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Research article

Comparing Individualized vs. Non-Individualized Locomotor Profiling on High-Intensity Interval Training Adaptations in Soccer Players: A Randomized Parallel Study

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Abstract

This study aimed to compare the effects of individualized versus non-individualized HIIT programming, based on players' locomotor profiles, on the magnitude of adaptations in aerobic, anaerobic, and neuromuscular capacities. A randomized, controlled, parallel-group design was conducted with 46 male youth soccer players (age: 16.5 ± 0.5 years), who were allocated into four groups: individualized HIIT (HIITind), long-interval HIIT only (HIITlong), repeated sprint training only (RST), and a control group that maintained regular training without any HIIT intervention. In the HIITind group, players were assigned to either HIIT-long or RST based on their locomotor profile - endurance or speed-oriented - determined by the difference between maximal sprint speed (MSS) and maximal aerobic speed (MAS), respectively. In contrast, players in the HIITlong and RST groups followed the same protocol regardless of their profile. The training intervention lasted six weeks, with sessions conducted twice per week. Players were assessed at baseline and post-intervention for countermovement jump (CMJ), MSS over 30 meters (km/h), repeated sprint ability (RSA), and MAS, using the 5-minute running test. Significant improvements were found in all training groups compared to the control. RST showed greater improvements in CMJ ($p < 0.001$), MSS ($p < 0.001$), anaerobic speed reserve (ASR) ($p < 0.001$), and RSAmean ($p < 0.001$) compared to HIIT-ind and HIITlong. No significant differences were observed between HIITind and HIITlong. Locomotor profiles influenced MSS ($p < 0.001$) and ASR ($p < 0.001$). These findings suggest that while both individualized and non-individualized HIIT protocols improve physical capacities, RST offers superior benefits for anaerobic and neuromuscular adaptations, whereas both HIIT-ind and long are more effective than RST for enhancing aerobic capacity, with no significant differences observed between them.

Key words: Football, intermittent training, aerobic fitness, anaerobic fitness.

Introduction

High-intensity interval training (HIIT) has been shown to be an effective method for improving performance in both youth and adult soccer players, regardless of the time of season (Kunz et al., 2019; Clemente et al., 2021). HIIT can enhance aerobic power (the ability to take in, transport, and utilize oxygen during exercise), anaerobic capacity (the ability to generate energy without oxygen during short bursts of high-intensity effort), and neuromuscular capacity (the efficient coordination between the nervous system and muscles to produce strength and power) when implemented over short training periods (Hostrup and Bangsbo, 2023). When compared to traditional endurance training, HIIT offers similar improvements in aerobic endurance and may provide additional benefits in explosive performance measures such as vertical jump (Howard and Stavrianeas, 2017). Concurrent HIIT and muscular strength training during the preseason has been found to significantly enhance players' sprint times, vertical jump height, and aerobic endurance compared to regular soccer training alone (Wong et al., 2010).

Recent studies have explored the use of anaerobic speed reserve (ASR) for individualizing HIIT. While ASR-based methods showed reduced coefficients of variation in physiological and perceptual responses during 10-minute HIIT sessions compared to maximal aerobic speed (MAS) methods, the differences were only practically meaningful for blood lactate and rating of perceived exertion (Bok et al., 2023). ASR showed good reliability and moderate correlations with acute physiological responses to HIIT in female soccer players (Aspin et al., 2024). In basketball players, HIIT prescribed using ASR resulted in more uniform physiological adaptations compared to other methods, although hormonal changes were similar across approaches (Wang and Ye, 2024). However, another study found that ASR-based methods were not significantly superior to MAS-based methods in reducing inter-subject variability of responses during short-format HIIT (Bok et al., 2023).

