Observation of Intermittent Running Performance During Different Training Periodizations in Youth Football Players

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Abstract

Background

This study investigated whether incorporating high-intensity interval training (HIIT) into Verheijen's periodised small-sided game (SSG) training model improves the intermittent running performance of elite U16 and U17 footballers.

Methods

The U-16 team (n = 16) followed the SSG+HIIT protocol, while the U-17 team (n = 16) served as the control group, performing only SSG sessions on days designated for physical conditioning. The intervention group's HIIT sessions were prescribed using individualized thresholds based on the 30 – 15 Intermittent Fitness Test (30 – 15 IFT). Both training protocols were matched for total volume, with the SSG-only group completed 136 minutes of SSG, and SSG+HIIT group performed 106 minutes of SSG plus 30 minutes of HIIT. Pre- and post-30–15 IFT final velocity (V_{IFT}) scores were compared within and between groups.

Results

In the SSG+HIIT group, a significant 8.1% improvement in V_{IFT} was observed after the intervention ($p<.001$, Cohen's $d = 1.54$), which was significantly greater than the non-significant 1.3% increase in the SSG-only group ($p = 0.087$, $d = 0.43$). The group×time interaction showed a large effect size ($\eta^2=0.404$), indicating the superior aerobic adaptations induced by the hybrid training model.

Conclusion

A combined SSG+HIIT training model enhances intermittent fitness more effectively than SSG-only training in elite youth football players, supporting its application in early-season conditioning programs.

Introduction

The physical demands of modern football have evolved significantly, with increasing emphasis on high-intensity intermittent running capacity, particularly among youth players aspiring to elite levels. In elite football, data indicate players perform approximately 1000–1400 activity changes per match, including 200–300 high-intensity efforts such as sprints, accelerations, and decelerations [1, 2]. These intermittent actions are crucial for match success, as they frequently occur during decisive game phases such as transitions, counterattacks, and goal-scoring opportunities [1]. In modern football, players are required to developed both aerobic and anaerobic capacities enabling them to meet the physical demands of football [3]. Additionally, adequate aerobic and anaerobic capacities are crucial in football, as they enable players to sustain high-intensity activities throughout the match, facilitating rapid changes in speed, endurance, and recovery, ultimately influencing overall performance on the field [4, 5]. As modern-day football performance requirements increase, greater importance is being placed on training interventions that focus on developing both aerobic and anaerobic capacities without compromising the training of technical and tactical skills specific to the game. Small-sided games (SSG) have, in this framework, become a commonly used training method that allows for a match-like context, which promotes physiological and cognitive responses important for the performance of the sport of football [6, 7].

When properly structured -through modifications in player numbers, field dimensions, or imposed constraints- small-sided games provide an ecologically valid method to simultaneously deliver technical, tactical, and metabolic loads that reflect the demands of real match play [8]. But, and despite their multidimensional advantages, traditional SSG formats typically do not achieve often the intensity thresholds necessary to stimulate significant adaptations in cardiovascular and intermittent endurance performance [9]. The caveat becomes even more relevant when analyzing well-trained adolescent athletes, in whom the concept of specificity of training is even more important [10]. Particularly when intermitted fitness tests are used to personalize the exercise load; high-intensity interval training (HIIT) constitutes a time-efficient and highly effective method for enhancing youth football players' VO_{2max}, repeated-sprint ability, and high-speed running performance [11]. Nevertheless, although HIIT certainly does provide evident aerobic adaptations, its use in isolation would detract from learning of critical technical-tactical skills, thus compromising HIIT ecological validity in football settings.

To address these limitations, more recent models have suggested HIIT to be incorporated within periodized SSG frameworks [12]. Recent research comparing combined high-intensity interval training (HIIT) with small-sided games (SSGs) indicates that a hybrid approach can elicit greater improvements in both physiological and sport-specific performance measures than either intervention alone [13]. Several recent studies have also been in support of both SSG and HIIT formats in order to enhance specific performance variables in young players. Buchheit et al. [14] for example, found HIIT protocols based on the final velocity of the 30 – 15 IFT (V_{IFT}) to provide better improvements in intermittent endurance when compared to continuous running. Subsequent studies [13, 15, 16] have been advocating for the effectiveness of a mixed approach of SSG and HIIT as a more beneficial stimulus than the sole application of SSG in terms of aerobic capacity, VO_{2max}, and repeated sprint performance. Combining both approaches allows coaches to adapt to training load but also keep training close to the specificity of competition.

Nonetheless, a few controlled trials have examined the relative efficacy of SSG versus SSG+HIIT in conditions of high ecological validity in elite youth populations [17–19]. Moreover, the potential impact of this type of training on early season mesocycles critical for establishing aerobic foundations, remains largely unexplored. An equally important consideration is the influence of age on training responsiveness, as U16 and U17 players undergo rapid developments in biological maturation, neuromuscular coordination, and tactical cognition. These factors may significantly affect their adaptations to various training stimuli. Notably, responses to different formats SSGs, including both traditional SSG and hybrid SSG+HIIT models, have been shown to vary across these age groups. Understanding the distinct physiological responses of each group is essential for developing age-appropriate and evidence-based training prescriptions [13, 20].

