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Research article

Can Maturation Level Influence Long-Term Physiological and Physical Adaptations in Youth Female Soccer Players Exposed to Combined Sided Games and HIIT? A Comparison Across Maturation Statuses

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Abstract

The aim of this study was to assess the effects of a 6-week high-intensity interval training combined with small-sided games (HIIT&SSG) program on maximal strength, sprint performance, and aerobic capacity in female athletes and to examine how these effects vary across different stages of maturity (pre-, mid-, and post-peak height velocity [PHV]). Specifically, we sought to determine whether the improvements in performance outcomes were consistent across maturity groups or if the training effects differed based on the athletes' maturity status. Fifty-four female soccer players (aged 9-16 years) were categorized into pre-PHV, mid-PHV, and post-PHV maturity groups. Participants were randomly assigned to either an HIIT&SSG group (n = 27) or a control group (n = 27). The HIIT&SSG group performed two additional training sessions per week, focusing on 2v2 small-sided games and individualized high-intensity runs at 85% of their final velocity during the 30-15 Intermittent Fitness Test (VIFT). Control continued their regular training routines. Pre- and post-intervention assessments included isometric mid-thigh pull (IMTP) for maximal strength, 30-meter sprint time, and VIFT for aerobic capacity. Pre- and post-intervention assessments included isometric mid-thigh pull (IMTP) for maximal strength, 30-meter sprint time, and VIFT for aerobic capacity. The HIIT&SSG group demonstrated large effect sizes for IMTP (ηp^2 = 0.996), 30-m sprint time (ηp^2 = 0.991), and VIFT (ηp^2 = 0.878), with substantial improvements in strength and aerobic capacity in mid- and post-PHV athletes. For IMTP, significant group differences were observed in mid-PHV (p = 0.021) and post-PHV athletes (p < 0.001). Post-PHV athletes also showed significantly faster 30-meter sprint times post-intervention (p < 0.001). VIFT improvements were significant across all maturity stages (Pre-PHV: p = 0.045; Mid-PHV: p < 0.001; Post-PHV: p < 0.001). Effect sizes for group differences ranged from moderate to large (ηp^2 = 0.540 to ηp^2 = 0.928). HIIT&SSG program is effective in enhancing maximal strength, sprint performance, and aerobic capacity, with particularly benefits for mid- and post-PHV athletes. However, the improvements in sprint performance were primarily observed in post-PHV athletes, which may limit the generalizability of these effects to all maturity stages.

Key words: Interval training; girl; football; maturation; peak height velocity.

Introduction

High-intensity interval training (HIIT) is an effective method for improving the performance of youth soccer players. Studies have shown that HIIT can enhance endurance, acceleration, agility, and repeated sprint ability in young athletes (Howard and Stavrianeas, 2017; Michailidis et al., 2023). HIIT has been shown to be as effective as small-sided games (SSG) in improving endurance and soccer-specific performance variables, although its impact on neuromuscular performance appears limited, possibly due to its less targeted focus on such outcomes (Kunz et al., 2019). When combined with SSG, HIIT can lead to improvements in physical performance and technical skills, regardless of the order in which they are performed, although performing HIIT before SSG may result in lower perceived exertion and greater physical enjoyment among players (Arslan et al., 2021).

When examining the relationship between physical training and youth athletes, maturation emerges as a biological factor, as it influences the rate and pattern of physical and physiological changes that occur during adolescence, such as increases in muscle mass, bone density, and cardiovascular capacity. These changes, in turn, may impact how athletes adapt to various forms of exercise, particularly as certain physiological systems mature at different rates during growth. For example, while some studies have found that maturation has little impact on the intensity experienced during SSGs—as demonstrated by (da Silva et al., 2011), who found no significant correlation between maturation level and either exercise intensity or ball involvement—other studies report contrasting findings. In particular, it has been observed that in HIIT, age at peak height velocity (a marker of maturation) positively correlates with higher training intensity in soccer-specific tasks (García-Ceberino et al., 2024). Additionally, maturation appears to substantially influence match-running performance in highly trained under-15 soccer players, particularly among attacking players (Buchheit and Mendez-Villanueva, 2014). The discrepancies in these findings may arise from differences in study design, the methods for assessing training intensity, or the maturity classifications of participants, which can all contribute to differing interpretations of how maturation influences training response and performance outcomes in youth athletes.

Research also indicates that maturation is strongly associated with various physical performance indicators, including countermovement jump height, sprint time, and change-of-direction speed (Lloyd et al., 2015; Hermassi et

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al., 2024). Early and average maturing players tend to outperform their late-maturing counterparts in height, weight, and power-based activities such as sprinting and jumping (Itoh and Hirose, 2020). However, the impact of maturation on long-term adaptations to training may vary. In girl football players, HIIT led to improvements in endurance and speed for some maturity groups, but also caused decrements in repeated-sprint ability and change-of-direction speed for others (Wright et al., 2016). Similarly, in insulin-resistant schoolchildren, early and normal maturation groups showed different responses to HIIT in metabolic, body composition, and performance variables (Alvarez et al., 2017).

It is widely accepted that the maturation effect is relevant when conducting physical training in youth female soccer players, due to the significant physiological and developmental changes that occur during adolescence (Emmonds et al., 2017). These changes necessitate the implementation of individualized training loads and progressions to ensure both safety and effectiveness, as the same training stimulus can have vastly different outcomes depending on an athlete's stage of maturation. Individualized approaches are essential to account for variations in physical capacity, hormonal changes, and neuromuscular development across different maturational stages, ensuring that each player is receiving an appropriate stimulus. While extensive research has explored the impact of maturation on adaptations to strength and plyometric training (Ramirez-Campillo et al., 2023), the literature remains limited when it comes to aerobic-based modalities such as HIIT and SSG. This gap in research can be significant, as aerobic fitness is a crucial component of overall athletic performance, especially in team sports like soccer, where both endurance and intermittent high-intensity efforts are essential. Moreover, the physiological adaptations that occur during maturation—such as changes in cardiovascular capacity, energy system efficiency, and metabolic responses—can vary across different training modalities. Without an understanding of how maturation interacts with aerobic training approaches like HIIT and SSG, we risk overlooking critical aspects describing how these methods might differently affect athletes at various stages of development. Therefore, further investigation is essential to optimize training protocols, ensuring they are not only effective but also developmentally appropriate and individualized to support performance enhancement in youth female soccer players. In light of this need, the present study aimed to compare the effects of a 6-week HIIT program combined with SSGs (HIIT&SSG) on maximal strength, sprint performance, and aerobic capacity in female athletes at different stages of maturation: pre-, mid-, and post-peak height velocity (PHV). Given the physiological and neuromuscular development that occurs during adolescence, we expect post-PHV athletes to show the greatest improvements in strength and sprint performance due to their more advanced stage of maturation.

Methods

Participants

The study included a total of 54 female soccer players, aged 9 to 16 years, each with at least one year of consistent soccer experience and engaging in regular training. The overall sample exhibited a mean decimal age of 12.76 ± 1.63 years, a stature of 154.66 ± 9.45 cm, a body mass of 53.30 ± 16.90 kg, a sitting height of 80.21 ± 6.64 cm, and a leg length of 73.93 ± 5.92 cm. Participants were classified based on their maturity offset relative to PHV as: Pre-PHV (≤−0.75 years before PHV), Mid-PHV (within ±0.75 years of PHV), and Post-PHV (≥0.75 years after PHV). For detailed demographic and anthropometric characteristics segmented by these maturity classifications and group allocation (HIIT vs. Control), please consider Table 1.