While training based on ASR is not the only method for individualizing the training process, it offers an alternative by accounting for both an athlete's maximal aerobic and anaerobic capacities, possibly leading to more accurate and individual conditioning (Sandford et al., 2021). As suggested in previous research (Sandford et al., 2021), defining a player's locomotor profile can be a key factor in optimizing the training stimulus. One past study (Sandford et al., 2021) introduced the concept of three distinct player profiles: a 'speed profile' (characterized by low maximal aerobic speed and high maximal sprint speed; large power reserve), an 'endurance profile' (high maximal aerobic speed and low maximal sprint speed; small power reserve), and a 'hybrid profile' (moderate values for both; moderate power reserve). These player profiles may offer more accurate indicators for selecting the most appropriate type of HIIT. In fact, among the various available HIIT formats, few studies (Bok et al., 2023) have investigated their key differences - or more importantly, the rationale behind prescribing a specific HIIT type to one player versus another (Buchheit and Laursen, 2013).

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Therefore, although ASR-based training is suggested to be more effective than alternative approaches, few studies have employed experimental and controlled designs to directly compare them - particularly in sports like soccer, where positional roles contribute to significant variability in player profiles. By testing this approach - individualizing the type of HIIT based on a player's locomotor profile - we can advance the current state of the art and provide coaches and practitioners with practical guidance on how individualized or non-individualized HIIT can enhance aerobic capacity, anaerobic performance, and neuromuscular function in soccer players. To address this gap in the literature, the present study aimed to compare the effects of individualized versus non-individualized HIIT programming, based on players' locomotor profiles, on the magnitude of adaptations in aerobic, anaerobic, and neuromuscular capacities. We hypothesize that adapting HIIT based on ASR can lead to more meaningful adaptations than using a non-individualized approach.

Methods

Approach to the problem

Our study utilized a randomized, controlled, parallel-group design, comprising three experimental groups and one control group. The experimental groups completed two additional HIIT sessions per week for six weeks, supplementing their regular team training. In contrast, the control group continued with their standard training regimen, without any added HIIT intervention. Two teams participated in the study, and players from both teams were distributed across all four groups to ensure balance and reduce bias related to team-specific training practices. The intervention was conducted during the early-season period. Randomization was performed using an online tool (Research Randomizer), with stratified randomization employed to ensure balanced representation of player profiles (speed, endurance, and hybrid) across all groups. Blinding was ensured only for the evaluators, who were unaware of the participants' group allocation.

Participants

To determine the necessary sample size for the 2 (assessment moments, within-subjects) x 4 (groups, between-subjects) mixed ANOVA design, an a priori power analysis was conducted using G*Power software (Version 3.1.9.7). Based on an anticipated medium effect size for the interaction (Cohen's f = 0.30), a desired statistical power of 0.80, and a significance level (α) of 0.05, the analysis revealed a required total sample size of 36 participants. To prevent dropout, the researchers recruited more participants than the recommended number.

The research team approached two local soccer teams competing at the same competitive level. Both teams trained under similar conditions, with three training sessions per week and official matches on weekends. Team managers communicated with the players and their legal guardians to invite them to participate. Those who agreed were enrolled as volunteers in the study.

The inclusion criteria, defined a priori, were as follows: (i) male players aged between 16 and 17 years; (ii) outfield players; (iii) participation in both pre- and post-intervention assessments; and (iv) attendance exceeded 90% across all HIIT intervention sessions. Exclusion criteria included: (i) sustaining an injury in the month prior the intervention or during the intervention period; (ii) participating in any additional strength and conditioning programs beyond regular team training; (iii) missing any of the specific HIIT sessions or assessment time points; and (iv) being goalkeeper.

Out of 52 potential players initially identified, 5 were excluded for being goalkeepers and 1 was excluded due to an injury sustained prior to the first assessment (Figure 1). This left 46 eligible players to take part in the study. All participants were male soccer players competing at the U-17 amateur local level (age: 16.5 ± 0.5 years; body mass:

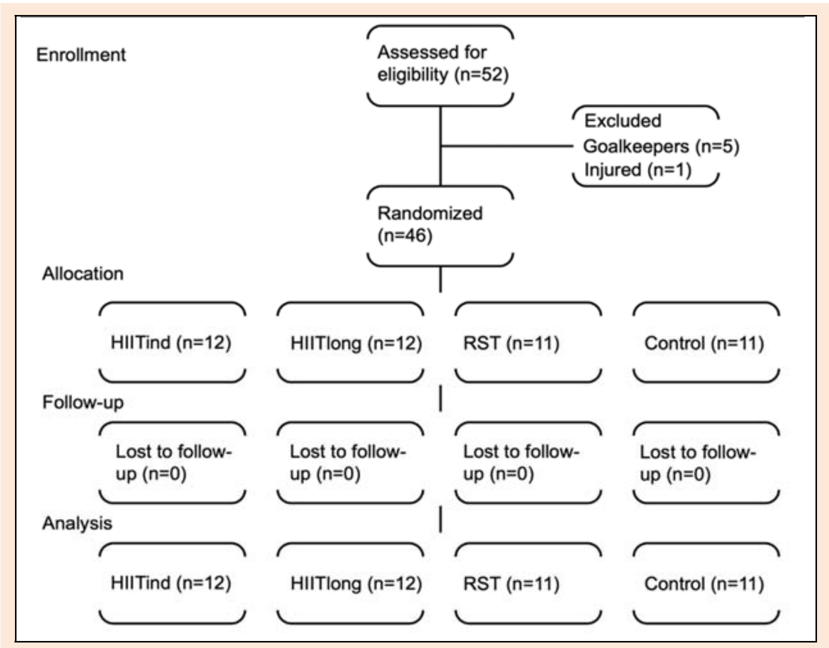

Figure 1. Flow of participants over the study. HIITind: individualized high-intensity interval training; HIITlong: long intervals high-intensity interval training; RST: repeated sprint training.

68.7 ± 3.7 kg; height: 178.5 ± 4.5 cm; playing experience: 4.8 ± 1.0 years). The players belonged to teams that typically trained three times per week, in addition to playing matches on weekends. However, during the study period, only friendly matches were held. Each training session lasted between 90 and 100 minutes and included a general warm-up, a physical conditioning phase, technical and tactical drills, and game-based scenarios. Although there were natural differences in training methodologies between teams, these were mitigated by randomly assigning players to different groups across teams, thereby reducing the influence of any one coach's specific training approach.

Prior to data collection, informed consent was obtained from both the participants and their legal guardians, ensuring their voluntary participation and full understanding of the study's purpose, procedures, and potential risks and benefits. All procedures adhered to the principles outlined in the Helsinki Declaration, emphasizing the protection of participants' well-being, confidentiality, and right to withdraw at any time without consequence. Approval for this research was obtained from the Nanchang Institute of Science & Technology ethics committee (code number NIST20250427) to ensure ethical conduct throughout the study.

HIIT interventions

Two main types of HIIT interventions were implemented: long-interval HIIT and repeated sprint training (RST). In the HIITind group, players with a speed-oriented profile were assigned to RST, while those with an endurance-oriented profile were assigned to long-interval HIIT (Table 1). Players with a hybrid profile were evenly distributed between the two interventions to maintain balance. In contrast, in the HIITlong group, all players performed long-interval HIIT regardless of their locomotor profile, and similarly, all players in the RST group followed the RST protocol irrespective of their profile.

Following the initial assessments, each player's locomotor profile was identified, and participants were then randomly assigned to their respective groups. Allocation was conducted prior to the intervention, and no changes were made to the groups during the study. The intervention began the week immediately after the assessments and was carried out twice per week for six consecutive weeks.

Each HIIT session was conducted during the team's first training session of the week - 48 hours of rest and before the start of the regular field training with the coaches. The second HIIT session was delivered during the second training day of the week, with a 24-hour interval after the previous training session. The HIIT interventions were prescribed by the research team with the support of the team's staff. The intervention sessions were conducted at approximately 5:00 PM and began with a standardized warm-up focused on the lower limbs. This included 5 minutes of light jogging, 5 minutes of dynamic stretching, and 5 minutes of lower-limb potentiation exercises. Following a 3-minute rest period, players proceeded with the HIIT interventions.

Table 1. Details of the high-intensity interval training interventions.

