08 ± 1.14	52.78 ± 1.34	49.28 ± 2.85	49.31 ± 2.71
P-value	0.005*		0.001*		0.927	
%Δ	3.5‡		5.4‡		0.2	
ES	0.61		1.17		0.01	
CV in %Δ	86.7%		31.4%		NA	
$\dot{V}O_2$/HR ($ml \cdot b^{-1} \cdot min^{-1}$)	19.96 ± 2.89	20.54 ± 3.01	17.35 ± 1.60	18.35 ± 1.83	19.70 ± 2.41	19.77 ± 2.40
P-value	0.004*		0.001*		0.343	
%Δ	2.9‡		5.7‡		0.03	
ES	0.21		0.61		0.02	
CV in %Δ	80.7%		18.1%		NA	
VT_1 (%$\dot{V}O_{2max}$)	69.3 ± 3.0	71.2 ± 3.2	72.2 ± 4.8	76.2 ± 5.6	70.2 ± 2.2	70.9 ± 2.6
P-value	0.007*		0.002*		0.111	
%Δ	2.7		5.5‡§		0.9	
ES	0.61		0.76		0.29	
CV in %Δ	92.2%		17.6%		NA	
VT_2 (%$\dot{V}O_{2max}$)	86.1 ± 5.2	89.2 ± 5.4	86.1 ± 3.2	90.8 ± 2.4	82.1 ± 4.9	82.4 ± 4.7
P-value	0.003*		0.001*		0.394*	
%Δ	3.6‡		5.4‡		0.3	
ES	0.58		1.66		0.006	
CV in %Δ	57.1%		48.5%		NA	

Values are means ± SD; %Δ, within group changes from pre- to post-training; ES, effect size. $\dot{V}O_2$max, maximum oxygen uptake; $\dot{V}O_2$/HR, O_2 pulse; VT_1, first ventilatory threshold; VT_2, second ventilatory threshold. N = 10 for each group. * Significantly greater than pre-training value ($P < 0.05$); ‡ Significantly greater changes than the CON ($P < 0.05$); § Significantly greater changes than the SSG ($P < 0.05$).

Table 2. Pre-training vs. post-training values for indicators of bio-motor abilities.

	SSG		sSIT		CON	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**
PPO (W)	827 ± 65	880 ± 76	820 ± 43	873 ± 47	822 ± 31	829 ± 43
P-value	0.001*		0.001*		0.254	
%Δ	6.4		6.4		0.8	
ES	0.74		1.17		0.18	
CV in %Δ	36.2%		12.9%		NA	
APO (W)	488 ± 28	513 ± 27	512 ± 30	539 ± 33	502 ± 11	506 ± 16
P-value	0.003*		0.002*		0.151	
%Δ	5.1		5.2		0.7	
ES	0.91		0.85		0.29	
CV in %Δ	32.9%		22.4%		NA	
20-m sprint (s)	3.14 ± 0.17	2.99 ± 0.15	3.11 ± 0.16	2.95 ± 0.15	3.12 ± 0.14	3.11 ± 0.17
P-value	0.007*		0.001*		0.682	
%Δ	-5.0		-5.4		-0.3	
ES	0.93		1.03		0.006	
CV in %Δ	31.5%		9.4%		NA	
COD (s)	6.30 ± 0.16	5.90 ± 0.15	6.03 ± 0.14	5.74 ± 0.16	6.02 ± 0.11	5.95 ± 0.13
P-value	0.005*		0.002*		0.051*	
%Δ	-6.7‡⁑		5.4		-1.2	
ES	2.51		0.93		0.56	
CV in %Δ	11.2%		23.0%		NA	
SJ (cm)	38.5 ± 1.6	40.6 ± 1.8	38.7 ± 2.2	40.8 ± 2.3	39.0 ± 1.9	39.9 ± 1.8
P-value	0.001*		0.002*		0.021*	
%Δ	5.4		5.4		2.3	
ES	1.23		0.93		0.48	
CV in %Δ	21.9%		23.0%		NA	
CMJ (cm)	41.2 ± 1.8	43.5 ± 2.0	41.1 ± 2.2	43.0 ± 2.7	41.4 ± 2.2	41.9 ± 2.2
P-value	0.007*		0.002*		0.071	
%Δ	5.5		4.6		1.2	
ES	1.21		0.77		0.22	
CV in %Δ	19.6%		29.1%		NA	