The present study therefore aimed to evaluate the effectiveness of incorporating high-intensity interval training into a Verheijen-model periodized small-sided game (SSG) framework. Specifically, it sought to determine whether such an integrated model produces superior improvements in intermittent running capacity as assessed by the 30 – 15 IFT in elite U16 and U17 male football players during the preseason conditioning phase. We hypothesized that players undertaking the combined SSG+HIIT training would exhibit significantly greater improvements in V_{IFT} compared to those following the SSG-only protocol, despite both groups being matched for total training volume.

Methods

Experimental Approach to the Problem

A randomised quasi-experimental pre-post design was implemented to examine the impact of incorporating additional HIIT sessions into periodised conditioning days, as outlined by Verheijen [8]. The study aimed to evaluate the effect of this intervention on intermittent running performance. This periodization approach is designed to systematically develop distinct physiological qualities -namely aerobic endurance, anaerobic capacity, and anaerobic power- on a weekly basis by manipulating task constraints such as player number and pitch size during small-sided games (e.g., 11v11, 7v7, 4v4 formats, including goalkeepers) [8]. In the present study, different types of HIIT, including both long- and short-interval formats, were integrated into this periodization model, with the aim of examining their effects on 30-15 Intermittent Fitness Test (30-15 IFT).

To this end, at the beginning of the 2024–2025 season, two youth teams (U16 and U17) from the same Turkish First Division professional football club were assigned to different intervention groups: the U16 team followed the SSG+HIIT protocol, while the U17 team served as the control group, performing only SSG sessions based on Verheijen's SSG periodization model [8]. The intervention lasted for 40 days, covering the preseason period and the initial week of competition, a phase commonly identified as the most effective for improving aerobic capacity due to the increased training load and physiological responsiveness [21]. All participants continued to engage in their regular technical and tactical training sessions, as well as friendly matches and one competitive match, throughout the intervention.

30-15 IFT was conducted at baseline and immediately after the 40-day training period. The final and highest velocity achieved during the test (V_{IFT}) was recorded for each participant and used as the sole dependent variable for both within-group (pre-post) and between-group comparisons. All tests and training sessions were conducted on a synthetic turf pitch under consistent environmental conditions (temperature: 15–25°C; relative humidity: 40–50%). Training sessions were held during the team's usual training hours (14:00–16:30) with players wearing standard soccer attire and cleats. Throughout the intervention, players were asked to maintain their habitual lifestyle routines, including regular sleep (~8 hours per night), adequate fluid intake, and sufficient carbohydrate consumption [22].

Subjects

A total of 36 youth football players competing in the U16 and U17 age categories of a professional club participating in the Turkish First League took part in the study. The mean and standard deviation values for age, height, and body weight of the participants are presented in Table 1. Inclusion criteria required all players to have attended every physical conditioning training session throughout the 40-day intervention period and to have been free of any injury during the two months preceding the start of the study. Goalkeepers were excluded from the analysis, although they participated in the regular training sessions. Prior to participation, all players and their legal guardians were fully informed about the study procedures, objectives, potential benefits, and risks, and provided written informed consent. The study protocol was approved by the Ethics Committee of Atatürk University (E-70400699-050.02.04-2500239949) and conducted in accordance with the principles outlined in the Declaration of Helsinki (2013). The study was conducted according to the ethical standards in sport and exercise science research [23].

<<< Table 1 about here >>>

Data collection tools

30-15 Intermittent Fitness Test (30-15 IFT)

Intermittent supramaximal performance involving changes of direction (CODs) was evaluated using the 30-15 Intermittent Fitness Test (30-15 IFT) [24, 25]. This test comprises repeated 30-second shuttle runs alternating with 15-second periods of passive recovery. The initial running speed is set at 8 km/h and increases by 0.5 km/h at the end of each 45-second stage. Participants are required to run continuously back and forth between two markers positioned 40 meters apart, following an auditory beep signal that regulates the pace. The test was terminated when the player could no longer sustain the required running pace or failed to reach within a 3-meter zone of the designated lines at the audio cue for three consecutive attempts. The running speed attained during the last successfully completed stage was recorded as V_{IFT}. This measure has demonstrated high test-retest reliability over two consecutive sessions separated by 48 hours (intraclass correlation coefficient=0.96; typical error=0.33 $km \cdot h^{-1}$; 95% confidence interval=0.26–0.45) [26].