	HIITlong	HIITlong	RST	RST
	Session 1	Session 2	Session 1	Session 2
Week 1	Sets: 6 Work duration: 2 min Relief duration: 2 min Work intensity: 95%MAS Relief intensity: passive	Sets: 6 Work duration: 2 min Relief duration: 2 min Work intensity: 95%MAS Relief intensity: passive	Sets: 6 Work duration: 4×30-m sprints Relief duration: 20s / sets: 5 min Work intensity: all-out Relief intensity: 50% MAS	Sets: 6 Work duration: 4×30-m sprints Relief duration: 20s / sets: 5 min Work intensity: all-out Relief intensity: 50% MAS
Week 2	Sets: 6 Work duration: 2 min Relief duration: 2 min Work intensity: 95%MAS Relief intensity: passive	Sets: 6 Work duration: 2 min Relief duration: 2 min Work intensity: 95%MAS Relief intensity: passive	Sets: 6 Work duration: 4×30-m sprints Relief duration: 20s / sets: 5 min Work intensity: all-out Relief intensity: 50% MAS	Sets: 6 Work duration: 4×30-m sprints Relief duration: 20s / sets: 5 min Work intensity: all-out Relief intensity: 50% MAS
Week 3	Sets: 6 Work duration: 2 min Relief duration: 2 min Work intensity: 100%MAS Relief intensity: passive	Sets: 6 Work duration: 2 min Relief duration: 2 min Work intensity: 100%MAS Relief intensity: passive	Sets: 6 Work duration: 6×30-m sprints Relief duration: 20s / sets: 5 min Work intensity: all-out Relief intensity: 50% MAS	Sets: 6 Work duration: 6×30-m sprints Relief duration: 20s / sets: 5 min Work intensity: all-out Relief intensity: 50% MAS
Week 4	Sets: 6 Work duration: 2 min Relief duration: 2 min Work intensity: 100%MAS Relief intensity: passive	Sets: 6 Work duration: 2 min Relief duration: 2 min Work intensity: 100%MAS Relief intensity: passive	Sets: 6 Work duration: 6×30-m sprints Relief duration: 20s / sets: 5 min Work intensity: all-out Relief intensity: 50% MAS	Sets: 6 Work duration: 6×30-m sprints Relief duration: 20s / sets: 5 min Work intensity: all-out Relief intensity: 50% MAS
Week 5	Sets: 6 Work duration: 3 min Relief duration: 2 min Work intensity: 100%MAS Relief intensity: passive	Sets: 6 Work duration: 3 min Relief duration: 2 min Work intensity: 100%MAS Relief intensity: passive	Sets: 6 Work duration: 8×30-m sprints Relief duration: 20s / sets: 5 min Work intensity: all-out Relief intensity: 50% MAS	Sets: 6 Work duration: 8×30-m sprints Relief duration: 20s / sets: 5 min Work intensity: all-out Relief intensity: 50% MAS
Week 6	Sets: 6 Work duration: 3 min Relief duration: 2 min Work intensity: 100%MAS Relief intensity: passive	Sets: 6 Work duration: 3 min Relief duration: 2 min Work intensity: 100%MAS Relief intensity: passive	Sets: 6 Work duration: 8×30-m sprints Relief duration: 20s / sets: 5 min Work intensity: all-out Relief intensity: 50% MAS	Sets: 6 Work duration: 8×30-m sprints Relief duration: 20s / sets: 5 min Work intensity: all-out Relief intensity: 50% MAS

HIITlong: long interval high-intensity interval training; RST: repeated sprint training; MAS: maximal aerobic speed.

In addition to HIIT, the players followed their regular training programs conducted and managed by their respective coaching staff, without any interference from the research team. All players underwent the same training within their teams, with natural variations reflecting the specific methodologies used by different coaching staffs. Adherence to the HIIT sessions was monitored during each training session. The adherence rates were 94.7 ± 1.2% for HIITind, 95.1 ± 2.1% for HIITlong, and 93.6 ± 0.9% for RST.

