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# Comparative analysis of consistency of adaptations to interval interventions individualized using sport-specific techniques in well-trained soccer players

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**This study aimed to investigate the uniformity of adaptive changes in cardiorespiratory fitness and anaerobic power to high-intensity interval interventions (HIIT) designed using techniques specified for soccer players. Thirty well-trained athletes (age = 25 ± 3.1 years; body mass = 82.4 ± 3.4 kg; height = 183 ± 2.1 cm) were randomly assigned to two experimental groups engaging in interval intervention individualized using 30–15 Intermittent Fitness Test [HIITv$_{IFT}$ (two sets of 5–8 min intervals, comprising 15 s of running at 95% of V$_{IFT}$ followed by 15 s of passive recovery)], and small-sided game with matched timing (SSG [4 sets of 2.5–4 min 3 v 3 efforts]), as well as an active control group. Before and after a 6-week intervention consisting of three sessions per week, participants underwent a lab-based cardiorespiratory fitness test using breath-by-breath gas analyzer and non-invasive impedance cardiography to evaluate aerobic fitness and cardiac function measures. Also, anaerobic power was measured using lower-body Wingate test. Both interventions resulted in significant enhancement in all measures of cardiorespiratory fitness and anaerobic power over the training period. Analyzing inter-individual variability through determining residuals in individual changes indicated HIITv$_{IFT}$ results in residuals in individual changes in ventilatory threshold (VT [first (VT$_1$) and second (VT$_2$)]), and peak and average power output than SSG (*p* = 0.02, 0.04, 0.02, and 0.01, respectively). In addition, the change in maximum oxygen uptake, maximal ventilation, and average power output following HIITv$_{IFT}$ was notably greater than SSG (*p* = 0.002, 0.006, and, 0.019, respectively). There was no significant difference between HIITv$_{IFT}$ and SSG in cardiac hemodynamics (cardiac output and stroke volume). Overall, by facilitating more homogenous stress, HIITv$_{IFT}$ results in more identical physiological demands and more uniform adaptations in ventilatory threshold and anaerobic power than SSG.**

**Keywords** Aerobic power, Team sport, Individual adaptations, Cardiorespiratory fitness, Anaerobic power

In various forms, high-intensity interval training (HIIT) has been shown to be s suitable practical training strategy for enhancing cardiorespiratory fitness and anaerobic metabolic pathways in soccer players[1–3]. Like the structure of HIIT, the game of soccer comprises repeated high-intensity actions separated with low- to moderate-intensity intervals for rest. Accordingly, HIIT is considered a sport-specific method for soccer[4].

HIIT interventions are prescribed using different approaches to facilitate athletes reach the desired external load to get optimal responses[5]. Procedures may consist prescription based on rate of perceived exertion, maximal aerobic speed or velocity corresponding to maximum oxygen uptake (MAS/vVO$_{2max}$), anaerobic speed reserve [ASR (difference between MAS and maximal sprint speed (MSS)], the 30–15 intermittent fitness test (30–15 IFT), all-out sprint interval training (SIT), track-and-field approach, and small-sided games or game-based

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HIIT[6]. Choosing an appropriate HIIT session for soccer requires considering various factors, including the player's profile, match-play demands, anticipated long-term adaptations, and training periodization[7].

Aligned with the key principle of training specificity and recognizing and importance of soccer's technical and tactical demands, there has been a substantial rise in interest in HIIT performed as small-sided games[8]. SSGs are acknowledged as a time-efficient training approach, given their capacity to boost physical performance, technical skills, and tactical awareness simultaneously[9]. Nonetheless, despite being recognized for their effectiveness in training, SSGs possess limitations. Variations in the number of vigorous activities within SSGs contribute to individual variations in workload, resulting in diverse adaptive responses to the interventions across members of a team[10–12]. Such limitations encourage the adoption of a more controlled yet less specialized HIIT format like HIIT prescribed using 30 – 15 IFT[6].

The 30–15 IFT has been developed to not only elicit MHR and $VO_2$ but also provide measures of acceleration, deceleration, inter-effort recovery capacity, and change of direction abilities[4]. Prescribing HIIT without considering these parameters may result in sessions with varying demands, may lead to sessions with diverse demands, impede standardizing external load, and restrict the ability to target desired physiological/neuromuscular adaptive responses[6]. It has been proposed that, by taking the aforementioned parameters into account, the final velocity reached during 30–15 IFT ($V_{IFT}$) calibrates the intensity of intervals according to the individual's locomotor abilities[4]. However, it is not well elucidated whether prescribing HIIT intervention using this approach may cause more homogenized adaptations than SSGs. By comparing the adaptive responses induced by SSG and $V_{IFT}$-based HIIT, we aim to contribute further insights to the understanding of conditioning for soccer. This attempt offers a new approach into prescribing sport-specific HIIT methods for soccer coaches, athletes, and practitioners. Therefore, we aimed to investigate the homogeneity of adaptive responses in cardiorespiratory fitness and anaerobic power to HIIT programs prescribed using the mentioned approaches. Since the workload of $V_{IFT}$-based HIIT is more controllable than that of SSGs, our hypothesis posits that calibrating HIIT intensity using $V_{IFT}$ would yield more consistent adaptations than SSG[13].