<<< Figure 1 about here >>>

Training Program of the Experimental Groups

The planning of the SSGs was based on the framework proposed by [8]. However, unlike the two-week microcycle blocks recommended in the original model, the present study implemented one-week blocks (Block 1 [Aerobic capacity]: 11v11, Block 2 [Anaerobic capacity]: 7v7, Block 3 [Anaerobic power]: 4v4). Goalkeepers were excluded from SSG formats involving fewer than 3 players. Each SSG session was conducted on a synthetic grass field, with two coaches positioned along the perimeter to encourage players and ensure continuous play by promptly supplying new balls when needed. To ensure balanced exposure, player positions and team compositions were rotated so that all 18 outfield players engaged equally in the games. Pitch dimensions were adjusted according to the number of players, following the spatial recommendations outlined by Verheijen [8].

For the SSG+HIIT group, high-intensity interval training (HIIT) volumes were adjusted in consideration of the conditioning stimulus already provided by the SSGs. Therefore, the HIIT loads were designed to represent approximately half of the total HIIT volume recommended by Buchheit and Laursen [10]. For example, instead of applying a “2x3x2’, 90% V_{IFT}, 2’ rest” protocol, the sessions were modified to “3x2’, 90% V_{IFT}, 2’ rest.” Running speed during HIIT intervals was regulated via metronome pacing to ensure target intensity levels. Each participant’s running speed was calculated as a percentage of the final velocity reached during the initial 30-15 IFT, and this individualized reference speed was used as the baseline for all conditioning HIIT sessions.

Throughout the 40-day intervention period, a total of seven sessions were designated for conditioning, while the remaining days were allocated to technical-tactical or regeneration training. All training sessions were conducted under comparable surface and environmental conditions for both groups. Hydration was permitted ad libitum during each session, and only one training session was performed per day.

Table 2 presents the detailed daily training schedule for both groups. Conditioning days are highlighted in red, and match days are indicated in green. During the intervention period, each team participated in three friendly matches and one official league match. The number of rest days, regeneration, and technical-tactical sessions was matched between the groups. As a result of this planning, the total training volume was equalized across groups, with both accumulating 136 minutes of high-intensity activity (SSG+HIIT group: 106 minutes of SSG + 30 minutes of HIIT and SSG group: 136 minutes of SSG).

<<< Table 2 about here >>>

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics (Version 25, IBM Corp., Armonk, NY, USA). Descriptive characteristics of the groups are presented in Table 1. The normality of the sample distribution was confirmed using the Shapiro-Wilk test. Since the data met the assumptions of normality and homogeneity of variances, parametric tests were applied. A two-way analysis of variance was conducted to examine the effects of group (SSG vs. SSG+HIIT), time (pre- and post-intervention), and their interaction on V_{IFT}. Effect sizes were calculated using partial eta squared (η^2), where values of 0.01, 0.06, and 0.14 represent small, medium, and large effects, respectively. To examine within-group changes (pre- vs. post-intervention), paired sample t-tests were conducted. Effect sizes were calculated using Cohen's d, with values of 0.2, 0.5, and 0.8 interpreted as small, medium, and large effects, respectively [27]. The level of statistical significance was set at $p<0.05$.

Results

<<< Figure 2 about here >>>

Figure 2 illustrates the individual percentage changes in 30-15 IFT performance for players in the SSG group (blue squares) and the SSG+HIIT group (red circles). Each data point represents one subject, with values demonstrating variability in response to the respective training interventions. A vertical reference line at 0% highlights individuals who did not exhibit a positive change.

<<< Figure 3 about here >>>

The analysis of the V_{IFT} revealed both within-group and between-group differences over the course of the intervention. At baseline (pre-test), the SSG group demonstrated a mean V_{IFT} of 20.06 km/h, while the SSG+HIIT group exhibited a lower mean value of 18.74 km/h. Following the 40-day intervention, the SSG group showed a modest increase in V_{IFT}, reaching a post-test mean of 20.31 km/h, which corresponds to a 1.3% improvement. However, this increase did not reach statistical significance ($p=0.087$), though the effect size was small-to-moderate (Cohen's d=0.43). In contrast, the SSG+HIIT group exhibited a statistically significant increase in V_{IFT}, with the post-test mean rising to 20.28 km/h. This reflects an 8.1% improvement from baseline, and the change was statistically significant ($p<.001$), with a large effect size (Cohen's d=1.54).

Between-group comparisons revealed a significant group × time interaction. The SSG+HIIT group showed a significantly greater improvement in V_{IFT} compared to the SSG group, as indicated by a significant F-value ($F_{(1,34)}=23.05$, $p<.01$) and a large partial eta squared ($\eta^2_p=0.404$), indicating a substantial proportion of the variance explained by group allocation.

Discussion

The primary objective of the study was to rigorously evaluate whether incorporating high-intensity interval training into a periodized small-sided game model would measurably improve intermittent running performance in elite youth football players. The findings indicate that players in the SSG+HIIT group exhibited significantly greater improvements in their 30 – 15 V_{IFT} scores compared to the SSG-only group (8.1% vs 1.3%). Moreover, the significant group × time interaction ($\eta^2=0.404$) highlights the effectiveness of the integrated model in producing superior aerobic adaptations.