Physical fitness assessments

Assessments were conducted during the week prior to the start of the 6-week intervention and in the week following the conclusion of the intervention period. Each assessment took place after 48 hours of rest, and both occurred during the first training session of the week. The evaluations were carried out at 5:00 PM in the afternoon, at the team's facilities. The testing began in a private room with anthropometric measurements, followed by a standardized warm-up protocol, and then proceeded with the same sequence of tests: countermovement jump (CMJ), 30-meter linear sprint, repeated sprint ability (RSA), and the 5-minute running test. A 5-minute rest period was taken between each test. The field tests were conducted on synthetic turf at the team's practice field. Outdoor temperatures were approximately 19.4 ± 1.2ºC, with a relative humidity of 61.2 ± 2.8%.

Countermovement jump (CMJ)

The capacity to generate forceful leg movements was gauged via the countermovement jump (CMJ) protocol. Utilizing a stable testing surface, participants performed the CMJ, with the MyJump 2 mobile application serving as the measurement instrument for vertical displacement. This application has been shown to provide dependable and accurate measurements of vertical jump height when benchmarked against photoelectric cell technology (Bogataj et al., 2020). The observations and recordings were conducted by the same researcher, who was tested for intra-observer reliability by assessing 10 movements with a 10-day interval. The intraclass correlation coefficient was 0.98, indicating high reliability in data collection. The procedure required participants to initiate from a standing posture, then execute a rapid preparatory downward motion involving bending at the knees and hips, immediately followed by a powerful extension to propel themselves vertically. Throughout the jump, participants maintained a hands-on-hips position to specifically assess lower limb power output. Following two successful trials, the average height achieved during the jumps, expressed in centimeters, was the variable used for statistical examination.

Linear sprint speed at 30-m

To evaluate maximum running speed, a 30-meter sprint test was administered. Participants began from a stationary stance, positioning their dominant foot just behind the starting line. The duration of the sprint was recorded using the Photo Finish mobile application (Marco-Contreras et al., 2024). This application was configured to capture times at the starting point, at 25-m and at the 30-meter mark. A single researcher carried out all observations and recordings. To assess intra-observer reliability, the researcher evaluated seven sprints on two occasions, separated by a 10-day interval. An intraclass correlation coefficient of 0.96 confirmed the consistency and reliability of the measurements. Maximal sprint speed (MSS) was calculated based on the time taken to cover the distance between the 25-meter and 30-meter marks, as previous study have demonstrated this method to be accurate (Zabaloy et al., 2024). Prior research has confirmed the dependability and accuracy of the Photo Finish application when its measurements are compared to those obtained with traditional photocell systems (Marco-Contreras et al., 2024). Each participant completed two successful sprints, and the MSS taken to cover the 30-meter distance was the value used for subsequent analysis.

Repeated Sprint Ability (RSA)

The repeated sprint ability (RSA) was assessed using a test protocol involving six shuttle sprints, each covering 40 meters (20 meters in one direction and 20 meters back) (Rampinini et al., 2009). Between each sprint, participants had 20 seconds of passive recovery. This test was designed to evaluate the participants' capacity to sustain sprint performance across multiple efforts, as well as their ability to change direction quickly (Rampinini et al., 2009). Each sprint began with the participants at the starting line, running 20 meters to touch a cone before returning to the starting point. A 20-second rest period followed each sprint. Prior to each sprint, participants were instructed to position themselves at the start line 5 seconds before the signal to begin. The average time of all sprints performed during the test was used to calculate the mean RSA (in seconds).

5-minute running test

Maximal aerobic speed (MAS) was estimated through a 5-minute continuous running test. This test has been previously validated as an accurate method for estimating maximal aerobic speed (MAS) when compared to the treadmill test (Berthon et al., 1997). More recently, it has also shown a stronger agreement in team sports players compared to the treadmill test (Bennett et al., 2024). Participants were instructed to cover as much distance as possible at a consistent maximal effort over the 5-minute duration on the field. The total distance covered in meters during this period was recorded and subsequently used to calculate the estimated maximal aerobic speed (MAS) for each participant, expressed in meters per second.

Locomotor profile

Participants were categorized based on their individual locomotor characteristics using the anaerobic speed reserve (ASR). The ASR was determined by calculating the difference between their maximal sprinting speed (MSS), as assessed by the 30-meter sprint, and their estimated maximal aerobic speed (MAS), derived from the 5-minute running test. This resulting ASR value provided a measure of the speed range available to each player above their aerobic threshold, reflecting their capacity for high-intensity, intermittent activities. These ASR values were then used as a basis for classifying players into distinct locomotor profiles for subsequent analysis.