## Methods

### Participants

Thirty well-trained male soccer players (age = 25 ± 3.1 years; body mass = 82.4 ± 3.4 kg; height = 183 ± 2.1 cm; Body fat = 11.2 ± 1.4%) signed a written informed consent and voluntarily participated in this experiment. All players were members of a professional club competing at provincial levels. They were medication-free, and following screening for any unknown medical complication[14] putting them at risk of strenuous exercise, the players were matched based on their playing position and were randomly assigned into two HIIT groups performing SSG or interval intervention prescribed using $V_{IFT}$ ($HIITv_{IFT}$), and one control group. All participants were experienced with interval training methods but had not participated in HIIT during the three months preceding this study. All experimental protocols and training interventions were approved by the Ethics Board of Xiamen University and were conducted in accordance with the guidelines of the World Medical Association (Declarations of Helsinki).

### Study design

Figure 1 outlines the study design. This study utilized a randomized controlled design comprising two experimental groups and an active control group. Prior to and after the six weeks of training, participants completed a lab-based incremental exercise test to evaluate their cardiorespiratory fitness measures, including $VO_{2max}$, Oxygen pulse ($VO_2$/HR), first ($VT_1$) and second ventilatory threshold ($VT_2$), maximal cardiac output ($Q_{max}$) and stroke volume ($SV_{max}$). A lower-body Wingate test using braked leg ergometer (894E, Monark, Sweden) also measured peak (PPO) and average power output (APO). Participants underwent testing sessions on separate days, with a 24-hour gap in between. They were asked to abstain from consuming alcohol[14] and to avoid engaging in strenuous physical activity between tests[16]. About 48 h after the completion of testing sessions, participants initiated the training intervention. Subsequently, 48 h after the lase session of intervention, participants completed the similar testing procedure, adhering to the same sequence and conditions as pre-test. To eliminate the impact of dietary intake on the results, participants were instructed to adhere to their regular eating habits and refrain from taking any additional supplements during the study. The adherence to these

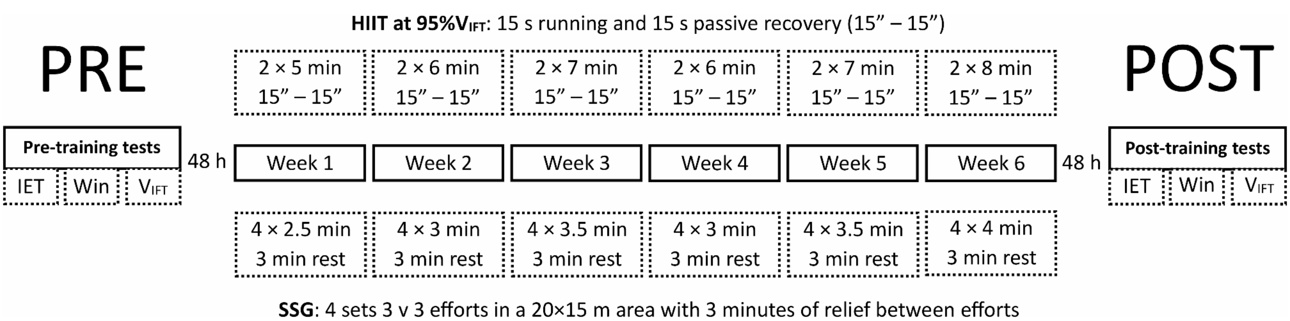


**Fig. 1**. Overview of the experimental protocol. *IET* incremental exercise test, *Win* lower-body Wingate test, $V_{IFT}$ 30 –15 incremental fitness test, *SSG* small-sided game, $HIITv_{IFT}$ HIIT using finial velocity attained at the end of $30–15_{IFT}$ test ($V_{IFT}$).

dietary guidelines was assessed through the collection of self-reported food diaries using the means of three 24-h dietary recalls (two weekdays and one weekend day)[17].

### Incremental exercise test

Following a ten-minute warm-up, comprising five minutes of jogging and five minutes of dynamic stretching, participants underwent an incremental exercise using NordicTrack 1750 treadmill (USA). The test initiated with an 8 km $h^{-1}$ workload which progressively increasing by 1 km $h^{-1}$ every three minutes. The stages were interspersed with 30 s of pauses for earlobe blood sampling to assess blood lactate concentraition. A MetaLyzer 3B-R2 (Cortex, Germany) gas analyzer continuously measured physiological parameters over the test. Before each test, the device was calibrated by a skilled technician. The $VO_{2max}$ was determined as the highest 30-second average of the $VO_2$ values, and reaching $VO_{2max}$ was confirmed according to the previously established criteria[18,19]. The second ventilatory threshold ($VT_2$) was established independently by two experts, following the criterion of a continuous increase in the $V_E{\cdot}VO_2^{-1}$ and $V_E{\cdot}VCO_2^{-1}$ ratio curve alongside the decrease in end-tidal $O_2$ tension ($P_{ET}O_2$). Similarly, the first ventilatory threshold ($VT_1$) was identified as the point at which there was a rise in $V_E{\cdot}VO_2^{-1}$ and $P_{ET}O_2$ without a simultaneous increase in $V_E{\cdot}VCO_2^{-1}$[11,20]. $Q_{max}$ and $SV_{max}$ were continuously measured using a non-invasive impedance cardiography (PhysioFlow® PF07 Enduro™, France).

### Lower-body Wingate test

Participants' anaerobic power was evaluated through a 30-second all-out Wingate anaerobic test (WAnT). The WAnT was conducted using an Excalibur Sport ergometer (Lode, Netherlands), with the load tailored to 0.075 kg per kilogram of body mass for each participant. Prior to the test, participants underwent a standardized warm-up consisting of five intervals of 30 s each (20 and 10 s at 70 and 100 RPM, respectively) at 100 W[21]. Following a two-minute rest period, participants pedaled against the load as rapidly as possible, receiving verbal encouragement throughout the test.