Participants for the study were selected based on specific inclusion and exclusion criteria to ensure a suitable and balanced cohort. Inclusion criteria primarily focused on female individuals aged 9 to 16 years who had at least one year of soccer experience, and engaged in regular training. Crucial exclusion criteria included the presence of any injury at the commencement of the study that would impede safe and full participation, non-adherence to the assigned intervention, and absence from either of the two designated assessment time points. From an initial pool of 59 identified participants, 5 were excluded due to existing injuries, leading to a final study sample of 54 participants (Figure 1).

The participants trained with local-level teams, typically engaging in training sessions two to three times per week. Each session lasted between 70 and 90 minutes and primarily focused on technical skill development and strategic or tactical training. These were complemented by specific conditioning exercises aimed at improving coordination, speed, and reaction time. Participants were recruited from various clubs across the region. Allocation to either the experimental or control group was balanced within each team to minimize potential bias related to training specificity and context.

Before any data collection, informed consent was obtained from both the players and their legal guardians. The consent process clearly outlined the study's purpose, procedures, potential risks and benefits, and the participants' right to withdraw at any time without penalty.

Table 1. **Mean ± standard deviation of participant characteristics by maturity classification and group allocation.**

	HIIT (n=27)			Control (n=27)		
Characteristics	**Post Mature**	**Mid Mature**	**Pre Mature**	**Pre Mature**	**Pre Mature**	**Pre Mature**
Decimal Age (years)	15.35±0.89	12.18±1.25	11.75±0.73	14.86±1.63	12.30±1.48	11.96±0.22
Maturity Offset (years)	1.11±0.17	0.40±0.44	-1.29±0.28	0.98±0.23	0.23±0.23	-1.09±0.35
Stature (cm)	166.44±2.87	157.83±7.50	142.72±6.42	162.72±7.03	156.44±5.12	144.94±7.42
Body Mass (kg)	75.60±2.05	56.96±8.28	34.39±3.25	69.76±5.17	52.69±8.23	36.44±2.89
Sitting Height (cm)	88.56±1.01	81.72±3.65	73.33±2.92	85.50±6.27	81.78±4.41	74.50±3.73
Leg Length (cm)	79.17±0.77	74.94±4.09	70.83±4.19	76.83±3.20	74.83±2.94	71.94±4.42

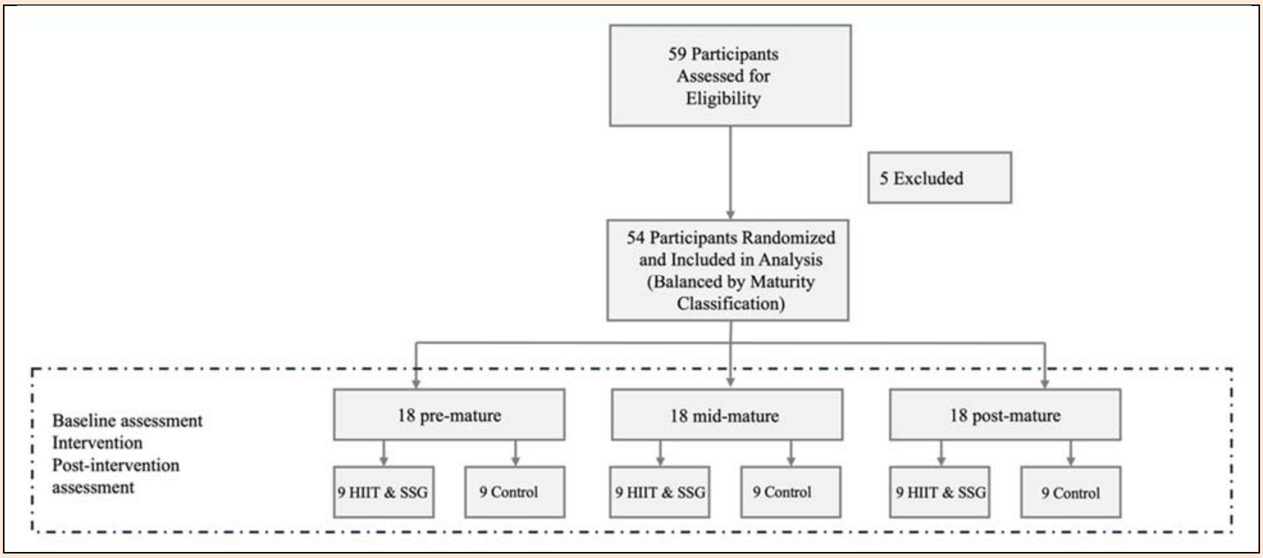

Figure 1. Flow of participants through the study.

In addition, assent was obtained directly from the youth participants to ensure their understanding and voluntary agreement to take part in the study. All research procedures were approved by the Sichuan Normal University Institutional Review Board (2025LS0041), and the study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki.

Experimental design

This study employed a short-term, parallel-group experimental design to investigate the effects of HIIT & SSG interventions on youth female soccer players. Within each maturity group, participants were randomly assigned to one of two groups groups: a HIIT&SSG group, or a control group. Participants were initially classified into different maturity groups based on their PHV and then randomly assigned to one of two groups: a HIIT+SSG group or a control group. Randomization was carried out using a computer-generated random sequence, ensuring that each participant had an equal chance of being assigned to either group. This process aimed to maintain balance across all groups in terms of maturity status and baseline physical fitness. The assignment ensured a balanced distribution of maturity statuses across all groups. All participants engaged in regular soccer-specific training three non-consecutive days per week. In addition to their regular soccer training, the HIIT+SSG group performed specific high-intensity interval training sessions integrated with small-sided games on two non-consecutive days when soccer training, preceding the standard training session conducted by their coaches. The control group continued with their standard soccer training regimen only, serving as a baseline for comparison. One week prior to the initiation of the 6-week training intervention, and one week after the end of the intervention period, the players were assessed for their physical fitness.

Training programme

The intervention for the HIIT+SSG group was designed to progress over six consecutive weeks, with two training sessions delivered per week on non-consecutive days. Each session commenced with a standardized 10-minute dynamic warm-up protocol, focusing on active mobility, light cardiovascular activity, and soccer-specific movements. Each training session for the HIIT+SSG group was structured into two primary components: Participants first engaged in 2v2 small-sided games. These games were played on a pitch of 20x15 m (75 m^2/player). Rest was provided between sets. After completing the SSGs, the HIIT was performed at a predetermined percentage of the participants' individual VIFT (Final Velocity achieved during the 30-15 Intermittent Fitness Test). The VIFT was assessed at baseline and used to individualize the target running velocity for each player, ensuring that the prescribed intensity (85% VIFT) was consistently maintained throughout the intervention. Runs were conducted over marked distances with audio cues to guide pacing, and rest was provided between sets. The volume and intensity of the HIIT&SSG intervention were progressively increased over the six-week period to optimize training adaptations. Table 2 provides a detailed overview of the training progression across the intervention period. The six-week program was structured into three 2-week blocks to facilitate progressions. During weeks 3-4, one additional set was added per session, while in weeks 5-6, the duration of each set was increased by one minute.

The control group continued their regular training routines, participating in the same field sessions as the other players, with the exception of not engaging in the additional experimental training. All training sessions were led and closely supervised by the research team who ensured adherence to the prescribed intensity, duration, and recovery periods. Research team provided verbal encouragement to maintain participant motivation. The control group had only their regular soccer-specific training schedules without additional prescribed interventions.

Assessments

Beyond anthropometric assessments, a short battery of physical fitness tests was conducted to evaluate

Table 2. Six-week progression of High-Intensity Interval Training and Small-Sided Game (HIIT&SSG) Intervention.