To classify participants into endurance, hybrid, and speed profiles based on their ASRpre values, the data was grouped according to the training intervention (HIITind, HIITlong, RST, and Control). Within each group, ASRpre values were sorted in ascending order and divided into three approximately equal parts. The division was done by computing the integer division of the group size by 3 (i.e., n // 3), with any remaining individuals assigned to the middle (hybrid) category to ensure balanced grouping. The lowest third were categorized as having an "Endurance" profile, representing individuals with the lowest ASRpre scores, potentially indicating higher fatigue resistance or aerobic dominance. The middle third, including any remainder from the division, were labeled "Hybrid", reflecting a balanced physiological profile, while the highest third were classified under the "Speed" profile, likely representing more anaerobically inclined or power-oriented individuals. For the HIITind group, ASRpre values ≤13.22 were Endurance, between 13.22 and 14.2 were Hybrid, and >14.2 were Speed. In the HIITlong group, values ≤13.24 were Endurance, 13.24–14.06 were Hybrid, and >14.06 were Speed. For RST, the cutoffs were ≤13.22 (Endurance), 13.22 - 14.24 (Hybrid), and >14.24 (Speed). Lastly, in the Control group, values ≤13.4 were categorized as Endurance, 13.4 - 14.52 as Hybrid, and >14.52 as Speed. This classification offers a practical way to interpret physiological tendencies based on relative ASR performance within each training context.

Statistical procedures

A two-way ANOVA was conducted using the delta values (post-pre) for each dependent variable, with the type of training and locomotor profile as independent variables. This analysis helped to control for baseline differences and isolate the impact of the intervention on the measured outcomes. Prior to the analysis, assumptions of normality, and homogeneity of variances. Normality was checked using the Shapiro-Wilk test, with $p > 0.05$ indicating no violation of the assumption. Homogeneity of variances was evaluated using Levene's test, with $p > 0.05$ suggesting that this assumption was met. Sphericity was assessed using Mauchly's test, and when violations were detected, corrections were applied using the Greenhouse-Geisser method. For significant main effects or interactions, post hoc analyses with Bonferroni corrections were performed to identify pairwise differences between group means. The effect size for main and interaction effects was measured using partial eta squared (ηp^2), with values of 0.01, 0.06, and 0.14 indicating small, medium, and large effects, respectively. Cohen's d was used to determine the magnitude (ES: effect size) of pairwise differences from post hoc analyses, with values of 0.20, 0.50, and 0.80 considered small, medium, and large, respectively. The significance level for all tests was set at $p < 0.05$, and all analyses were performed using SPSS software (version 28.0.0, USA).

Results

Table 2 presents the pre- and post-intervention measurements, along with the changes in the main outcomes analyzed. The two-way ANOVA using the delta values (post-pre) revealed no significant interactions between the training group and locomotor profile for the outcomes of CMJ ($p = 0.652$; $\eta p^2 = 0.110$), distance covered in the 5-minute test ($p = 0.923$; $\eta p^2 = 0.053$), MAS ($p = 0.924$; $\eta p^2 = 0.053$), and RSAmean ($p = 0.746$; $\eta p^2 = 0.092$). However, significant interactions were found for MSS ($p < 0.001$; $\eta p^2 = 0.589$) and ASR ($p < 0.001$; $\eta p^2 = 0.558$).