### 30–15 intermittent fitness test

In this test, participants completed a series of 30 s shuttle runs, each separated by 15 s rest. The test was commenced with an initial speed of 8 km $h^{-1}$, followed by incremental increases of 0.5 km $h^{-1}$ every 45 s. They were guided to run back and forth between two lines positioned 40 m apart. They received guidance from a pre-recorded audio file that signaled when they were required to be within a 3-m area around the target line. In the recovery phase, athletes moved forward to reach the closest line, preparing to begin the next step. Participants were encouraged to accomplish the maximum number of stages possible. The test was stopped when participants could no longer maintain the running pace or failed to enter the 3-meter zone around each line after hearing the audio signal three times[13]. The velocity achieved at the final stage of the test was denoted as $V_{IFT}$.

### HIIT protocols

The athletes followed their standard off-season soccer-specific routine, which comprised tactical and technical drills as well as simulated matches held twice a week. Their regular soccer-specific sessions typically lasted between 75 and 85 min and took place from 4:10 to 6:10 p.m. The SSG and $HIITv_{IFT}$ sessions were conducted on Sundays, Tuesdays, and Thursdays before the regular soccer training sessions.

Each session began with approximately 5 min of jogging, followed by 5–10 min of dynamic movements and sprints incorporating game-specific technical movements. After completing the warm-up, players in the G-$V_{IFT}$ performed 2 sets of intervals lasting 5, 6, 7, 6, 7, and 8 min each (progressing from the 1st to the 6th week), comprising 15-s runs at 95% of their $V_{IFT}$ followed by 15 s of passive recovery[4]. The SSG consisted of 4 sets of time-matched sessions, each lasting 2.5, 3, 3.5, 3, 3.5, and 4 min respectively, in a 20 × 15 m area. There was a 3-min break between each session. SSG sessions were held with no goalkeeper, with two practitioners to motivate athletes and supply balls to sustain the game's pace. Teams were evenly matched based on the players' positions, and the game's primary goal was to retain possession of the ball for as extended a period as achievable[12,22]. The control group followed their usual training over the study period.

### Statistical analysis

Statistical analyses were conducted using SPSS software, version 25 (IBM Corp., Chicago, IL), and the sample size was estimated using G*Power software[23]. According to Cohen's effect size "*f*" conventions defined as small (0.10), medium (0.25), and large (0.40)[24–26], with significance level (α) set at 0.05, power (1 − β) at 0.95, and the $f = 0.40$, the required sample size for this experiment was estimated to be 30. Data The data is expressed as mean ± SD. The normality of distribution was examined using the Shapiro–Wilk test, and the homogeneity of variances was assessed using Levene's test. A two-factor group (SSG, $HIITv_{IFT}$, and CON) × time (pre-training & post-training) analysis of variance (ANOVA) analyzed the between groups difference in the changes. Tukey's post hoc test analyzed the significant interactions or main effects when a significant *F*-ratio was observed. Inter-individual variability in adaptive changes during the training period was evaluated using two approaches. Initially, individual percent changes in the measured variables were computed, and the coefficient of variation (CV) in the mean group changes was determined by dividing the mean changes by the standard deviation. Subsequently, individual residuals in the magnitude of changes were calculated as the square root of the squared difference between mean group changes and individual percent changes in the measured variables. Finally, a one-way ANOVA with Tukey's post hoc test was conducted to compare between-group differences in the residuals. Effect sizes were assessed using Cohen's d (*d*), with a significance level set at 0.05.

## Results

A time-regimen interaction was observed for $VO_{2max}$ [$F_{(2, 27)} = 4.33$, $p = 0.002$], $V_E$ [$F_{(2, 27)} = 5.14$, $p = 0.008$], $VT_1$ [$F_{(2, 27)} = 4.98$, $p = 0.014$], $VT_2$ [$F_{(2, 27)} = 6.17$, $p = 0.006$], CO [$F_{(2, 27)} = 5.51$ $p = 0.010$], SV [$F_{(2, 27)} = 6.01$ $p = 0.009$], PPO [$F_{(2, 27)} = 11.46$, $p = 0.001$], and APO [$F_{(2, 27)} = 6.73$ $p = 0.004$]. Post-hoc test indicated that in comparison to CON group, $HIITv_{IFT}$ and SSG groups indicated greater changes in $VO_{2max}$ ($p = 0.003$ & 0.007, respectively), $V_E$ ($p = 0.001$ & 0.005), $VT_1$ ($p = 0.019$ & 0.021), $VT_2$ ($p = 0.006$ & 0.008), CO ($p = 0.012$ & 0.033), SV ($p = 0.004$ & 0.006), PPO ($p = 0.001$ & 0.003), and APO ($p = 0.006$ & 0.008). In addition, $HIITv_{IFT}$ resulted in greater changes in $VO_{2max}$ ($p = 0.002$), $V_E$ ($p = 0.006$), and APO ($p = 0.019$) than SSG.

No between-group difference was seen at the baseline for the measured variables ($p > 0.05$). Both groups significantly enhanced measures of cardiorespiratory fitness over time. Also, anaerobic power significantly improved in response to both interventions (Table 1).

As shown in Figs. 2, 3, 4 and 5, $HIITv_{IFT}$ led to reduced residuals in individual changes in $VT_1$ ($p = 0.02$; 95% CI: 0.31 to 1.27), $VT_2$ ($p = 0.04$; 95% CI: 0.02 to 1.51), PPO ($p = 0.02$; 95% CI: 0.19 to 2.07), and APO ($p = 0.01$; 95% CI: 0.21 to 1.75) compared to SSG. Moreover, the CVs in mean percent changes in all measured parameters following $HIITv_{IFT}$ were lower than those of SSG (Table 1).