There is substantial evidence in the literature indicating that all forms of HIITs, including SSGs as a contextual HIIT modality, effectively enhance aerobic capacity, with multiple meta-analyses reporting significant within-group improvements across VO_{2max} and field-based endurance tests [12, 16, 28, 29]. This finding is consistent with previous literature by Buchheit and Laursen [10], who reported that HIITs performed at intensities exceeding 95–100% of VO_{2max} (90%V_{IFT}) and yields significant aerobic gains in youth athletes. According to Clemente et al. [16], both SSGs and running-based HIIT lead to improvements in aerobic performance among soccer players; however, the magnitude and variability of these improvements differ. The meta-analysis revealed that SSG protocols resulted in VO_{2max} changes ranging from − 0.7% to + 8.6%, and improvements in field-based endurance tests between + 1.8% and + 18.1%. In contrast, running based HIIT interventions produced VO_{2max} changes from − 1.6% to + 8.3%, with a broader range of improvements in field-based tests, ranging from + 0.3% to + 23.4%. In another meta-analysis, effects of various HIIT modalities, including long-interval, short-interval, and repeated sprint training on aerobic fitness investigated in male soccer players [28]. The results showed that HIIT significantly improved VO_{2max}, with effect sizes of 0.57 in controlled trials and 0.66 in non-controlled studies. Field-based endurance tests also showed significant gains, with effect sizes of 0.52 and 0.35, respectively. Importantly, when SSGs were included as a comparator in subgroup analyses, they demonstrated a comparable effect on VO_{2max} (ES = 0.83). In contrast to the findings of Clemente et al. [28], which demonstrated that running-based HIIT protocols were more effective than SSGs in improving field-based endurance test outcomes, the 2019 meta-analysis reported that SSGs induced greater improvements in these sport-specific tests compared to conventional endurance training [29]. Our findings align more closely with those of Clemente et al. [28], although both groups demonstrated improvements in the 30 – 15 IFT, the SSG+HIIT group achieved a substantially greater percentage increase (+ 8.1%). The greater improvement observed in the SSG+HIIT group in our study may partly be attributed to the specific compatibility between the nature of the HIIT sessions and the physiological demands of the 30 – 15 IFT. Both modalities involve repeated high-intensity efforts interspersed with brief recovery periods, engaging similar energy systems and movement patterns. In particular, the use of short-interval, running-based HIIT likely elicited targeted adaptations that may transferred more effectively to performance in the 30 – 15 IFT, thereby enhancing the test-specific responsiveness in the intervention group who completed four short-interval and three long-interval HIIT sessions during the experiment period.

Several studies have reported no significant differences in aerobic capacity improvements between running-based HIIT and SSGs, suggesting that both modalities can be equally effective under certain training conditions and populations [16, 28–34]. For example, SSGs prescribed with similar regimens as long interval HIIT (two to five bouts of 2–4 min of intense effort) reveals moderate improvements in VO_{2max} [28], thus confirming previous findings that have compared the efficacy of running based exercises and SSGs [29]. In one study, 21 youth football players completed 7 weeks of football-specific SSGs and mixed generic fitness training. Improvements in YYIRTL1 performance were observed in both groups over time; and no significant differences were found between the groups [31]. However, these findings are primarily based on interventions and meta-analyses comparing distinct types of HIIT protocols, rather than examining combined models such as the integrated SSG+HIIT approach implemented in the present study.

The periodization model adopted in this study was based on Verheijen's football conditioning framework, which systematically manipulates pitch size, player numbers, and game formats to target specific physiological demands [8]. While SSGs undoubtedly offer the benefit of developing technical, tactical, and metabolic components simultaneously [35], previous research has shown that SSGs may not always elicit the necessary high-speed running volumes or consistently reach the HR target zones necessary for optimal maximal aerobic adaptation, as traditional SSG formats do [14, 36]. Additionally, higher inter-subject variabilities have been observed in SSGs than in running-based HIIT, suggesting a limitation of SSGs when individualizing training [36, 37]. In this scenario, we reported that the combination of SSGs with personalized running HIIT routines represents a more accurate training stimulus, maintaining the required ecological validity for improved conditioning results. It is also important to highlight that the intervention was conducted during the preseason period, which is usually associated with increased training tolerance and greater physiological plasticity [21]. But, in practice, this period is arguably a prime opportunity to incorporate high-intensity conditioning practices to maximize fitness adaptations ahead of competitive match play.