Week	Component	Sets	Duration per Set	Intensity / Format	Recovery Between Sets
1-2	Small-Sided Game (2v2)	2	2 minutes	20x15m pitch, mini-goals, no offside, target RPE 8-9	2 minutes active recovery
	High-Intensity Runs	2	2 minutes	85% VIFT (continuous)	3 minutes passive recovery
3-4	Small-Sided Game (2v2)	3	2 minutes	20x15m pitch, mini-goals, no offside, target RPE 8-9	90 seconds active recovery
	High-Intensity Runs	3	2 minutes	85% VIFT (continuous)	3 minutes passive recovery
5-6	Small-Sided Game (2v2)	3	3 minutes	20x15m pitch, mini-goals, no offside, target RPE 8-9	90 seconds active recovery
	High-Intensity Runs	3	3 minutes	85% VIFT (continuous)	2.5 minutes passive recovery

RPE: rating of perceived exertion; VIFT: Final Velocity achieved during the 30-15 Intermittent Fitness Test

performance indicators relevant to youth female soccer players. These assessments were performed under standardized conditions. All tests were executed on a single day, both one week prior to and immediately following the 6-week training intervention, taking place in the afternoon to control for diurnal variations. Participants were instructed to arrive well-rested, adequately hydrated, and to avoid strenuous physical activity for at least 24 hours before testing. Each testing session began with a standardized 10-minute warm-up protocol, comprising light aerobic activity, dynamic stretching, and specific low-intensity movements related to the subsequent tests.

Anthropometric assessment

Anthropometric evaluations were conducted by research team following standardized procedures. Stature was measured to the nearest 0.1 cm using a wall-mounted stadiometer (Seca 213, Germany). Participants stood barefoot with heels together, shoulders relaxed, and head in the Frankfort plane, taking a deep inhalation while full extension was applied to the trunk. Body mass was recorded to the nearest 0.1 kg using a calibrated digital scale (Seca 813, Germany), with participants wearing only light clothing and no footwear. Sitting height was measured to the nearest 0.1 cm using an anthropometric chair or a customized sitting height apparatus. Participants sat upright with their back firmly against the vertical board, hips and knees at 90∘ flexion, and head in the Frankfort plane, ensuring maximum vertebral column extension. Leg length was subsequently calculated as the difference between stature and sitting height. All measurements were taken twice, and the average value was used for analysis; if the two measures differed by more than a predefined tolerance (e.g., 0.5 cm for linear measures or 0.2 kg for mass), a third measurement was taken, and the median value was used.

The biological maturity offset for each female participant was estimated using the Mirwald et al. (2002) equation, a commonly applied method in growth and maturation research. This calculation incorporated decimal age, standing height (stature), sitting height, and body mass. Specifically, leg length was derived by subtracting sitting height from standing height. The formula employed was:

Maturity Offset (years) = −9.376 + (0.0001882 × Leg Length × Sitting Height) + (0.0022 × Decimal Age × Leg Length) + (0.005841 × Decimal Age × Sitting Height) − (0.002658 × Decimal Age × Body Mass) + (0.07693 × (Body Mass/Stature×100)).

A positive maturity offset value indicates that the individual has passed their PHV, while a negative value signifies that PHV has not yet been reached.

Following the calculation of maturity offset, participants were categorized into three maturity groups based on established thresholds: Post Mature, defined as a maturity offset ≥+0.75 years, indicating the individual has reached PHV at least 9 months prior; Mid Mature, characterized by a maturity offset between −0.75 and +0.75 years, signifying being within 9 months of PHV; and Pre Mature, identified by a maturity offset ≤−0.75 years, suggesting PHV is still at least 9 months in the future. This classification provides a standardized approach to group individuals based on their biological maturity status relative to PHV.

Isometric mid-thigh pull (IMTP)

Isometric mid-thigh pull (IMTP) performance was assessed in female youth soccer players utilizing a specialized crane scale system. A specific crane scale (CS, with a capacity of 300 kg and measuring in 0.1 kg increments) was rigidly affixed to an unyielding frame. This methodological arrangement adhered to the guidelines outlined in the initial validation research for this procedure (Urquhart et al., 2018), thereby promoting measurement consistency and reliability. Prior to each trial, participants were guided into a standardized posture: feet placed at shoulder-width directly below the measurement device, knees flexed to approximately 135∘, and hips subtly abducted. The female soccer players gripped a padded bar, linked to the crane scale, using an overhand, pronated grasp, maintaining full arm extension. Verbal cues instructed participants to exert maximal upward force with utmost rapidity, simulating a jump against the fixed resistance of the crane scale. Each isometric pull was sustained for a duration of 5 seconds, with consistent verbal encouragement offered across the entire duration. Following a single familiarization attempt, three maximal effort repetitions were executed, with a 2-minute inter-trial recovery period. The peak force, normalized to body mass (reported in Newtons per kilogram), from the strongest valid trial was selected for subsequent analysis. The coefficient of variation for the IMTP trials was 3.7%.

Sprint test at 30-m

To evaluate dynamic sprint performance, particularly involving a change of direction, a 30-meter sprint test was administered. Participants initiated their effort from a standing start, with their preferred foot positioned at the starting line. Sprint timings throughout the trial were precisely captured using the Photo Finish mobile application (Marco-Contreras et al., 2024). The camera for the Photo Finish application was strategically positioned at the center of the course to capture data for the entire sprint distance. The camera was mounted on a tripod at a height of approximately 1.5 meters, ensuring a clear, unobstructed view of the athletes' movements. Markers were placed along the sprint track to clearly identify the target points for further evaluation. This application was strategically set up to record splits at the initial starting line, a 5-meter mark (which also served as a turning point), and the final 30-meter finish line. The reliability and validity of the Photo Finish application have been previously confirmed through comparisons with traditional photocell timing systems (Marco-Contreras et al., 2024). Each participant completed two successful trials, with the average time across these attempts used for subsequent analysis. The coefficient of variation for the sprint trials was 4.3%.

Final velocity at 30-15 intermittent fitness test

To quantify the aerobic capacity and intermittent endurance pertinent to soccer, the 30-15 Intermittent Fitness Test (30-15 IFT) was administered. This assessment's core purpose was to gauge the players' capacity for repeated high-intensity efforts interspersed with brief recovery periods, a reflection of the physiological demands inherent to the sport. The test protocol involved participants shuttling back and forth across a 40-meter distance for 30 seconds of work, immediately followed by 15 seconds of passive recovery. The initial running velocity was set at 8 km/h, and the speed incrementally increased by 0.5 km/h at the commencement of each subsequent 30-second stage. This progressive increase in pace demanded continuous adaptation from the athletes. The test concluded when a participant could no longer maintain the prescribed speed for two consecutive stages, despite receiving verbal encouragement, or voluntarily ceased participation due to fatigue. The primary outcome derived from the 30-15 IFT was the final velocity achieved (VIFT), expressed in km/h, which represented their maximal intermittent running speed. This VIFT served as a crucial indicator of aerobic fitness and was subsequently utilized to individualize training intensities.

Statistical analysis

An *a priori* power analysis was conducted using G*Power software (Version 3.1.9.7, Heinrich-Heine-Universität Düsseldorf, Germany). This calculation specifically targeted an F-test for a repeated measures ANOVA with a within-between interaction design (Time × Maturation × Group). For the analysis, an alpha level (α) was set at 0.05, a desired statistical power (1-β) at 0.80, and an estimated effect size (f=0.30). Considering the six distinct groups (three maturity classifications × two intervention groups) and two repeated measures (pre- and post-intervention), along with an assumed correlation of 0.50 among repeated measures, the analysis indicated a required total sample size of 48 participants to detect a statistically significant effect.