## Discussion

This study is the first to compare the consistency of adaptive changes in measures of aerobic fitness, cardiac function and Wingate anaerobic power induced by SSG or $V_{IFT}$-based HIIT over a 6-week training period. The most striking findings of this experiment were that when analyzing individual residuals in the magnitude of adaptations over the training period, $HIITv_{IFT}$ produced more consistent adaptive changes in $VT_1$, $VT_2$, PPO, and APO than SSG across team members. Also, the change in $VO_{2max}$, $V_E$, and APO following $HIITv_{IFT}$ was markedly greater than SSG. In addition, the CVs in mean percent changes in all measured variables in response to $HIITv_{IFT}$ was lower than SSG. Both interventions resulted in significant enhancement in all measures of cardiorespiratory fitness and anaerobic power over the training period.

Exercise intervention outcomes are typically presented as mean group values, assuming that these averages accurately reflect individual responses. Individual adaptive responses to a given intervention have been shown to vary widely among participants due to factors such as physiological ceilings, locomotor profiles, and trainability, as reported in previous studies[10–12,27]. Our findings corroborate earlier studies highlighting significant diversity in individual responses to diverse HIIT interventions[4,28,29]. When evaluating SSG and $HIITv_{IFT}$, it is crucial to take into account the external stress induced by the training interventions. The interaction of teams within various contextual factors is known to influence the dynamic nature of the game, introducing variability in the stimuli experienced during training[30]. Consequently, every training scenario involves a certain level of unpredictability, naturally resulting in heightened variability of stimuli[10]. The variability in physiological demands during training sessions is associated with a range of adaptive responses, as demonstrated in prior research[31]. The cumulative external load induced during an exercise is affected by parameters such as duration and intensity, acting as a stimulus that initiates subsequent changes[27]. Adaptive alterations in cellular levels to a given intervention are a consequence of the total collective effect of particular transcriptional and translational 'micro-adaptations' that manifest following intervention[32]. Differences in acute exercise stimuli have been linked to variations in accumulated individual responses over the training period[27]. In order to mitigate diversity in individual adaptations, coaches employ a variety of fixed reference intensities, including $VO_{2max}$, maximum heart rate, anaerobic speed reserve, $V_{IFT}$, and exercise durations customized based on individual exercise tolerance or the nature of the sport in which the athlete engages. Previous research indicates that calibrating exercise interventions based on an athlete's physiological capacity and locomotor ability reduces divergence in measured physiological variables, contributing to more consistent outcomes[6]. Accordingly, we utilized $V_{IFT}$ to calibrating the intensity according to the athletes' physiological capacity and locomotor ability to see how participants could maintain their exercise intensity within a narrower range to get more homogenized adaptations in comparison to SSG. Our result indicated this approach facilitates more uniform homeostatic stress, identical degrees of physiological demands and more homogenized adaptations than SSG.

Another noteworthy discovery in this study was that both interventions sufficiently stimulated adaptive mechanisms involved in enhancing measures of aerobic and anaerobic metabolic pathways. However, $HIITv_{IFT}$ resulted in significantly greater adaptations in $VO_{2max}$, $V_E$, and APO than SSG. Aerobic power improvements are well-documented to result from enhanced oxygen delivery (central component of aerobic fitness) and utilization by active muscles (peripheral component of aerobic fitness)[33,34]. Increased SVmax and Qmax following training interventions such as SSG and $HIITv_{IFT}$ have been reported as indicators of improved central components of cardiorespiratory fitness in prior studies. Mechanisms behind improved anaerobic power include activation and elevated discharge rate and of high-threshold motor units, enhanced biochemical content of active muscles (e.g., creatine), and an improved muscle buffering capacity[33,35,36]. Greater changes in response to $HIITv_{IFT}$ may be attributed to SSG's failure in imposing adaptive stimulus non-uniformly causing to lower changes in the mentioned variables when compared to $HIITv_{IFT}$.

One possible limitation of this study was the lack of control over genetic variances among participants, which are recognized to impact trainability and adaptive responses. Additionally, participants continued their habitual soccer-related training alongside the intervention. This ongoing training introduces potential confounding effects, as we could not isolate the impact of our intervention from the influence of their regular activity. As a result, it remains unclear to what extent the observed adaptations were solely attributable to our intervention, rather than a combined effect of both the intervention and their habitual training. Future studies should consider implementing a controlled training environment with no additional training to more accurately assess the intervention's effects.