Köklü et al. [18] provide evidence that combining SSG with running-based HIIT elicits superior acute physiological responses compared to SSG alone. Köklü's study demonstrated acute effects of training stimulus in which the SSG+HIIT model resulted in significantly higher heart rate responses, blood lactate concentrations reflecting a greater internal load [18]. Possibly, the high effort promoted by running-based methods justifies the increased anaerobic synthesis, thus increasing blood lactate levels [38]. RPE was significantly greater in the combined forms as well [18, 22]. These findings suggest that incorporating HIIT into the SSG format increases training intensity while maintaining the sport-specific context. This makes it a valuable strategy for periods requiring intensified conditioning.

Evidence regarding the effects of combined training model on aerobic capacity remains relatively limited [12, 17, 22, 39]. Above mentioned acute responses observed in studies [18, 19, 22, 39] do not consistently appear to translate into meaningful chronic physiological adaptations, and their long-term effects remain uncertain due to the limited body of evidence. The study comparing a combined form and only SSGs revealed that the group exposed to the combination improved by 6.6%, while those exposed only to SSGs improved by 4.2% [17]. In contrast, the study comparing combined form (SSG + endurance and speed running) and only SSGs presented no significant differences between interventions, even though the SSG-only group exhibited significant within-group improvements after the intervention (+ 1.79%) [22]. In another study, 21 youth football players were divided into an SSG+HIIT group and a control group. The experimental group underwent a combined intervention consisting of four SSG sessions and four running-based HIIT sessions, whereas the control group did not participate in any of these training sessions [39]. Despite the lack of significant difference between the two groups, it was observed that the experimental group (SSGs+HIIT) recorded a noteworthy improvement in the 30 – 15 IFT (%change = 8.8, Cohen's d = 0.41) during postintervention compared to the control group [39]. In a 4-week intervention study involving 19 male youth soccer players, one group engaged in five weekly sessions of SSGs combined with HIIT, while the control group followed regular training including only one such session per week. The SSG+HIIT group demonstrated a significant improvement in 30 – 15 IFT (from 17.0 ± 1.1 to 18.4 ± 0.8 km/h; $p < 0.05$; ES = 0.57), whereas the control group showed a negligible change (from 17.9 ± 1.3 to 18.2 ± 1.6 km/h; ES = 0.10) [19]. However, it is important to note that training volume was not equalized between the groups in these studies.

In light of these findings, the improvement observed in the present study is not fully supported across the existing literature. This improvement in aerobic capacity may be interpreted as a physiological adaptation resulting from the more controlled and elevated cardiovascular, metabolic and muscular stress induced by the additional running-based HIIT sessions [40]. This study is considered to be a decisive contribution to evaluating the differential effects of SSG and SSG+HIIT formats on aerobic capacity development. The present study aims to fill these gaps by utilizing a pre-post design with elite-level players from two age categories while providing an equal dose of SSG in each intervention arm. In addition to the increasing literature supporting the addition of HIIT as an alternative training approach in youth soccer, the present study supports the feasibility of incorporating short, high- intensity HIIT "snippets" within traditional SSG-based training regimens without sacrificing significant benefits in intermittent endurance capacity. Additionally, this study presents a clearly structured open training model that incorporates Verheijen's small-sided game (SSG) periodisation and Buchheit's long and short HIIT principles. This enhances the model's practical applicability and usability for coaches.

Several limitations should be acknowledged. First, the inclusion of players from two distinct age categories (U16 and U17) may have introduced developmental variance. This age difference became particularly evident in the baseline measurement, where a notable difference in mean scores was observed. Furthermore, the lower training response observed in the U-17 team may reflect the residual effects of the previous season and suggest that these players had already achieved a certain level of aerobic adaptation. Conducting the study during the preseason period, when players were transitioning from the off-season, may have contributed to increased inter-individual variance and variability in training adaptations among participants. Additionally, the lack of randomization, stemming from the teams competing in different age categories, and the absence of a control group in the experimental design can be considered additional sources of bias in the present study. Future research should incorporate objective measures of biological age to better account for these factors. Second, although V_{IFT} is a robust and reliable performance indicator, the addition of internal load metrics such as heart rate recovery, blood lactate levels, or perceived exertion would have strengthened the physiological interpretation of training responses. Finally, this study was limited to short-duration intervention. Further research is required to investigate the chronic adaptations, recovery kinetics and cumulative effects of combining HIIT and SSG methods throughout a whole season.

Practical Recommendations

This study provides evidence that, for elite youth football players, incorporating high-intensity interval training into a periodised small-sided game model enhances intermittent running performance more effectively than SSG training alone. The superior gains observed in the SSG+HIIT group suggest that such a hybrid model can bridge the gap between technical-tactical and physiological development.

Practical Implications

During the preseason, coaches should consider incorporating 2–3 HIIT sessions per week at intensities of ≥ 90% of individual VIFT scores. Individualizing HIIT prescription according to VIFT ensures precise targeting of aerobic capacity without overloading players. Periodizing HIIT within the context of football-specific SSGs enables maintenance of technical and tactical engagement while eliciting aerobic adaptations. Equalizing overall training loads between intervention groups is critical for accurately assessing the impact of training content on performance outcomes.