Values are means ± SD; %Δ, within group changes from pre- to post-training; ES, effect size. $\dot{V}O_2$max, maximum oxygen uptake; $\dot{V}O_2$/HR, O_2 pulse; VT_1, first ventilatory threshold; VT_2, second ventilatory threshold. N = 10 for each group. * Significantly greater than pre-training value ($P < 0.05$); ‡ Significantly greater changes than the CON ($P < 0.05$); § Significantly greater changes than the SSG ($P < 0.05$).

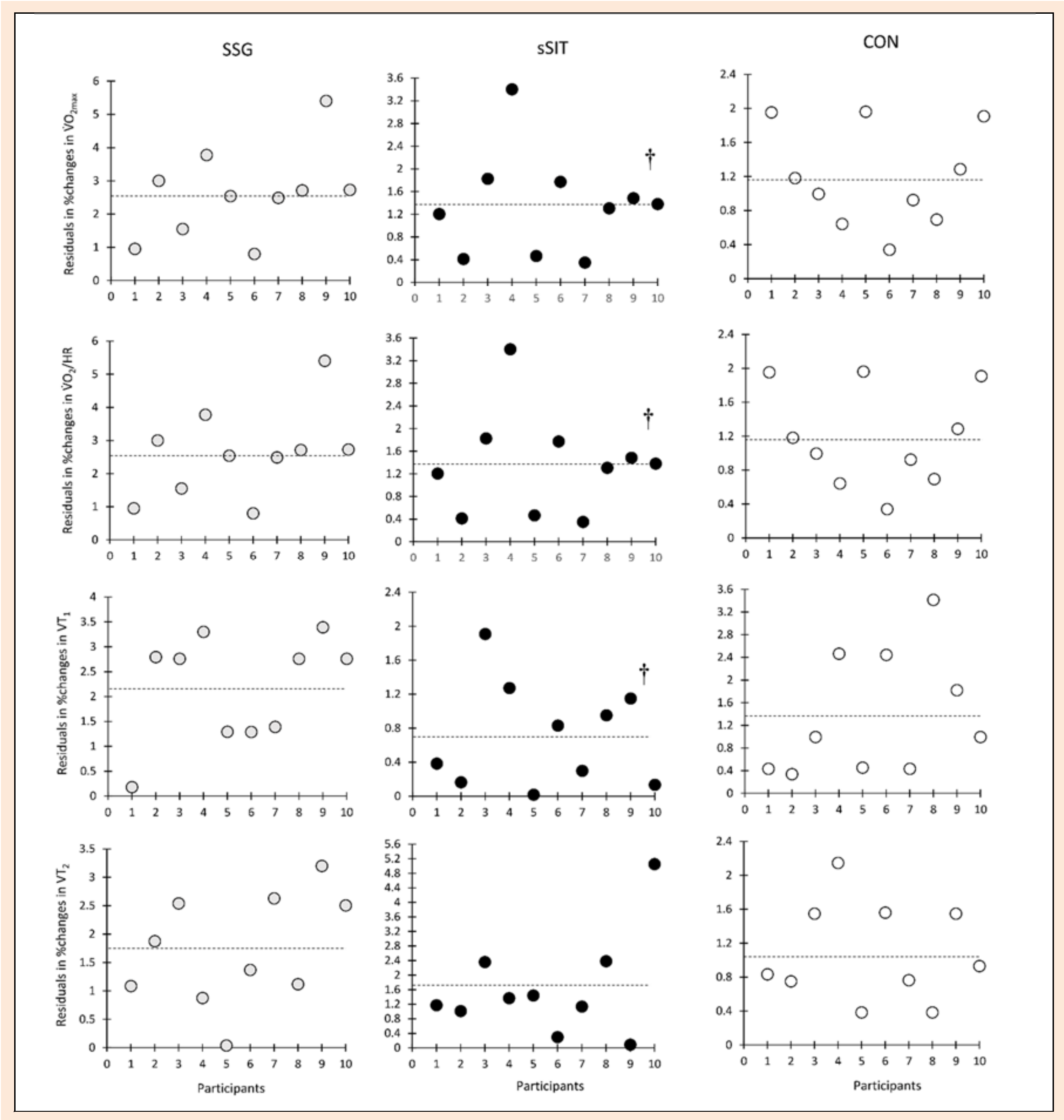

Figure 3. Individual residuals in the percent change in cardiorespiratory fitness measures. $\dot{V}O_{2max}$, maximum oxygen uptake; $\dot{V}O_2$/HR, oxygen pulse; VT_1, first ventilatory threshold; VT_2, second ventilatory threshold.

Discussion

This study is the first to compare inter-individual variability in adaptative responses of cardiorespiratory fitness and bio-motor abilities measures to HIIT interventions prescribed as small-sided games (SSG) or short sprint interval training (sSIT) in young basketball players. The most remarkable finding of this study was that, despite the sufficient stimulation of adaptive mechanisms by both HIIT interventions to enhance the mean group values of mentioned variables significantly, sSIT resulted in more homogenized adaptations in $\dot{V}O_{2max}$, O_2pulse, VT_1, PPO, and linear speed across athletes with varying profiles when compared to the SSG. Moreover, sSIT resulted in more responders in $\dot{V}O_{2max}$, O_2pulse, VT_1, VT_2, and linear speed than SSG.

The overall external load imposed by an exercise session results from the interplay of factors including duration and intensity of the exercise. This serves as stimulus that triggers adaptive responses (Mann et al., 2014). For instance, muscular adaptations to an exercise bout are manifested by the accumulative effects of "transcriptional and translational micro-adaptations that occur after each exercise bout (Flück, 2006)." Consequently, discrepancies in the acute exercise stimulus received may partly account for the individual variations in the training responses that accrue over time (Mann et al., 2014). Regardless of the method of measurement, coaches prescribe training based on external load to achieve the desired physiological response. This workload leads to a certain reaction in the body, which we call the internal training load. Therefore, measurements of internal load can serve as indicators of the real physical response that the body triggers to deal with the demands caused by the external workload (Impellizzeri et al., 2019). It can be challenging to accurately compare how individual athletes respond to or cope with training.