Prior to conducting the main analyses, the assumptions for parametric testing were thoroughly examined. Normality of data distribution was assessed using the Shapiro-Wilk test ($p>0.05$). The assumption of sphericity for the repeated measures factor was evaluated using Mauchly's test, with the Greenhouse-Geisser correction applied when sphericity was violated. A three-way mixed-model ANOVA was conducted to investigate the effects of training (Group: HIIT+SSG vs. Control), Maturation (Post Mature vs. Mid Mature vs. Pre Mature), and Time (Pre- vs. Post-intervention) on all dependent variables. Significant main effects or interactions were further explored using Bonferroni-adjusted post-hoc pairwise comparisons to identify specific differences. The level of statistical significance was set at $\alpha=0.05$. For all significant findings, partial eta squared ($\eta p2$) was calculated and reported as a measure of effect size, with values of 0.01, 0.06, and 0.14 representing small, medium, and large effects, respectively. All statistical analyses were performed using IBM SPSS Statistics software (Version 28.0.1.0, Armonk, NY: IBM Corp.).

Results

Table 3 presents the mean and standard deviation (± SD) of performance variables for the HIIT+SSG and Control groups, across three maturational levels (pre-PHV, mid-PHV, and post-PHV), at pre- and post-intervention time points.

Isometric mid-thigh pull test

The main effect of time was statistically significant, $F_{(1, 48)} = 12904.33$, $p < 0.001$, indicating a significant change in IMTP performance from pre- to post-intervention across all groups and maturational levels. The effect size, as measured by partial eta squared (ηp^2), was large ($\eta p^2 = 0.996$), indicating a very strong magnitude of effect. A significant two-way interaction was observed between time and allocation (group), $F_{(1, 48)} = 1947.67$, $p < 0.001$, with a large effect size ($\eta p^2 = 0.976$), reflecting a substantial interaction effect. Another significant two-way interaction was found between time and maturity classification, $F_{(2, 48)} = 658.71$, $p < 0.001$, with a large effect size ($\eta p^2 = 0.965$), suggesting a pronounced effect across different maturity groups. Furthermore, a significant three-way interaction was identified between time, allocation, and maturity classification, $F_{(2, 48)} = 149.12$, $p < 0.001$, also demonstrating a large effect size ($\eta p^2 = 0.861$), indicating a substantial combined effect. Figure 2 illustrates the mean percentage change in IMTP from pre- to post-intervention across different maturity classifications and allocation groups.

Group differences at each maturational level and time point

Post hoc comparisons per maturational level revealed that at Pre-PHV there was no significant difference in IMTP between the HIIT+SSG and Control groups ($p = 0.979$). Post-intervention, there was still no significant difference between groups ($F_{(1, 48)} = 1.47$, $p = 0.231$).

Table 3. Mean and standard deviation (± SD) of performance variables for the HIIT+SSG and Control groups, across three maturational levels (pre-PHV, mid-PHV, and post-PHV), at pre- and post-intervention time points.

		HIIT&SSG		Control	
Maturational status	**Outcome**	**Pre-intervention**	**Post-intervention**	**Post-intervention**	**Post-intervention**
Pre-PHV	**IMTP (kg)**	15.9 ± 1.0	17.5 ± 1.0	15.9 ± 0.9	16.8 ± 0.9
	VIFT (km/h)	13.8 ± 0.6	14.8 ± 0.5	14.1 ± 0.5	14.3 ± 0.5
	30-m Sprint (s)	5.18 ± 0.15	5.00 ± 0.14	5.19 ± 0.18	5.11 ± 0.18
Mid-PHV	**IMTP (kg)**	19.0 ± 1.1	22.1 ± 1.2	19.4 ± 1.2	20.6 ± 1.2
	VIFT (km/h)	15.4 ± 0.7	16.9 ± 0.6	15.3 ± 0.5	15.6 ± 0.3
	30-m Sprint (s)	4.97 ± 0.12	4.63 ± 0.10	4.91 ± 0.14	4.74 ± 0.14
Post-PHV	**IMTP (kg)**	21.8 ± 1.3	25.8 ± 1.4	21.9 ± 1.8	23.7 ± 1.8
	VIFT (km/h)	16.0 ± 0.6	17.5 ± 0.6	15.8 ± 0.6	16.0 ± 0.5
	30-m Sprint (s)	4.70 ± 0.17	4.35 ± 0.16	4.81 ± 0.12	4.63 ± 0.13

IMTP: isometric mid-thigh pull test; VIFT: final velocity at 30-15 Intermittent Fitness test; PHV: peak height velocity; HIIT&SSG: high-intensity interval training and small-sided games.

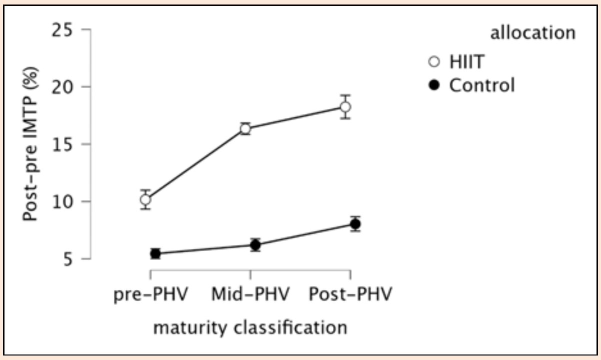

Figure 2. Post-pre Isometric Mid-Thigh Pull test (IMTP) percentage change (%) by allocation and maturity classification. PHV: peak height velocity

In the Mid-PHV, at pre-intervention, no significant difference was found between the HIIT+SSG and Control groups (p = 0.435). However, post-intervention, a significant difference emerged, with the HIIT+SSG group showing higher IMTP values compared to the Control group ($F_{(1, 48)}$ = 5.68, p = 0.021, Mean Difference = 1.43, 95% Confidence Interval, CI [0.22, 2.64]). Finally, at Post-PHV, at pre-intervention, there was no significant difference in IMTP between the HIIT+SSG and Control groups (p = .882). Post-intervention, a highly significant difference was observed, with the HIIT+SSG group demonstrating substantially greater IMTP values compared to the Control group (F(1, 48) = 12.62, p < 0.001, Mean Difference = 2.13, 95% CI [0.93, 3.34]).

Maturational differences within groups at each time point

In the HIIT+SSG Group, at Pre-intervention, there was a significant effect of maturity classification on IMTP ($F_{(2, 48)}$ = 51.61, p < 0.001, ηp^2 = 0.683), indicating a large effect size. Pairwise comparisons revealed significant differences between all maturational levels, namely, at Pre-PHV vs. Mid-PHV: Mid-PHV had significantly higher IMTP (Mean Difference = -3.07, p < 0.001, 95% CI [-4.52, -1.61]), at Pre-PHV vs. Post-PHV: Post-PHV had significantly higher IMTP (Mean Difference = -5.96, p < 0.001, 95% CI [-7.41, -4.50]), and at Mid-PHV vs. Post-PHV, Post-PHV had significantly higher IMTP (Mean Difference = -2.88, p < 0.001, 95% CI [-4.34, -1.43]). In the post-intervention, there was a significant effect of maturity classification on IMTP (F(2, 48) = 96.29, p < 0.001, ηp2 = 0.800). Pairwise comparisons also showed significant differences between all maturational levels, namely, Pre-PHV vs. Mid-PHV, Mid-PHV had significantly higher IMTP (Mean Difference = -4.55, p < .001, 95% CI [-6.04, -3.06]); at Pre-PHV vs. Post-PHV, Post-PHV had significantly higher IMTP (Mean Difference = -8.32, p < 0.001, 95% CI [-9.81, -6.83]), and at Mid-PHV vs. Post-PHV: Post-PHV had significantly higher IMTP (Mean Difference = -3.77, p < 0.001, 95% CI [-5.26, -2.28]).