In conclusion, the integrated SSG+HIIT training model offers a time-efficient, sport-specific, and physiologically robust framework for developing aerobic fitness in elite youth football players.

Limitations and Future Directions

Despite its contributions, this study is not without limitations. First, only healthy U16 and U17 age group male soccer players were included in the study, which limited the generalization of the findings to female athletes in the same age group or to healthy soccer players in other age groups. Accordingly, external validity is limited to healthy young men with similar training levels. On the other hand, age-specific physical and physiological differences can affect performance during the test and therefore the results. Also, the use of two different age categories, U16 and U17, together may introduce differences due to development/maturation, which was also seen in the difference in baseline (pre-test) values. Therefore, future research could check biological maturation assessments with indicators such as PHV, as there may be differences in biological maturation at ages such as U16-U17, to better explain the development shown [41].

Secondly, the fact that the application was carried out in the pre-season period and was short (40 days) may lead to some results. Training responses may be more variable in players who have just come out of the off-season, which may increase inter-athlete variance. Furthermore, inferences regarding chronic adaptations, recovery kinetics, and cumulative effects throughout the season were limited. Future research could examine outcomes such as chronic adaptation, recovery, and "load accumulation-injury risk" by following up throughout the season.

Thirdly, the lack of randomization due to the teams being in different age categories is a drawback. Future research could, if possible, use randomized assignment within the same age group or at least methods such as "matched groups" or "cluster randomization," and also reduce bias with a real control condition/additional control groups.

Finally, only VIFT was used as a performance outcome. While VIFT is a strong indicator, its physiological interpretive power is limited because internal load indicators such as lactate, RPE, and HR were not included. Future studies could provide a clearer answer to the question "Why did they improve more?" by including HR, HRR, lactate, RPE, and, if possible, GPS metrics (HSR, sprint count, acc./dec., etc.). Furthermore, in the future, they could classify players according to their response profiles (e.g., %ΔVIFT) and show which profiles benefit most from SSG+HIIT. Another important aspect is the examination of football-specific positional roles (e.g., midfielders, forwards, fullbacks, wingers), as their physical and physiological requirements differ depending on the position. Including these factors will increase the validity of the results obtained and provide more comprehensive information for coaches.

The integrated SSG+HIIT training model offers a time-efficient, sport-specific, and physiologically robust framework for developing aerobic fitness in elite youth football players. Future research should expand on these findings by exploring long-term adaptations, recovery kinetics, and injury risk mitigation.

Declarations

Ethics approval and consent to participate

The study was approved by the Atatürk University Ethics Committee (E-70400699-050.02.04-2500239949) and was conducted in accordance with the ethical principles of the Declaration of Helsinki. Because all participants were minors (< 17 years), written informed consent to participate was obtained from their parents or legal guardians, and age-appropriate information and verbal assent were obtained from the children themselves. Before enrolment, participants, their parents/legal guardians, and coaches were provided with detailed information about the purpose of the research, the procedures, and the possible risks. Participants' personal information and research data were protected in accordance with confidentiality principles; all data were anonymized and securely stored.

Consent for publication

Not applicable

Competing interests

The authors declare no competing interests.

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Author Contribution

All authors have contributed sufficiently to the manuscript and have approved the final version. Concept and design (OS, EG, HİC); Data collection (OS); Analysis (VGG); Interpretation (OS, EG, HİC, AGY, SG, AEC, VVG); Draft preparation (all authors); Revision (GB, VGG); Final approval (all authors) and acceptance of responsibility (all authors) stages.

Data availability

The data sets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Tables

Tables 1 and 2 are available in the Supplementary Files section.