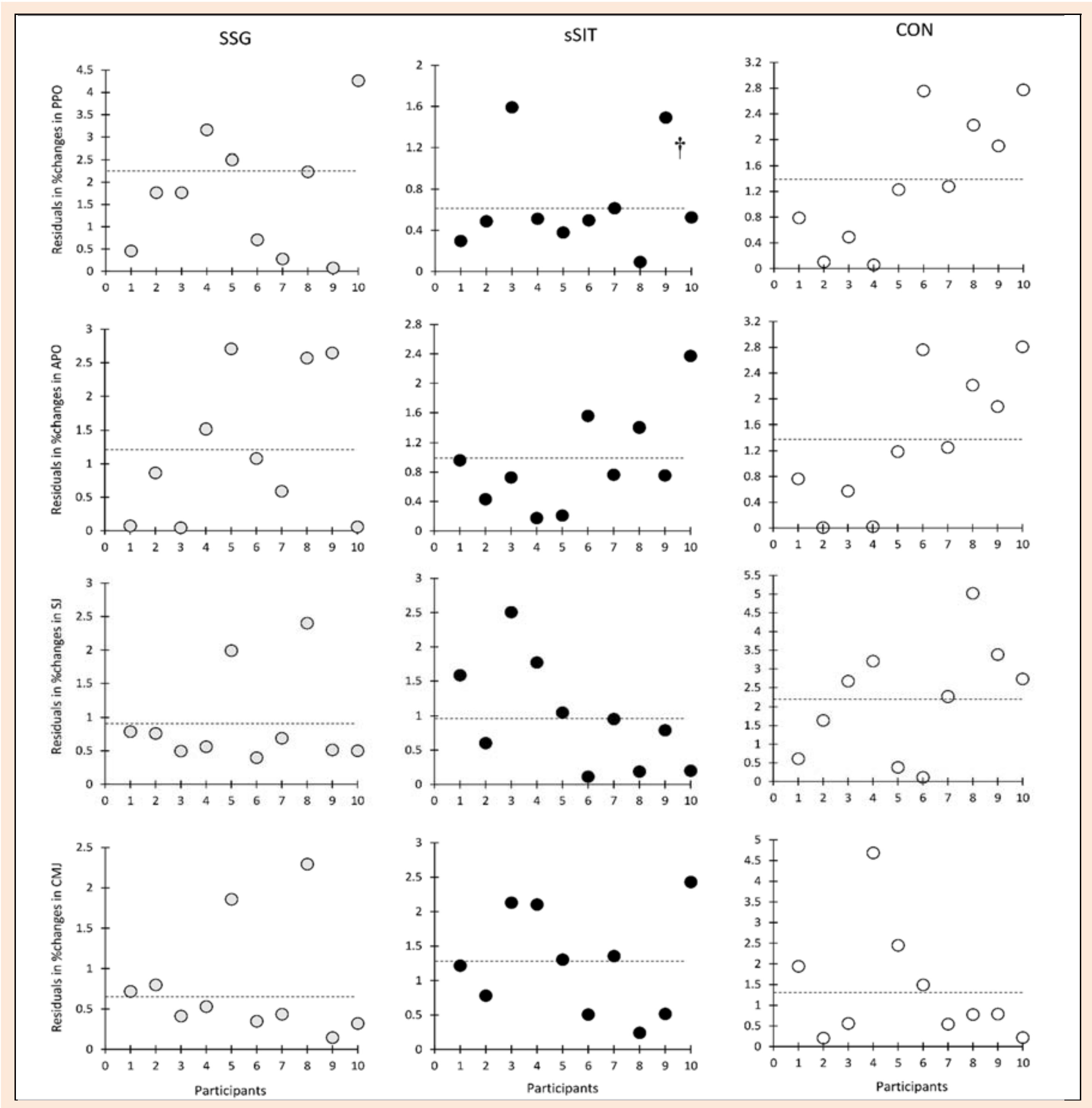

Figure 4. Individual residuals in the percent change in bio-motor abilities. PPO, peak power output; APO, average power output; VJ, vertical jump; CMJ, countermovement jump.