Countermovement jump

Figure 2 exhibits mean values and 95% confidence intervals (CI) for the delta differences (post-pre) of the main outcomes across the different training groups. Comparisons between groups for CMJ delta values (post-pre) revealed significant differences ($p < 0.001$; $\eta p^2 = 0.775$). The control group showed significantly less improvement compared to HIITind (mean difference: -1.29 cm; $p < 0.001$, Cohen's *d* = 0.41, small ES), HIITlong (mean difference: -0.914 cm; $p < 0.001$, Cohen's *d* = 0.25), and RST (mean difference: -1.95 cm; $p < 0.001$, Cohen's *d* = 0.62, smedium ES). Additionally, RST showed significantly greater improvement in CMJ compared to HIITind (mean difference: 0.67 cm; $p = 0.005$, Cohen's *d* = 0.21, small ES) and HIITlong (mean difference: 1.04 cm; $p < 0.001$, Cohen's *d* = 0.31, small ES). No significant differences were observed between HIITind and HIITlong ($p = 0.228$). Comparisons between locomotor profiles revealed no significant differences ($p = 0.978$; $\eta p^2 = 0.001$).

Maximal sprint speed

Comparisons between groups for MSS delta values (post-pre) revealed significant differences ($p < 0.001$; $\eta p^2 = 0.538$). The control group showed significantly less improvement compared to RST (mean difference: -1.84 km/h; $p < 0.001$, Cohen's *d* = 1.22, large ES), but not to HIITind (mean difference: -0.06 km/h; $p > 0.999$, Cohen's *d* = 0.04, trivial ES), and HIITlong (mean difference: 0.57 km/h; $p = 0.917$, Cohen's *d* = 0.38, small ES).

Table 2. Mean and standard deviations of the outcomes in pre and post-intervention moments. Data are means (±SD).

	HIITind pre	HIITind post	HIITlong pre	HIITlong post	RST pre	RST post	Control pre	Control post
CMJ (cm)	35.2 ± 3.1	36.6 ± 3.1	35.7 ± 3.7	36.7 ± 3.8	35.7 ± 3.8	37.8 ± 3.7	35.2 ± 3.9	35.3 ± 3.8
MSS (km/h)	29.2 ± 1.3	29.1 ± 1.3	29.4 ± 1.7	28.6 ± 1.6	29.6 ± 1.5	30.6 ± 1.5	29.7 ± 1.7	29.5 ± 1.6
5-min distance (m)	1289.2 ± 59.7	1409.8 ± 64.4	1288.3 ± 83.9	1414.2 ± 87.5	1292.3 ± 76.3	1330.4 ± 77.9	1295.7 ± 82.6	1302.8 ± 81.7
MAS (km/h)	15.5 ± 0.7	16.9 ± 0.8	15.5 ± 1.0	17.0 ± 1.0	15.5 ± 0.9	16.0 ± 0.9	15.5 ± 1.0	15.6 ± 1.0
ASR (km/h)	13.8 ± 0.7	12.2 ± 0.6	14.0 ± 0.8	11.7 ± 0.6	14.1 ± 0.6	14.7 ± 2.3	14.1 ± 0.7	13.8 ± 0.7
RSA mean (s)	7.58 ± 0.09	7.33 ± 0.10	7.59 ± 0.13	7.46 ± 0.13	7.59 ± 0.11	7.3 ± 0.1	7.57 ± 0.11	7.58 ± 0.10

CMJ: countermovement jump; MSS: maximal sprint speed; MAS: maximal aerobic speed; ASR: anaerobic speed reserve; RSA: repeated sprint ability; HIITind: individualized high-intensity interval training; HIITlong: long intervals high-intensity interval training; RST: repeated sprint training.