In the control group, at pre-intervention, there was a significant effect of maturity classification on IMTP ($F_{(2, 48)}$ = 53.33, p < 0.001, ηp^2 = 0.690), indicating a large effect size. Pairwise comparisons revealed significant differences between all maturational levels, namely at Pre-PHV vs. Mid-PHV, Mid-PHV had significantly higher IMTP (Mean Difference = -3.51, p < 0.001, 95% CI [-4.97, -2.06]), at Pre-PHV vs. Post-PHV, Post-PHV had significantly higher IMTP (Mean Difference = -6.03, p < 0.001, 95% CI [-7.48, -4.57]), and at Mid-PHV vs. Post-PHV, Post-PHV had significantly higher IMTP (Mean Difference = -2.51, p < 0.001, 95% CI [-3.97, -1.06]). During the post-intervention, there was a significant effect of maturity classification on IMTP ($F_{(2, 48)}$ = 66.60, p < 0.001, ηp2 = 0.735, large). Pairwise comparisons also showed significant differences between all maturational levels at Pre-PHV vs. Mid-PHV, Mid-PHV had significantly higher IMTP (Mean Difference = -3.85, p < 0.001, 95% CI [-5.34, -2.36]), at Pre-PHV vs. Post-PHV, Post-PHV had significantly higher IMTP (Mean Difference = -6.92, p < 0.001, 95% CI [-8.41, -5.43]), and at Mid-PHV vs. Post-PHV, Post-PHV had significantly higher IMTP (Mean Difference = -3.06, p < 0.001, 95% CI [-4.55, -1.58]).

The 30-m sprint time

The main effect of time was statistically significant, $F_{(1, 48)}$ = 5491.19, p < 0.001, indicating a significant change in 30-m sprint time from pre- to post-intervention across all groups and maturational levels. The effect size was large (ηp2 = 0.991). A significant two-way interaction was observed between time and allocation (group), F(1, 48) = 620.51, p < 0.001, with a large effect size (ηp2 = 0.928). Another significant two-way interaction was found between time and maturity classification, $F_{(2, 48)}$ = 207.38, p

< 0.001, with a large effect size (ηp2 = 0.896). Furthermore, a significant three-way interaction was identified between time, allocation, and maturity classification, $F_{(2, 48)}$ = 28.14, $p < 0.001$, also demonstrating a large effect size (ηp2 = 0.540). Figure 3 illustrates the mean percentage change in sprint performance from pre to post-intervention across different maturity classifications and allocation groups.

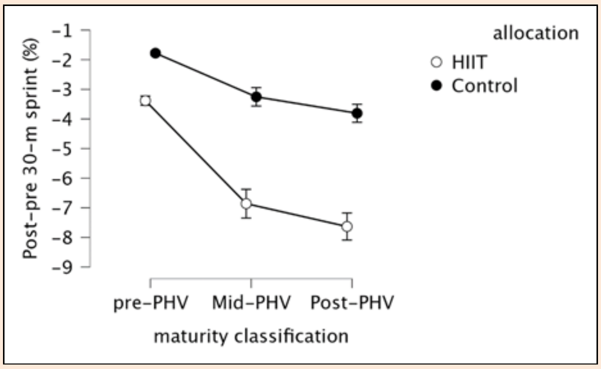

Figure 3. Post-pre 30-m sprint time percentage change (%) by allocation and maturity classification. PHV: peak height velocity.

Group differences at each maturational level and time point

At pre-intervention, pre-PHV, there was no significant difference in 30-m sprint time between the HIIT+SSG and Control groups (p = .863). Post-intervention, there was still no significant difference between groups ($F_{(1, 48)}$ = 1.98, p = 0.166). In the Mid-PHV, at pre-intervention, no significant difference was found between the HIIT+SSG and Control groups (p = 0.373). Post-intervention, there was no significant difference between groups ($F_{(1, 48)}$ = 2.88, p = 0.096). Finally, at Post-PHV, at pre-intervention, there was no significant difference in 30-m sprint time between the HIIT+SSG and Control groups (p = 0.149). However, post-intervention, a highly significant difference was observed, with the HIIT+SSG group demonstrating a significantly faster 30-m sprint time compared to the Control group ($F_{(1, 48)}$ = 16.61, $p < 0.001$, Mean Difference = -0.28, 95% CI [-0.42, -0.14]).

Maturational differences within groups at each time point

Considering the HIIT+SSG group, at pre-intervention, there was a significant effect of maturity classification on 30-m sprint time ($F_{(2, 48)}$ = 23.03, $p < 0.001$, ηp2 = 0.490, large). Pairwise comparisons revealed significant differences between all maturational levels, namely, comparing Pre-PHV vs. Mid-PHV, Mid-PHV had significantly faster sprint times (Mean Difference = 0.21, p = 0.012, 95% CI [0.04, 0.39]). Moreover, at Pre-PHV vs. Post-PHV, Post-PHV had significantly faster sprint times (Mean Difference = 0.48, $p < 0.001$, 95% CI [0.30, 0.65]). Also the comparison Mid-PHV vs. Post-PHV showed Post-PHV had significantly faster sprint times (Mean Difference = 0.26, p = 0.001, 95% CI [0.09, 0.44]). At post-intervention, there was a significant effect of maturity classification on 30-m sprint time ($F_{(2, 48)}$ = 46.29, $p < 0.001$, ηp2 = .659). Pairwise comparisons also showed significant differences between all maturational levels, namely, Pre-PHV vs. Mid-PHV, Mid-PHV had significantly faster sprint times (Mean Difference = 0.38, $p < 0.001$, 95% CI [0.21, 0.55]). Also, Pre-PHV vs. Post-PHV showed Post-PHV had significantly faster sprint times (Mean Difference = 0.66, $p < 0.001$, 95% CI [0.49, 0.83]). Finally, Mid-PHV vs. Post-PHV, Post-PHV had significantly faster sprint times (Mean Difference = 0.28, p = 0.001, 95% CI [0.11, 0.45]).

In the Control Group, at Pre-intervention, there was a significant effect of maturity classification on 30-m sprint time ($F_{(2, 48)}$ = 16.22, $p < 0.001$, ηp2 = 0.403, large). Pairwise comparisons revealed significant differences between all maturational levels, namely Pre-PHV vs. Mid-PHV, Mid-PHV had significantly faster sprint times (Mean Difference = 0.29, $p < 0.001$, 95% CI [0.11, 0.46]). Also, Pre-PHV vs. Post-PHV, Post-PHV had significantly faster sprint times (Mean Difference = 0.39, $p < 0.001$, 95% CI [0.21, 0.56]). However, at Mid-PHV vs. Post-PHV, no significant difference was found between Mid-PHV and Post-PHV (p = 0.513). At post-intervention, there was a significant effect of maturity classification on 30-m sprint time ($F_{(2, 48)}$ = 25.95, $p < .001$, ηp2 = 0.519, large). Pairwise comparisons showed significant differences, namely, Pre-PHV vs. Mid-PHV, the Mid-PHV had significantly faster sprint times (Mean Difference = 0.36, $p < 0.001$, 95% CI [0.19, 0.53]). Moreover, Pre-PHV vs. Post-PHV, the Post-PHV had significantly faster sprint times (Mean Difference = 0.48, $p < 0.001$, 95% CI [0.31, 0.65]). However, at Mid-PHV vs. Post-PHV, no significant difference was found between Mid-PHV and Post-PHV (p = 0.270).