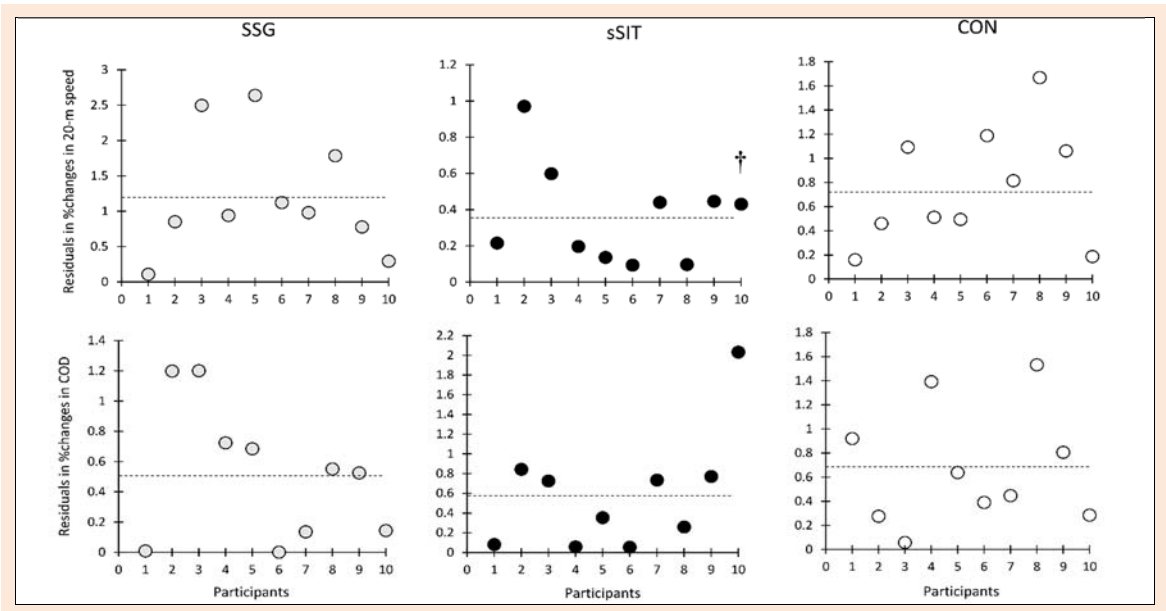

Figure 5. Individual residuals in the percent change in linear speed and change of direction (COD) ability.

SSG

CON	Individual response										NR (%)
	1	2	3	4	5	6	7	8	9	10	
$\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	↑	↑	→	↑	→	↑	→	↑	→	↑	**40 %**
$\dot{V}O_2$/HR (ml·b^{-1}·min^{-1})	→	↑	→	↑	→	↑	→	→	↑	→	**60 %**
VT_1 (%)	→	→	↑	↑	↑	→	→	↑	→	↑	**60 %**
VT_2 (%)	↑	→	→	↑	↑	→	↑	→	↑	→	**50 %**
PPO (W)	↑	↑	↑	→	↑	↑	↑	↑	↑	↑	**10 %**
APO (W)	↑	↑	↑	↑	↑	↑	↑	↑	→	↑	**10 %**
Speed (s)	↑	→	↑	↑	→	↑	↑	→	↑	↑	**30 %**
COD (s)	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	**0 %**
SJ (cm)	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	**0 %**
CMJ (cm)	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	**0 %**

sSIT

CON	Individual response										NR (%)
	1	2	3	4	5	6	7	8	9	10	
$\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	**0 %**
$\dot{V}O_2$/HR (ml·b^{-1}·min^{-1})	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	**0 %**
VT_1 (%)	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	**0 %**
VT_2 (%)	↑	↑	→	↑	↑	↑	↑	→	↑	↑	**20 %**
PPO (W)	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	**0 %**
APO (W)	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	**0 %**
Speed (s)	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	**0 %**
COD (s)	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	**0 %**
SJ (cm)	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	**0 %**
CMJ (cm)	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	**0 %**

CON

CON	Individual response										NR (%)
	1	2	3	4	5	6	7	8	9	10	
$\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	↑	↓	→	↓	↑	→	↓	→	→	↓	**80 %**
$\dot{V}O_2$/HR (ml·b^{-1}·min^{-1})	↑	↓	→	→	↑	→	↓	→	→	↓	**80 %**
VT_1 (%)	→	→	→	↓	→	↓	→	↑	→	→	**90 %**
VT_2 (%)	→	→	↓	→	→	↓	→	→	→	→	**100 %**
PPO (W)	→	→	→	→	↓	→	→	↓	↑	↑	**80 %**
APO (W)	→	↓	→	→	→	→	→	→	↓	↑	**90 %**
Speed (s)	→	→	↓	→	↓	→	→	↓	→	→	**100 %**
COD (s)	↑	↑	→	↓	↑	→	↑	↓	↑	↑	**40 %**
SJ (cm)	↑	→	↑	↑	→	↑	↑	↑	→	↑	**30 %**
CMJ (cm)	↑	→	→	↑	→	↑	→	↑	→	→	**50 %**

Figure 6. Individual patterns of response to SSG, sSIT, or CON. ↑ denote responders (white boxes); → denote non-responders (grey boxes), and ↓ indicate adverse responses (black boxes). The percentage of participants demonstrate non-responders including both non- and adverse responses.