Figures

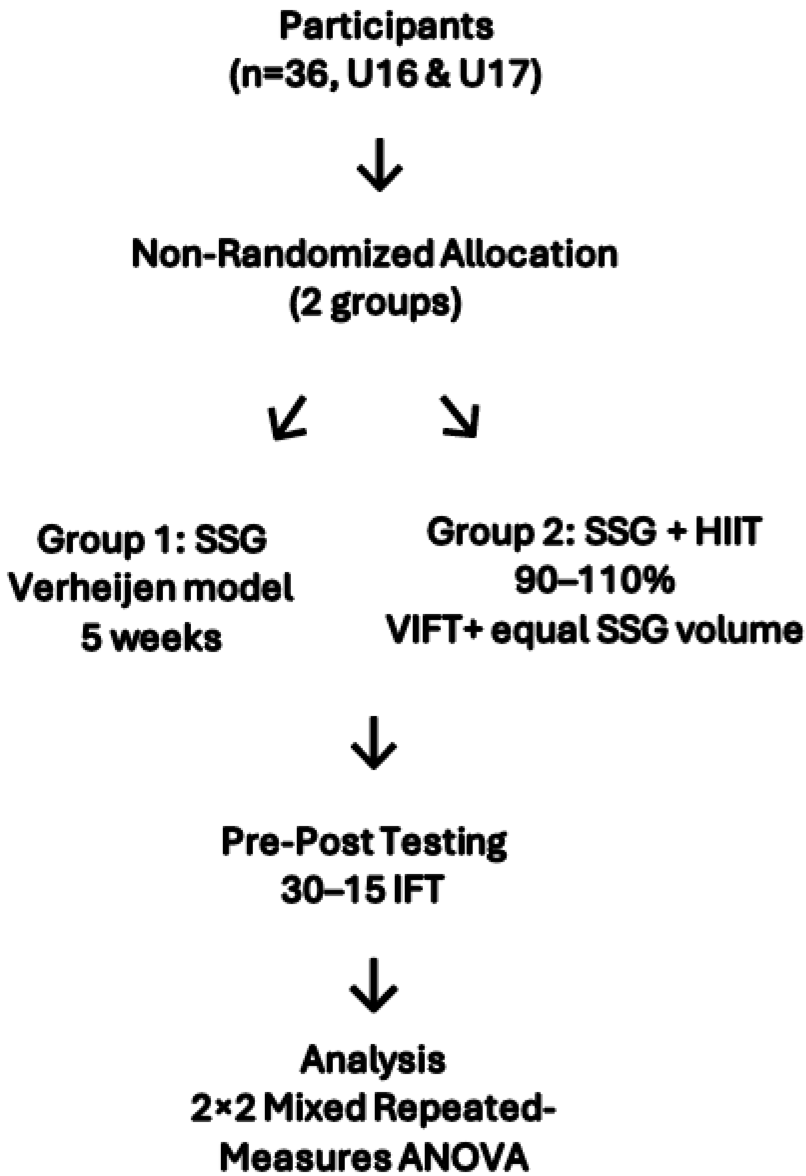

Figure 1

Research design flowchart

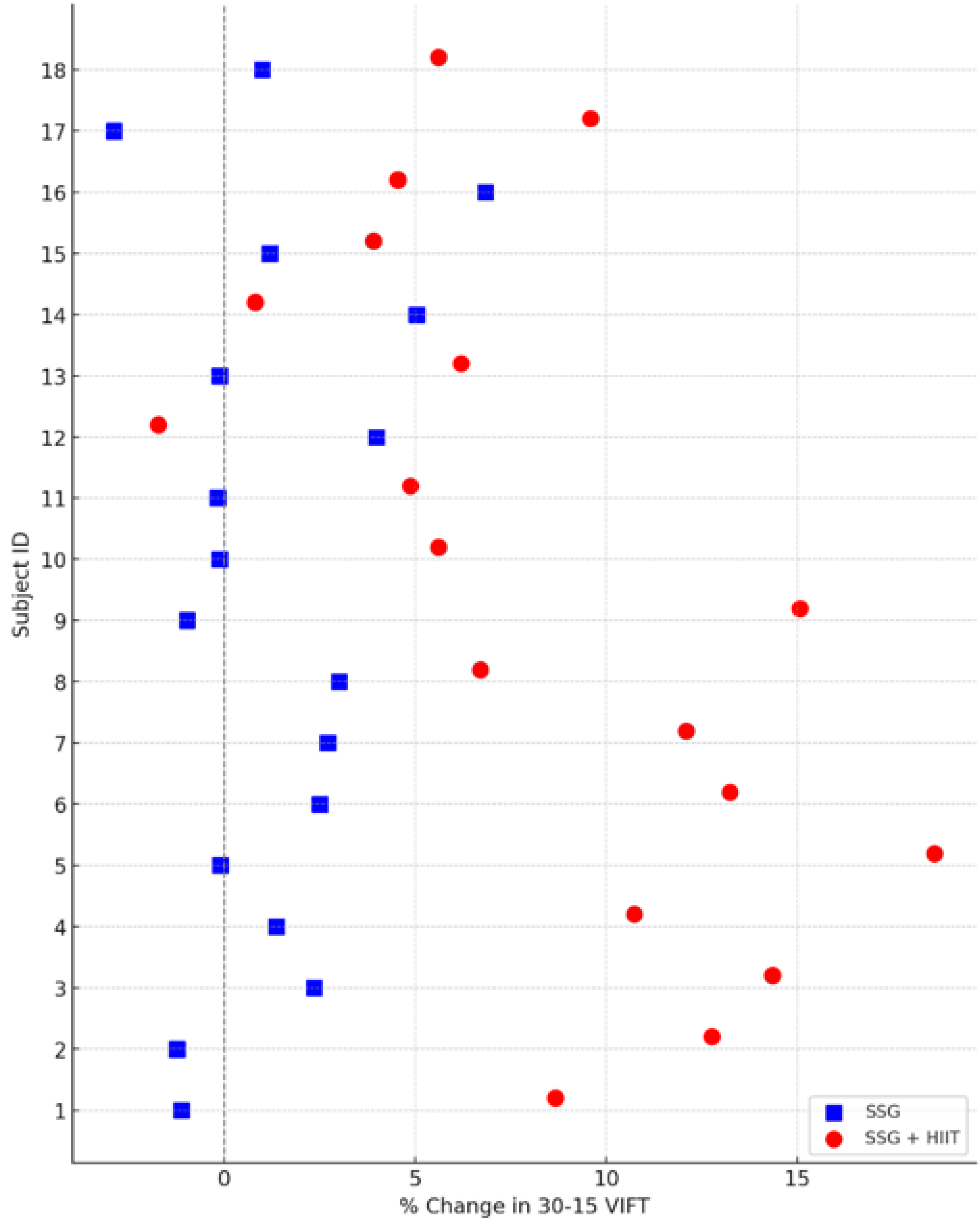

Figure 2

Scatter plot of individual % changes in 30-15 V_{IFT}