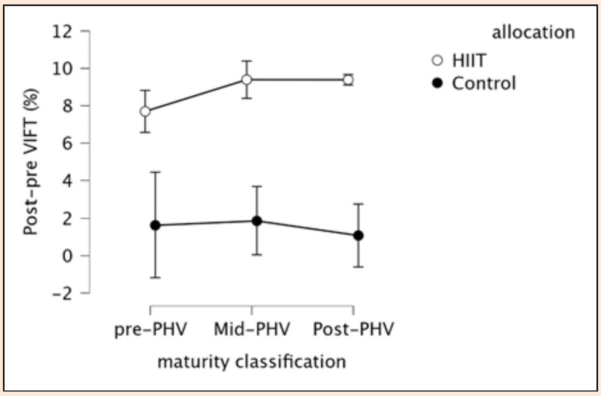

Figure 4. Post-pre final velocity at 30-15 Intermittent Fitness Test (VIFT) percentage change (%) by allocation and maturity classification. PHV: peak height velocity

Final velocity at 30-15 intermittent fitness test

The main effect of time was statistically significant, $F_{(1, 48)}$ = 344.20, $p < 0.001$, indicating a significant change in VIFT from pre- to post-intervention across all groups and maturational levels. The effect size was large (ηp2 = 0.878). A significant two-way interaction was observed between time and allocation (group), $F_{(1, 48)}$ = 175.61, $p < 0.001$, with a large effect size (ηp2 = .785). No significant two-way interaction was found between time and maturity classification, $F_{(2, 48)}$ = 2.78, p = 0.072, with a small effect size (ηp2 = 0.104). Furthermore, no significant three-way interaction was identified between time, allocation, and maturity classification, $F_{(2, 48)}$ = 3.07, p = 0.055, with a small effect size (ηp2 = 0.114). Figure 4 shows the mean percentage change in VIFT from pre to post-intervention across different maturity classifications and allocation groups.

Group differences at each maturational level and time point

At Pre-PHV, pre-intervention, there was no significant difference in VIFT between the HIIT+SSG and Control groups ($p = 0.222$). Post-intervention, a significant difference was observed, with the HIIT+SSG group showing higher VIFT values compared to the Control group ($F_{(1, 48)} = 4.23$, $p = 0.045$, Mean Difference = 0.50, 95% CI [0.01, 0.99]). At Mid-PHV, pre-intervention, no significant difference was found between the HIIT+SSG and Control groups ($p = 0.682$). However, post-intervention, a highly significant difference emerged, with the HIIT+SSG group showing higher VIFT values compared to the Control group ($F_{(1, 48)} = 27.60$, $p < 0.001$, Mean Difference = 1.28, 95% CI [0.79, 1.77]). At Post-PHV, pre-intervention, there was no significant difference in VIFT between the HIIT+SSG and Control groups ($p = 0.539$). Post-intervention, a highly significant difference was observed, with the HIIT+SSG group demonstrating substantially greater VIFT values compared to the Control group ($F_{(1, 48)} = 38.04$, $p < 0.001$, Mean Difference = 1.50, 95% CI [1.01, 1.99]).

Maturational differences within groups at each time point

Considering HIIT+SSG Group, at Pre-intervention, there was a significant effect of maturity classification on VIFT ($F_{(2, 48)} = 36.88$, $p < 0.001$, ηp2 = 0.606, large). Pairwise comparisons revealed significant differences, namely comparing Pre-PHV vs. Mid-PHV, the Mid-PHV had significantly higher VIFT (Mean Difference = -1.67, $p < 0.001$, 95% CI [-2.34, -1.00]). Moreover, comparing Pre-PHV vs. Post-PHV, the Post-PHV had significantly higher VIFT (Mean Difference = -2.22, $p < 0.001$, 95% CI [-2.89, -1.55]). However, comparing Mid-PHV vs. Post-PHV, No significant difference was found between Mid-PHV and Post-PHV ($p = 0.134$). At post-intervention, there was a significant effect of maturity classification on VIFT ($F_{(2, 48)} = 65.98$, $p < 0.001$, ηp2 = 0.733, large). Pairwise comparisons also showed significant differences, namely comparing Pre-PHV vs. Mid-PHV, the Mid-PHV had significantly higher VIFT (Mean Difference = -2.06, $p < 0.001$, 95% CI [-2.66, -1.45]). Also, comparing Pre-PHV vs. Post-PHV, the Post-PHV had significantly higher VIFT (Mean Difference = -2.67, $p < .001$, 95% CI [-3.27, -2.06]). However, comparing Mid-PHV vs. Post-PHV, no significant difference was found between Mid-PHV and Post-PHV ($p = 0.046$).

Considering the control group, at Pre-intervention, there was a significant effect of maturity classification on VIFT ($F_{(2, 48)} = 21.65$, $p < 0.001$, ηp2 = 0.474, large). Pairwise comparisons revealed significant differences, namely, Pre-PHV vs. Mid-PHV, showing that Mid-PHV had significantly higher VIFT (Mean Difference = -1.22, $p < 0.001$, 95% CI [-1.89, -0.55]). Comparisons between Pre-PHV vs. Post-PHV revealed that Post-PHV had significantly higher VIFT (Mean Difference = -1.72, $p < 0.001$, 95% CI [-2.39, -1.05]). However, comparisons between Mid-PHV vs. Post-PHV showed no significant difference was found between Mid-PHV and Post-PHV ($p = 0.209$). At post-intervention, there was a significant effect of maturity classification on VIFT ($F_{(2, 48)} = 25.70$, $p < 0.001$, ηp2 = 0.517, large). Pairwise comparisons showed significant differences, namely, Pre-PHV vs. Mid-PHV, Mid-PHV had significantly higher VIFT (Mean Difference = -1.28, $p < 0.001$, 95% CI [-1.88, -0.67]). Moreover, comparing Pre-PHV vs. Post-PHV, the Post-PHV had significantly higher VIFT (Mean Difference = -1.67, $p < 0.001$, 95% CI [-2.27, -1.06]). However, comparing Mid-PHV vs. Post-PHV, no significant difference was found between Mid-PHV and Post-PHV ($p = 0.349$).

Discussion

This study aimed to compare the effects of HIIT&SSG program on maximal strength, sprint performance, and aerobic capacity in female soccer players at different stages of maturation. Our main findings reveal that the HIIT&SSG intervention significantly improved IMTP performance, 30-meter sprint time, and VIFT across all maturational groups. The enhancements in IMTP and VIFT were more pronounced in the mid- and post-PHV athletes within the intervention group. While overall sprint performance improved, the HIIT&SSG program showed a significant advantage in 30-meter sprint times specifically for post-PHV athletes compared to the controls, highlighting that this benefit can more pronounced in post-PHV athletes.

Our study revealed significant overall improvements in IMTP performance, with the HIIT&SSG group showing greater benefits compared to the control group. Furthermore, a significant interaction with maturity status was observed. While all participants improved, the most substantial advantages in IMTP performance within the HIIT&SSG group were seen in mid- and post-PHV athletes, whereas pre-PHV athletes showed no significant difference between groups. This maturational effect is consistent with previous research, which suggests that strength increases in pre-pubertal athletes are primarily driven by neural adaptations (Hakkinen et al., 1988), whereas the hormonal changes during mid- and post-PHV stages—such as increases in testosterone, growth hormone, and insulin-like growth factor (IGF-1)—support more evident strength development (Ramsay et al., 1990). The HIIT component possibly promoted neuromuscular adaptations through repeated muscular strain (Mochizuki et al., 2019). Meanwhile, the SSGs (conducted in a 2v2 format on a 20x15 m pitch) may have increased the overall number of explosive and high-intensity actions, such as accelerations, decelerations, and changes of direction (Beato et al., 2023). These movements usually involve frequent eccentric contractions, placing considerable load on the lower limbs (Madison et al., 2019). Additionally, the reactive nature of SSGs may help enhance reactive strength and power (Nayıroğlu et al., 2022), as athletes must rapidly respond to dynamic game scenarios, frequently reapplying force. However, further research is needed to establish the causal mechanisms that may underlie the observed adaptations.