At both ends of the spectrum of individual responses to a training intervention, there are individuals who exhibit exceptionally large responses (high responders) and individuals who show exceptionally small responses (low responders). However, individuals who exhibit a low training response in one aspect (such as $\dot{V}O_{2max}$) may not necessarily demonstrate a low training response in other factors (such as submaximal heart rate) (Vollaard et al., 2009; Scharhag-Rosenberger et al., 2012). This complexity adds nuance to the distinction between high responders and low responders. In fact, athletes exercising at the same relative intensity (e.g., $\dot{V}O_{2max}$) may experience different internal load responses, which can account for varying training-induced adaptations, explaining apparently different training-induced adaptations (responder *vs.* non-responder when using the percentage of $\dot{V}O_{2max}$ as internal load indicator) (Vollaard et al., 2009). In accordance with these notions, our results indicated heterogeneous adaptive changes to SSG compared to sSIT, implying non-uniform external load imposed by SSG or varying internal load response among team members.

To overcome inter-subject variability in the adaptations, many authors employed various interventions to facilitate the same degrees of physical stress across athletes with varying profiles and ensure more homogenous adaptations (Bagger et al., 2003; Mann et al., 2014; Dai and Xie, 2023; Wang and Zhao, 2023). To be specific, they have utilized different reference intensities such as %MHR, %$\dot{V}O_{2max}$, and different proportions of anaerobic speed reserve with a sport-specific duration and frequency. Although such approaches produce comparable external load among individuals with different physiological ceilings, they fail to normalize all components of exercise interventions simultaneously (Mann et al., 2014). Consequently, if the prescription method for relative exercise intensity is ineffective, variations in the inter-individual internal load response may arise during each training session (McPhee et al., 2010). To overcome this issue, we employed higher bound of supramaximal intensity (*all-out*) to employ full capacity of individuals. By doing so, it seems, all parameters affecting employing the same proportions of individual's physiological and locomotor capacities are covered. Consequently, athletes underwent the same proportions of their capacity (100%) and experience the same homeostatic stress. In support of this, Bagger and colleagues (2003) indicated lower variability in measured physiological variables at higher exercise intensity, with the lowest variation during maximal conditions. In other study, O'Grady (2021) examined the individual variability of effort-based exercise and reported, when exercising at higher absolute exercise intensity, participants are likely to control their exercise intensity within a closer bandwidth. It seems, as the intensity of exercise increases, within-subject variability decreases and causes to greater homogeneity in the adaptive changes. However, game-based *all-out* interventions fails to impose uniform stress as divergence in the quantity of high-intensity activities performed during SSG creates individual variations in workload, impeding uniform adaptations to the training among team members.

Enhanced cardiorespiratory fitness and bio-motor abilities in response to SSG and sSIT were another finding of this study. Our results corroborate previous findings indicating positive effects of these interventions on the sport-specific measures such as cardiorespiratory fitness (Gamble, 2004; Benítez-Flores et al., 2018; Delextrat et al., 2018; McKie et al., 2018; Figueira et al., 2022), Jumping ability (Benítez-Flores et al., 2018; Arslan et al., 2022), sprint performance (Delextrat et al., 2018; McKie et al., 2018; Arslan et al., 2022), defensive and offensive agility (Arslan et al., 2022), technical-tactical performance (Figueira et al., 2022; Arslan et al., 2022). Enhanced cardiorespiratory fitness could be attributed to the increased central (oxygen delivery) (Fereshtian et al., 2017; Sheykhlouvand et al., 2022) and peripheral (extract and utilization of oxygen by the active muscles) components of aerobic fitness (Sheykhlouvand et al., 2016a; 2018b; Rasouli Mojez et al., 2021; Sayevand et al., 2022). Elevated aerobic fitness in our participants could in part be amplified the central component which could be verified by elevated O_2pulse (Dai and Xie, 2023). Regarding the ventilatory threshold, sSIT resulted in significantly greater changes in VT_1 than SSG. The analysis of non-responders (Figure 6) reveals that 60% of participants did not respond to SSG in VT_1. The fluctuating external load in SSG might hinder athletes from reaching their optimal intensities, affecting VT_1. In contrast, the consistent external loads in sSIT help uniformly influence VT_1 among athletes. Consequently, the non-responders to SSG contribute to lower group changes than the sSIT group.