| | SSG | | HIITv$_{IFT}$ | | CON | |
|---|---|---|---|---|---|---|
| | **Pre** | **Post** | **Pre** | **Post** | **Pre** | **Post** |
| $VO_{2max}$(**ml·kg**$^{-1}$ min$^{-1}$) | 51.72 ± 2.37 | * 53.66 ± 1.95 | 51.99 ± 2.66 | * 54.92 ± 2.81 | 52.7 ± 4.6 | 53.1 ± 3.8 |
| P-value | 0.009 | | 0.002 | | 0.281 | |
| %Δ | 3.75 † | | 5.63 †§ | | 0.7 | |
| ES (d) | 0.89 | | 1.07 | | - | |
| CV of %Δ | 38% | | 13% | | - | |
| $V_E$(**l·min**$^{-1}$) | 159.0 ± 6.2 | * 164.8 ± 6.4 | 161.2 ± 8.3 | * 169.8 ± 8.7 | 164.4 ± 11.1 | 165.1 ± 10.6 |
| P-value | 0.019 | | 0.001 | | 0.336 | |
| %Δ | 3.6 † | | 5.3 †§ | | 0.4 | |
| ES (d) | 0.91 | | 1.00 | | - | |
| CV of %Δ | 35% | | 16% | | - | |
| $VT_1$(%$VO_{2max}$) | 71.7 ± 3.3 | * 75.2 ± 4.1 | 73.3 ± 4.0 | * 77.5 ± 4.2 | 72.4 ± 6.1 | 73.0 ± 6.9 |
| *P-value* | 0.009 | | 0.002 | | 0.412 | |
| %Δ | 4.9 † | | 5.7 † | | 0.82 | |
| ES (d) | 0.94 | | 1.02 | | - | |
| CV of %Δ | 32% | | 16% | | - | |
| $VT_2$(%$VO_{2max}$) | 86.4 ± 3.2 | * 90.1 ± 2.4 | 87.7 ± 2.8 | * 91.7 ± 2.4 | 85.1 ± 5.1 | 86.2 ± 4.9 |
| P-value | 0.004 | | 0.001 | | 0.602 | |
| %Δ | 4.28 † | | 4.56 † | | 1.3 | |
| ES (d) | 1.31 | | 1.53 | | - | |
| CV of %Δ | 43% | | 26% | | - | |
| CO (l min$^{-1}$) | 31.17 ± 1.38 | * 32.36 ± 1.43 | 30.16 ± 1.91 | * 31.34 ± 1.96 | 31.41 ± 2.0 | 31.82 ± 2.2 |
| P-value | 0.006 | | 0.001 | | 0.536 | |
| %Δ | 3.81 † | | 3.91 † | | 1.2 | |
| ES (d) | 0.84 | | 0.70 | | - | |
| CV of %Δ | 42% | | 28% | | - | |
| SV (ml beat$^{-1}$) | 155.9 ± 6.8 | * 161.7 ± 6.6 | 160.1 ± 10.5 | * 166.4 ± 9.3 | 157.2 ± 7.8 | 158.3 ± 7.7 |
| P-value | 0.019 | | 0.008 | | 0.311 | |
| %Δ | 3.72 † | | 3.93 † | | 0.7 | |
| ES (d) | 0.86 | | 0.63 | | - | |
| CV of %Δ | 56% | | 31% | | - | |
| PPO (W) | 878.7 ± 57.8 | * 918.0 ± 54.1 | 881.7 ± 59.7 | * 927.8 ± 58.8 | 868.4 ± 46.2 | 871.6 ± 49.9 |
| P-value | 0.004 | | 0.002 | | 0.122 | |
| %Δ | 4.47 † | | 5.22 † | | 0.3 | |
| ES (d) | 0.70 | | 0.77 | | - | |
| CV of %Δ | 56% | | 22% | | - | |
| APO (W) | 547.4 ± 45.6 | * 575.4 ± 50.0 | 539.3 ± 41.9 | * 576.9 ± 40.1 | 544.7 ± 39.6 | 552.3 ± 41.7 |
| P-value | 0.002 | | 0.0005 | | 0.136 | |
| %Δ | 5.11 † | | 6.97 †§ | | 1.4 | |
| ES (d) | 0.58 | | 0.91 | | - | |
| CV of %Δ | 47% | | 18% | | - | |

**Table 1**. Changes in the measured variables over the 6-week training period. Values are means ± SD. $VO_{2max}$ maximum oxygen uptake; $V_E$ maximal ventilation, $VT_1$ first ventilatory threshold, $VT_2$ second ventilatory threshold, *CO* maximal cardiac output, *SV* stroke volume, *PPO* peak power output, *APO* average power output. $N = 10$ for each group. *Significantly greater than pre-training value ($P < 0.05$). †Significantly greater than CON. §Significantly greater than SSG.

Another limitation of this study is the difference in exercise intensity between the two training protocols. During the SSG sessions, exercise intensity could have been influenced by the dimensions of the pitch, leading to potential variability in player exertion. In contrast, the HIIT protocol based on the $V_{IFT}$, ensuring consistently high exercise intensity. This discrepancy in intensity between the protocols may have contributed to differences in performance adaptations and should be considered when interpreting the findings.

## Conclusions

Through analyzing inter-individual variability across participants, this experiment investigated the homogeneity of adaptive changes in cardiorespiratory fitness and anaerobic power induced by SSG or $V_{IFT}$-based HIIT over a 6-week training period. Our result indicated, both interventions adequately stimulate adaptive mechanisms