Our analysis of 30-meter sprint performance revealed a significant three-way interaction with maturity classification indicated that only post-PHV athletes in the HIIT&SSG group experienced significant reductions in sprint times (not peak speed) compared to their control counterparts. In contrast, pre-PHV and mid-PHV athletes did not reveal similarly distinct group differences. This maturational influence on sprint performance is consistent with existing literature, which indicates that while sprint speed can be improved at all stages of development through technical and skill-based adaptations (Hillis and Holman, 2014), more pronounced benefits tend to occur in later maturational stages (Oliver et al., 2013). Within the HIIT&SSG group, the greater improvement observed in post-PHV athletes may be partially attributable to the HIIT, which included high-speed linear running, which may have contributed to neuromuscular stimulus and enhanced motor unit recruitment (Stankovic et al., 2023). At the same time, although the SSG component may appear less directly linked to linear speed development, the frequent accelerations embedded within the small-sided games could have supported improvements in force production within dynamic, game-like contexts as previously observed in elite women (Mara et al., 2016). Likely, the enhanced sprint response in post-PHV athletes can be attributed to growth factors that influence their ability to adapt to these training stimuli. For example, increased myelination of motor neurons during late adolescence can improve the speed and efficiency of neural transmission, which is crucial for rapid muscle contractions during sprinting (Viru et al., 1999).

Our study also revealed significant improvements in VIFT across participants, with the HIIT&SSG group showing greater increases compared to the control group. These improvements were observed across all three maturational stages (pre-PHV, mid-PHV, and post-PHV), suggesting that the HIIT&SSG program may enhance intermittent running performance regardless of an athlete's biological maturity. This contrasts with the more maturity-dependent adaptations seen in IMTP and 30-meter sprint performance. The HIIT component of the intervention is commonly associated with improvements in maximal oxygen uptake (Rowan et al., 2012) and anaerobic threshold (Arazi et al., 2017), which may help explain the observed benefits in VIFT. At the same time, SSGs have been shown to elicit high-intensity efforts that closely simulate match-play demands, effectively challenging and developing aerobic performance (Nayıroğlu et al., 2022), although the heterogeneous physical demands often observed in these games introduce variability, some consistency in the physiological stimulus still exists (Hill-Haas et al., 2008). This integrated training approach may therefore support intermittent running performance across different stages of adolescent development as observed in a previous study (Alvarez et al., 2017). The consistent effectiveness of intermittent endurance training across maturity groups could be attributed to its primary focus on aerobic capacity, which remains adaptable throughout childhood and adolescence (Enríquez-del-Castillo et al., 2022).

While our study provided new findings, limitations include its relatively short intervention duration, the lack of recovery control, and the inherent variability in training stimuli within SSGs, which can make dosage difficult to standardize. Additionally, since multiple teams were included in the sample, some variability in the training stimulus could occur due to the regular in-field sessions, in which the research team did not participate. Future research should explore longitudinal adaptations across a wider range of female youth soccer players, and investigate the necessary dose-response relationships of combined HIIT and SSG for specific maturational stages. For example, examining how different maturational stages influence outcomes such as strength, sprint performance, and aerobic capacity could help clarify the optimal dosage and sequencing of HIIT and SSG for each developmental phase. Practically, coaches of female youth soccer players may integrate both structured HIIT and SSGs into training programs, adjusting the relative emphasis based on individual maturational status and specific performance goals, such as prioritizing HIIT for improving maximal strength and aerobic capacity in post-PHV athletes, and emphasizing SSGs for developing tactical content and game-specific fitness, particularly for pre- and mid-PHV athletes. This approach would allow for more targeted training that supports overall fitness, as well as technical and strategic development.

Conclusion

In conclusion, this study suggests the efficacy of a HIIT&SSG intervention in enhancing strength, speed and aerobic capacity in youth female soccer players, albeit with maturational nuances. While overall improvements were observed across all physical fitness variables, the most pronounced improvements in IMTP and linear sprint speed (30m sprint) were predominantly evident in mid- and post-PHV athletes, emphasizing the influence of biological maturity on these specific adaptations. Conversely, intermittent endurance showed significant improvements across all maturational stages. Therefore, coaches of female youth soccer players may integrate both structured, individualized HIIT and SSGs into their training regimens, adjusting intensity and volume to optimize specific adaptations across different maturational phases.

Acknowledgements
The experiments comply with the current laws of the country in which they were performed. The authors have no conflict of interest to declare. The datasets generated during and/or analyzed during the current study are not publicly available but are available from the corresponding author who was an organizer of the study.

References

Alvarez, C., Ramírez-Campillo, R., Ramírez-Vélez, R. and Izquierdo, M. (2017) Effects of 6-Weeks High-Intensity Interval Training in Schoolchildren with Insulin Resistance: Influence of Biological Maturation on Metabolic, Body Composition, Cardiovascular and Performance Non-responses. *Frontiers in Physiology* **8**. https://doi.org/10.3389/fphys.2017.00444

Arazi, H., Keihaniyan, A., EatemadyBoroujeni, A., Oftade, A., Takhsha, S., Asadi, A. and Ramírez-Campillo, R. (2017) Effects of Heart Rate vs. Speed-Based High Intensity Interval Training on Aerobic and Anaerobic Capacity of Female Soccer Players. *Sports* **5**, 57. https://doi.org/10.3390/sports5030057

Arslan, E., Kilit, B., Clemente, F.M., Soylu, Y., Sögüt, M., Badicu, G., Akca, F., Gokkaya, M. and Murawska-Cialowicz, E. (2021) The Effects of Exercise Order on the Psychophysiological Responses, Physical and Technical Performances of Young Soccer