Vertical jump is a crucial skill in basketball (Stevanovic et al., 2019). The improvement in vertical jump observed in this study aligns with findings from previous studies utilizing various HIIT protocols (Arslan et al., 2022; García-Pinillos et al., 2017). Enhanced explosiveness in vertical jump could be attributed to parameters such as reactive strength and muscular power (Panoutsakopoulos and Bassa, 2023). Improved jumping ability could potentially be attributed to heightened neuromuscular adaptations, including increased rate of force development and muscle firing rate (Buchheit and Laursen, 2013), as well as enhanced anaerobic power production in the plantar flexors and knee extensors (Maffiuletti et al., 2002). The improvement in lower-body Wingate anaerobic power also may be explained by an increase in the recruitment of high-threshold motor units, enhanced buffering capacity of active muscles, and elevated total creatine content in muscles (Sheykhlouvand et al., 2016b; 2018a).

A quick COD could be a result of rapid force development and high power generation by the lower extremities (Miller et al., 2006). Results indicated SSG causes to a significantly greater changes in COD than sSIT. During tasks requiring COD ability, the leg extensor muscles experience rapid transitions between eccentric and concentric muscle actions, with minimal ground contact time (Miller et al., 2006; Clemente et al., 2022). Greater impact of SSG on COD could be attributed to the sport-specific drill during SSG (Song et al., 2023). Given that all training programs were the same between groups, more emphasize on change of direction during SSG could be the only explanation for this difference. Such movements may indirectly enhance COD ability more effectively than linear running (Arslan et al., 2022).

Regarding sprint performance, both the SSG and sSIT groups showed improvement in this locomotor ability over six weeks. Our results are consistent with prior research indicating the beneficial effects of HIIT on sprint performance (Clemente et al., 2022). The enhancement in sprint acceleration and velocity resulting from interval training involves fast-twitch muscle fibers and improvements in stride length, which contribute to improvements in sprinting ability (Lee et al., 2020).

A potential limitation of sSIT approach is its inability to emphasize basketball-specific technical and tactical behaviors. While responses under the SSG approach exhibit variability, it is conceivable that it contributed more significantly to enhancing these qualities compared to sSIT. Therefore, future studies exploring a more comprehensive intervention are warranted; specifically, combination of sSIT and SSG to concurrently stimulate technical-tactical aspects along with physical and physiological conditioning. Inability to closely monitoring maturation was another limitation of this study, which should be considered in future investigations.

Conclusion

The findings from our study revealed that a 6-week of sSIT and SSG significantly enhanced cardiorespiratory fitness, anaerobic power, and bio-motor abilities. Comparing inter-individual variability in the adaptive changes by analyzing residuals in individual adaptations indicated that sSIT leads lower inter-individual variability in adaptations of aerobic fitness and related physiological parameters, as well as basketball-specific bio-motor abilities. More specifically, sSIT resulted in lower residuals in percent changes in $\dot{V}O_{2max}$, O_2pulse, VT_1, PPO, and linear speed across athletes with varying profiles compared to the SSG. Moreover, sSIT resulted in more responders than SSG in $\dot{V}O_{2max}$, O_2pulse, VT_1, VT_2, and linear speed.

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The authors declare no 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

- Both SSG and sSIT protocols sufficiently stimulate adaptive mechanisms to enhance the mean group values of cardiorespiratory fitness and bio-motor abilities. Basketball coaches and players have the flexibility to choose either protocol based on the specific training mode.
- Short-duration sprint interval training generates a uniform stimulus compared to Small-Sided Games through lowering residuals in the magnitude of the adaptations and coefficient of variations.
- Such an approach potentially resulting in more comparable physiological demands and more homogenous adaptations among team members.

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