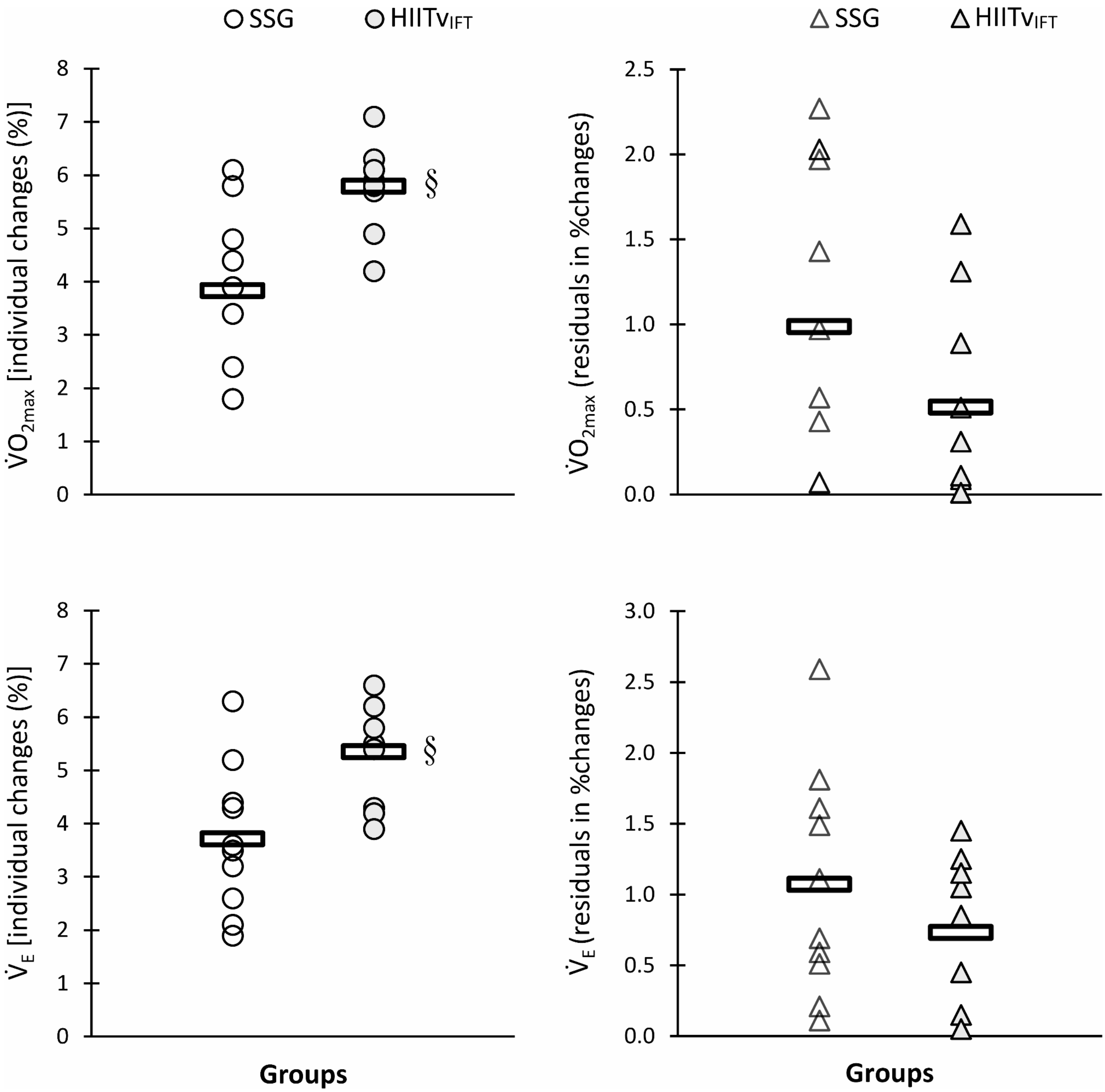


**Fig. 2**. Individual percent change and residuals in individual changes in response to SSG and $HIITv_{IFT}$ over the training period. $VO_{2max}$, maximum oxygen uptake; $V_E$, maximal ventilation. § Significantly greater changes than SSG.

responsible for enhancing the mentioned qualities. However, by facilitating more homeostatic stress than SSG, $HIITv_{IFT}$ results in more uniform adaptive changes in ventilatory threshold and anaerobic power. Moreover, the magnitude of changes in $VO_{2max}$, $V_E$, and APO in response to $HIITv_{IFT}$ was markedly higher than SSG.

## Practical applications

This study highlights the effectiveness of $HIITv_{IFT}$ as a superior training method for achieving consistent and significant improvements in aerobic fitness, anaerobic power, and cardiac function compared to SSG. By tailoring training intensity to individual physiological capacities and locomotor abilities, $HIITv_{IFT}$ minimizes variability in adaptations, providing more uniform performance improvements among athletes. While SSG can enhance fitness, its inherent variability makes it less effective for achieving targeted physiological gains, emphasizing the need for structured, individualized approaches like $HIITv_{IFT}$ in optimizing athletic performance.