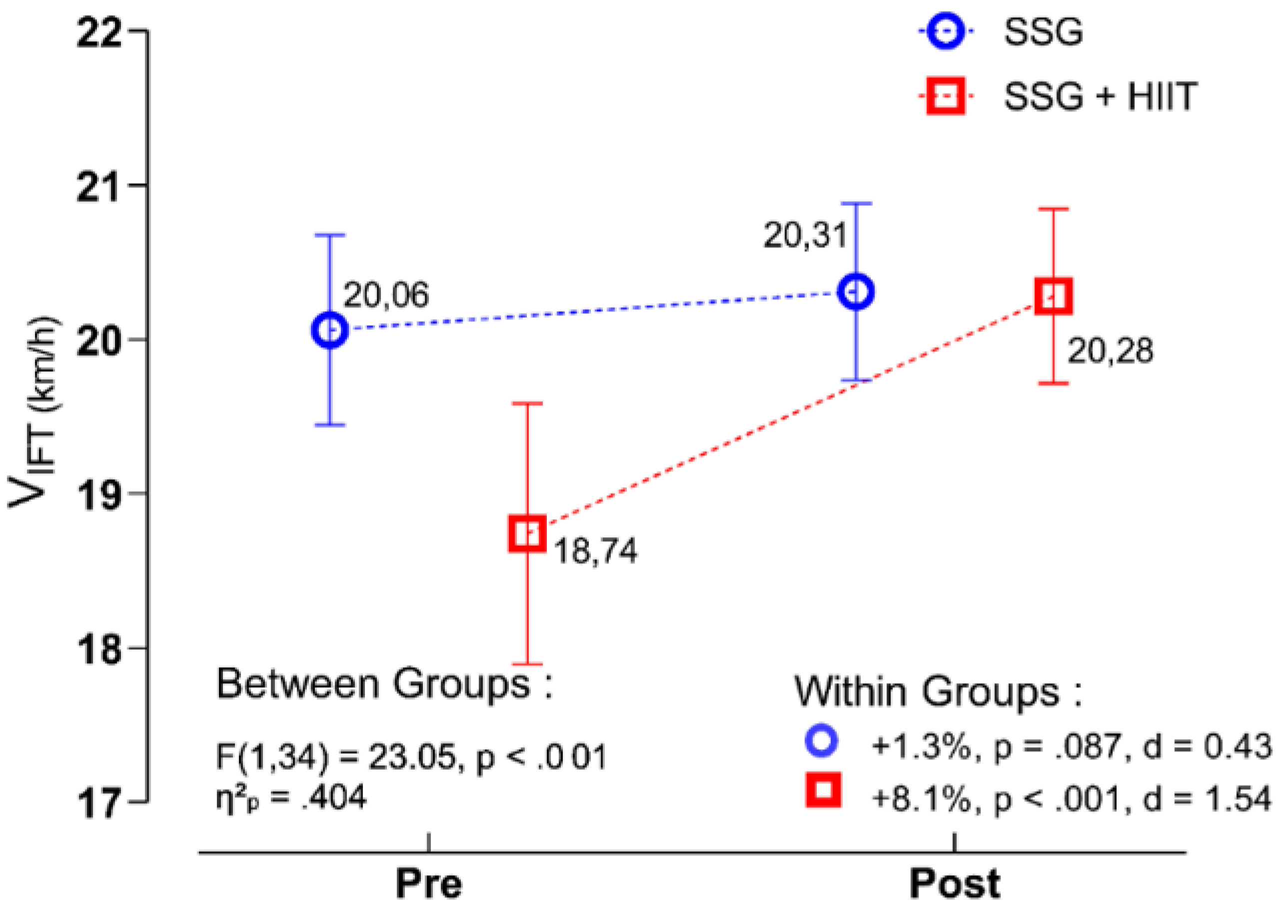

Figure 3

Within-group and between-group differences

Supplementary Files

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