Players: Combined Small-Sided Games and High-Intensity Interval Training. *Biology* **10**, 1180. https://doi.org/10.3390/biology10111180
Beato, M., Vicens-Bordas, J., Peña, J. and Costin, A.J. (2023) Training load comparison between small, medium, and large-sided games in professional football. *Frontiers in Sports and Active Living* **5**. https://doi.org/10.3389/fspor.2023.1165242
Buchheit, M. and Mendez-Villanueva, A. (2014) Effects of age, maturity and body dimensions on match running performance in highly trained under-15 soccer players. *Journal of Sports Sciences* **32**, 1271-1278. https://doi.org/10.1080/02640414.2014.884721
Emmonds, S., Morris, R., Murray, E., Robinson, C., Turner, L. and Jones, B. (2017) The influence of age and maturity status on the maximum and explosive strength characteristics of elite youth female soccer players. *Science and Medicine in Football* **1**, 209-215. https://doi.org/10.1080/24733938.2017.1363908
Enríquez-del-Castillo, L.A., Ornelas-López, A., De León, L.G., Cervantes-Hernández, N., Quintana-Mendias, E. and Flores, L.A. (2022) Strength and VO2max Changes by Exercise Training According to Maturation State in Children. *Children* **9**, 938. https://doi.org/10.3390/children9070938
García-Ceberino, J.M., Cantonero-Cobos, J.M., Conde, C. and Fernández-Ozcorta, E.J. (2024) Variations in External and Internal Intensities and Impact of Maturational Age on Soccer Training Tasks. *Sensors* **24**, 5656. https://doi.org/10.3390/s24175656
Hakkinen, K., Pakarinen, A., Alen, M., Kauhanen, H. and Komi, P. V. (1988) Neuromuscular and hormonal adaptations in athletes to strength training in two years. *Journal of Applied Physiology* **65**, 2406-2412. https://doi.org/10.1152/jappl.1988.65.6.2406
Hermassi, S., Konukman, F., Al-Marri, S.S., Hayes, L.D., Bartels, T. and Schwesig, R. (2024) Associations between biological maturation, physical performance, postural control, and mathematical achievement in youth soccer players. *PLOS ONE* **19**, e0298301. https://doi.org/10.1371/journal.pone.0298301
Hill-Haas, S., Rowsell, G., Coutts, A. and Dawson, B. (2008) The reproducibility of physiological responses and performance profiles of youth soccer players in small-sided games. *Int J Sports Physiol Perform* **3**, 393-396. https://doi.org/10.1123/ijspp.3.3.393
Hillis, T.L. and Holman, S. (2014) The Relationship between Speed and Technical Development in Young Speed Skaters. *International Journal of Sports Science & Coaching* **9**, 393-400. https://doi.org/10.1260/1747-9541.9.2.393
Howard, N. and Stavrianeas, S. (2017) In-Season High-Intensity Interval Training Improves Conditioning In High School Soccer Players. *International Journal of Exercise Science* **10**, 713-720. https://doi.org/10.70252/XFJU8567
Itoh, R. and Hirose, N. (2020) Relationship Among Biological Maturation, Physical Characteristics, and Motor Abilities in Youth Elite Soccer Players. *Journal of Strength and Conditioning Research* **34**, 382-388. https://doi.org/10.1519/JSC.0000000000003346
Kunz, P., Engel, F.A., Holmberg, H.-C. and Sperlich, B. (2019) A Meta-Comparison of the Effects of High-Intensity Interval Training to Those of Small-Sided Games and Other Training Protocols on Parameters Related to the Physiology and Performance of Youth Soccer Players. *Sports Medicine - Open* **5**, 7. https://doi.org/10.1186/s40798-019-0180-5
Lloyd, R.S., Oliver, J.L., Radnor, J.M., Rhodes, B.C., Faigenbaum, A.D. and Myer, G.D. (2015) Relationships between functional movement screen scores, maturation and physical performance in young soccer players. *Journal of Sports Sciences* **33**, 11-19. https://doi.org/10.1080/02640414.2014.918642
Madison, G., Patterson, S.D., Read, P., Howe, L. and Waldron, M. (2019) Effects of Small-Sided Game Variation on Changes in Hamstring Strength. *Journal of Strength and Conditioning Research* **33**, 839-845. https://doi.org/10.1519/JSC.0000000000002955
Mara, J.K., Thompson, K.G. and Pumpa, K.L. (2016) Physical and Physiological Characteristics of Various-Sided Games in Elite Women's Soccer. *International Journal of Sports Physiology and Performance* **11**, 953-958. https://doi.org/10.1123/IJSPP.2015-0087
Marco-Contreras, L.A., Bataller-Cervero, A.V., Gutiérrez, H., Sánchez-Sabaté, J. and Berzosa, C. (2024) Analysis of the Validity and Reliability of the Photo Finish® Smartphone App to Measure Sprint Time. *Sensors* **24**, 6719. https://doi.org/10.3390/s24206719
Michailidis, Y., Ganotakis, C., Motsanos, N. and Metaxas, T. (2023) The effects of an HIIT program on young soccer players' physical performance. *International Journal of Sports Science & Coaching* **18**, 1155-1163. https://doi.org/10.1177/17479541221102530
Mochizuki, Y., Kikuchi, N., Kaji, N., Okada, T., Terada, K., Haakaku, Y., Tomabechi, N., Soga, T., Era, T., Kobatake, N. and Nishiyama, T. (2019) Effects Of High-intensity Strength Training On Muscle Strength Gain And Muscle Hypertrophy In Males And Females: A Meta-analysis. *Medicine & Science in Sports & Exercise* **51**, 188-188. https://doi.org/10.1249/01.mss.0000561067.64587.e3
Nayıroğlu, S., Yılmaz, A.K., Silva, A.F., Silva, R., Nobari, H. and Clemente, F.M. (2022) Effects of small-sided games and running-based high-intensity interval training on body composition and physical fitness in under-19 female soccer players. *BMC Sports Science, Medicine and Rehabilitation* **14**, 119. https://doi.org/10.1186/s13102-022-00516-z
Oliver, J.L., Lloyd, R.S. and Rumpf, M.C. (2013) Developing Speed Throughout Childhood and Adolescence. *Strength & Conditioning Journal* **35**, 42-48. https://doi.org/10.1519/SSC.0b013e3182919d32
Ramirez-Campillo, R., Sortwell, A., Moran, J., Afonso, J., Clemente, F.M., Lloyd, R.S., Oliver, J., Pedley, J. and Granacher, U. (2023) Plyometric-Jump Training Effects on Physical Fitness and Sport-Specific Performance According to Maturity: A Systematic Review with Meta-analysis. *Sports Medicine - Open* **9**, 23. https://doi.org/10.1186/s40798-023-00568-6
Ramsay, J.A., Blimkie, C.J.R., Smith, K., Garner, S., Macdougall, J.D. and Sale, D.G. (1990) Strength training effects in prepubescent boys. *Medicine & Science in Sports & Exercise* **22**, 605-614. https://doi.org/10.1249/00005768-199010000-00011
Rowan, A., Kueffner, T. and Stavrianeas, S. (2012) Short Duration High-Intensity Interval Training Improves Aerobic Conditioning of Female College Soccer Players. *International Journal of Exercise Science* **5**, 232-238. https://doi.org/10.70252/LLXC7170
da Silva, C.D., Impellizzeri, F.M., Natali, A.J., de Lima, J.R., Bara-Filho, M.G., Silami-Garçia, E. and Martins, J. (2011) Exercise Intensity and Technical Demands of Small-Sided Games in Young Brazilian Soccer Players: Effect of Number of Players, Maturation, and Reliability. *Journal of Strength and Conditioning Research* **25**, 2746-2751. https://doi.org/10.1519/JSC.0b013e31820da061
Stankovic, M., Djordjevic, D., Trajkovic, N. and Milanovic, Z. (2023) Effects of High-Intensity Interval Training (HIIT) on Physical Performance in Female Team Sports: A Systematic Review. *Sports Medicine - Open* **9**, 78. https://doi.org/10.1186/s40798-023-00623-2
Urquhart, M., Bishop, C. and Turner, A.N. (2018) Validation of a crane scale for the assessment of portable isometric mid-thigh pulls. *Journal of Australian Strength & Conditioning* **25**, 28-33.
Viru, A., Loko, J., Harro, M., Volver, A., Laaneots, L. and Viru, M. (1999) Critical Periods in the Development of Performance Capacity During Childhood and Adolescence. *European Journal of Physical Education* **4**, 75-119. https://doi.org/10.1080/1740898990040106
Wright, M.D., Hurst, C. and Taylor, J.M. (2016) Contrasting effects of a mixed-methods high-intensity interval training intervention in girl football players. *Journal of Sports Sciences* **34**, 1808-1815. https://doi.org/10.1080/02640414.2016.1139163

Key points

- HIIT&SSG significantly improved maximal strength in mid- and post-PHV athletes.
- Aerobic capacity (VIFT) improved across all maturity groups in the HIIT&SSG group.
- Sprint performance improved significantly only in post-PHV athletes after HIIT&SSG.

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