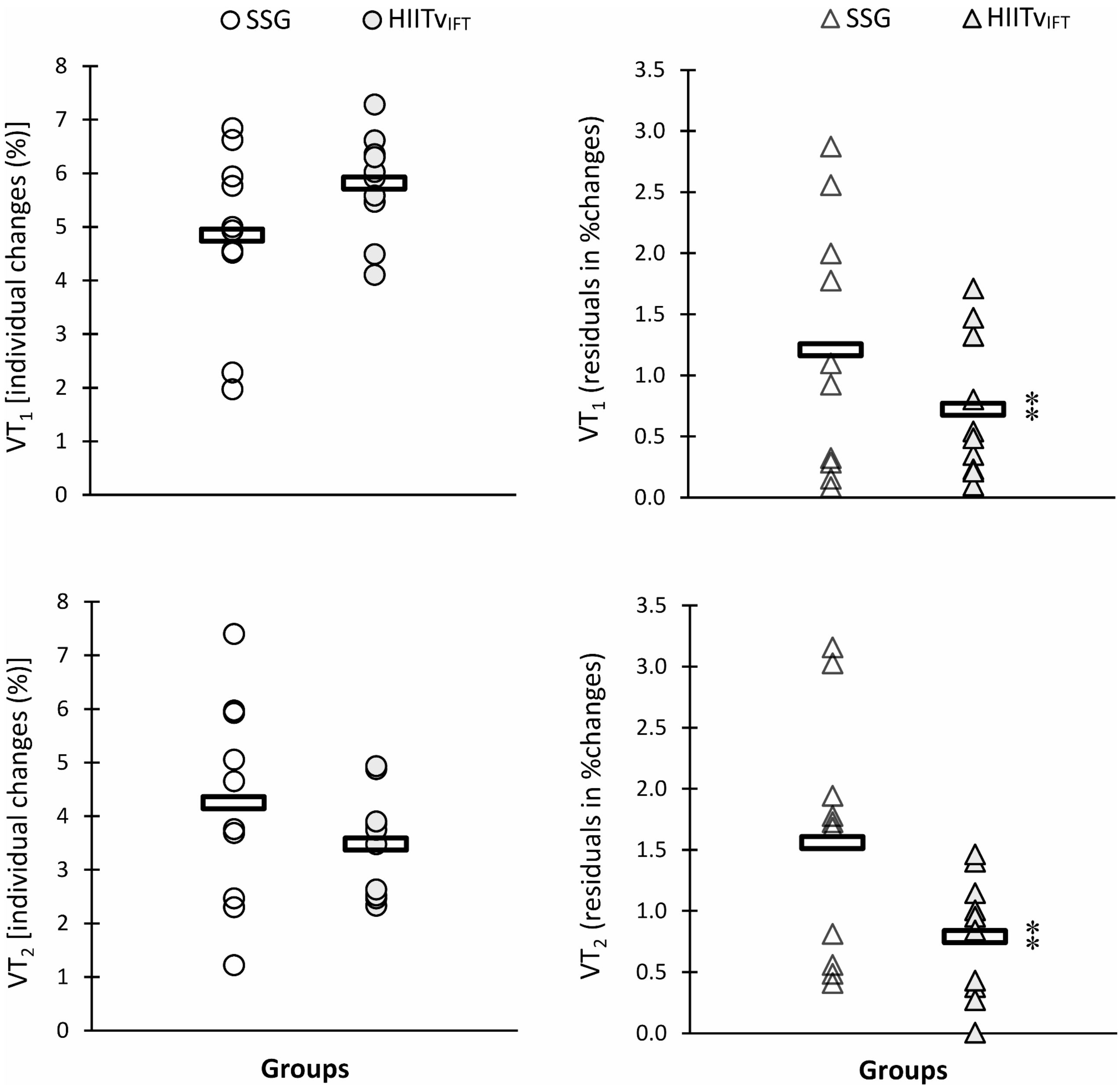


**Fig. 3**. Individual percent change and residuals in individual changes in response to SSG and HIITv$_{IFT}$ over the training period. $VT_1$, first ventilatory threshold; $VT_2$, second ventilatory threshold. ⁑ Significantly lower residuals in mean group changes than SSG.

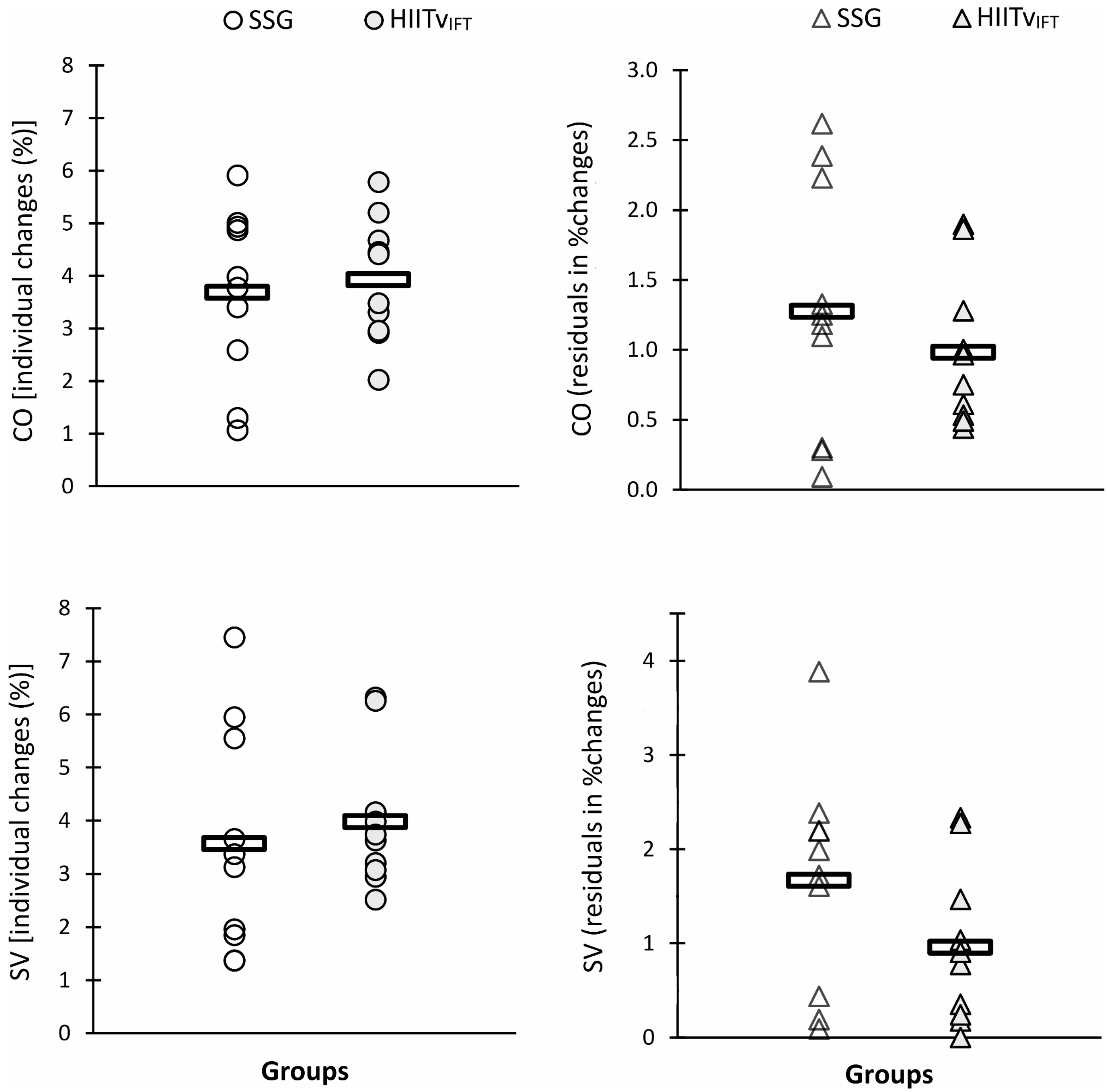


**Fig. 4**. Individual percent change and residuals in individual changes in response to SSG and HIITv$_{IFT}$ over the training period. $Q_{max}$, cardiac output; $SV_{max}$, stroke volume.

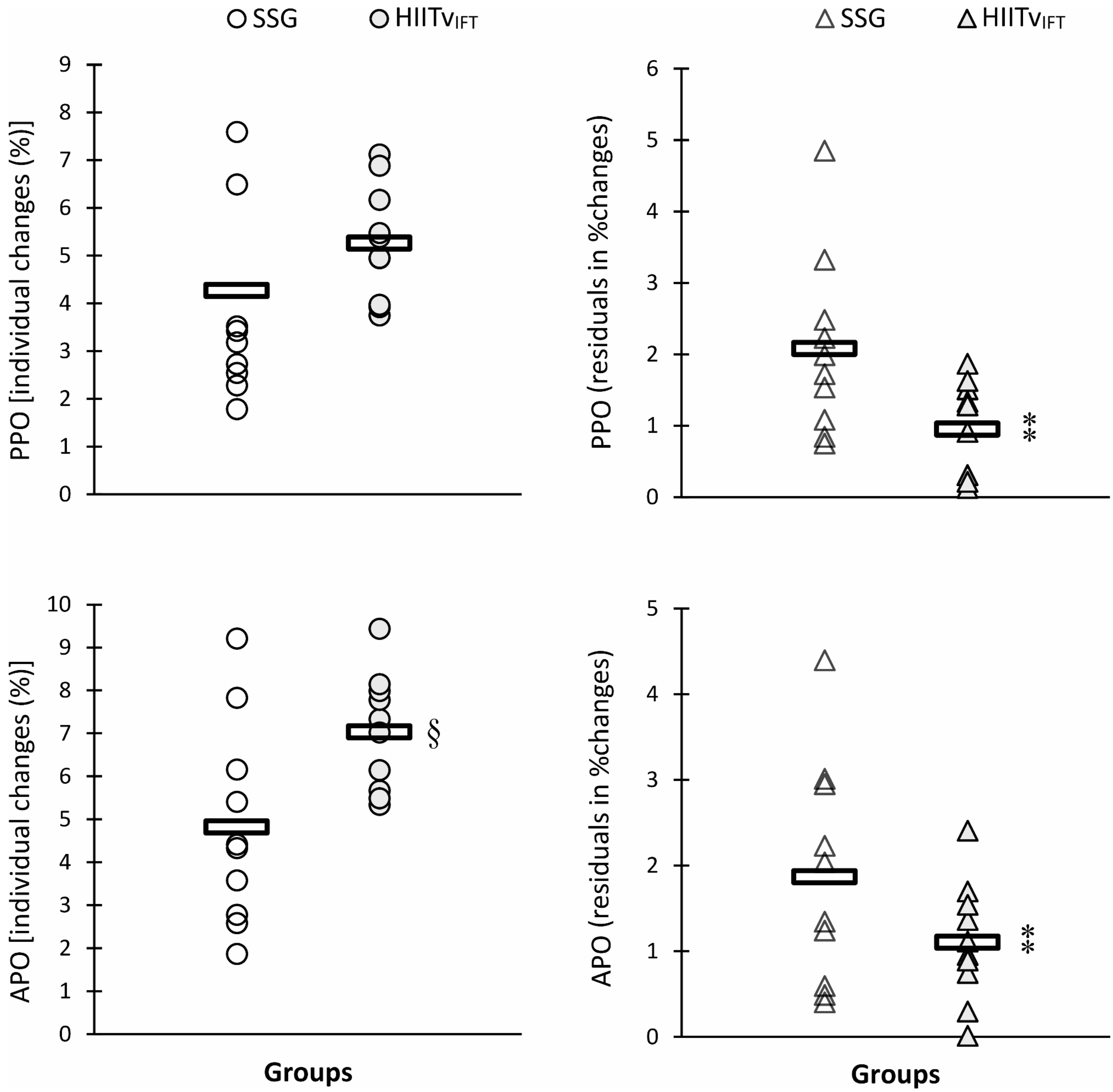


**Fig. 5**. Individual percent change and residuals in individual changes in response to SSG and $HIITv_{IFT}$ over the training period. PPO, peak power output; APO, average power output. §Significantly greater changes than SSG. *Significantly lower residuals in mean group changes than SSG.

## Data availability

The datasets used and analyzed during the current study are available from the corresponding authors (S.L & H.Z) upon reasonable request.

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## Author contributions

H.Z., S.L., and B.Y. contributed equally to every aspect of this experiment, including conceptualization, study design, supervision, data collection, statistical analysis, interpretation, writing, and reviewing. All authors reviewed and endorsed the final version of the manuscript.

## Declarations

### Competing interests
The authors declare no competing interests.

### Additional information
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