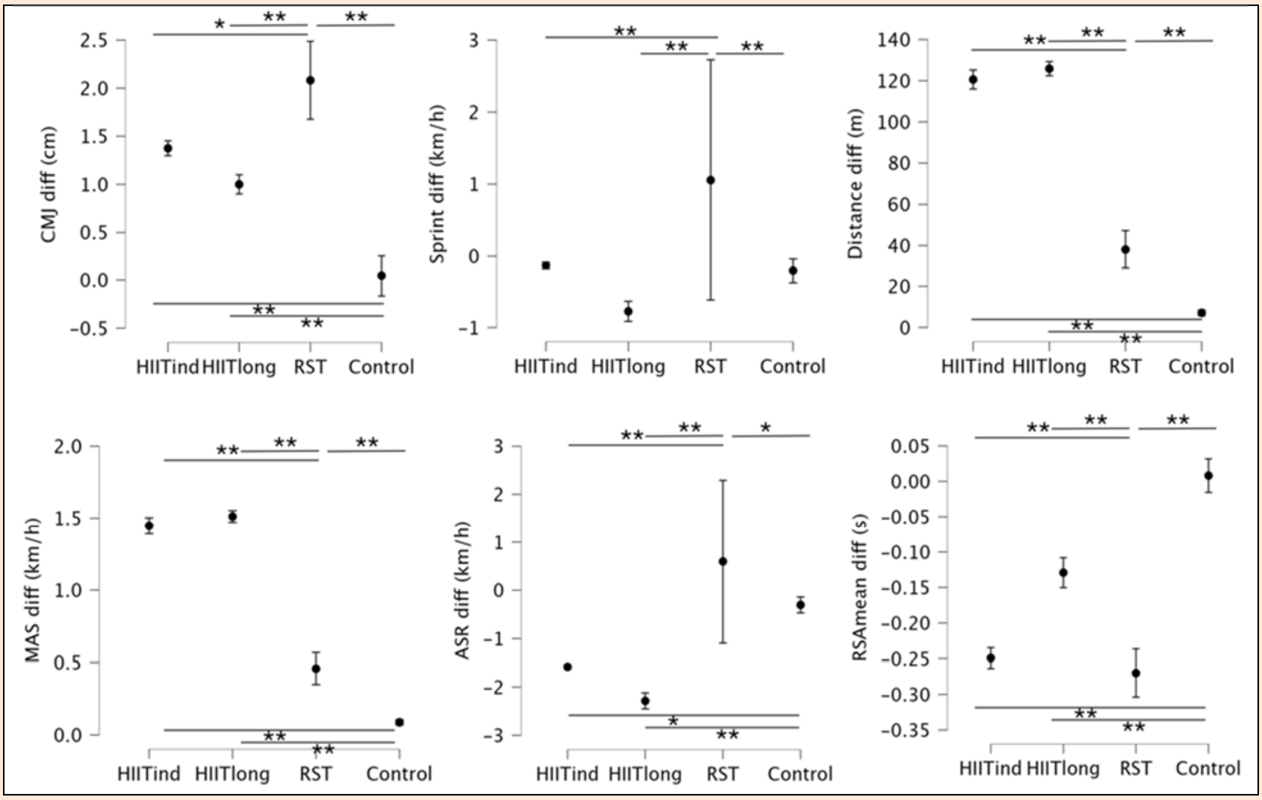

Figure 2. Mean values and 95% confidence intervals (CI) for the delta differences (post-pre) of the main outcomes across the different training groups. CMJ: countermovement jump; MAS: maximal aerobic speed; ASR: anaerobic speed reserve; RSA: repeated sprint ability; HIITind: individualized high-intensity interval training; HIITlong: long intervals high-intensity interval training; RST: repeated sprint training. *: significant differences between-groups at p <0.05; **: significant differences between-groups at p < 0.001.

Additionally, RST showed significantly greater improvement in MSS compared to HIITind (mean difference: 1.78 km/h; $p < 0.001$, Cohen's $d = 1.18$, large ES) and HIITlong (mean difference: 2.40 km/h; $p < 0.001$, Cohen's $d = 1.59$, large ES). No significant differences were observed between HIITind and HIITlong ($p = 0.650$, Cohen's $d = 0.31$, small ES). Comparisons between locomotor profiles revealed significant differences ($p < 0.001$; $\eta p^2 = 0.379$), with the endurance profile presenting greater improvements compared to hybrid ($p = 0.021$, Cohen's $d = 0.67$, medium ES) and speed ($p < 0.001$, Cohen's $d = 1.24$, large ES).

Distance at 5-minute test

Comparisons between groups for distance covered at 5-min test delta values (post-pre) revealed significant differences ($p < 0.001$; $\eta p^2 = 0.972$). The control group showed significantly less improvement compared to HIITind (mean difference: -113.19 m; $p < 0.001$, Cohen's $d = 1.94$, large ES), HIITlong (mean difference: -118.34 m; $p < 0.001$, Cohen's $d = 1.93$), and RST (mean difference: -31.53 m; $p < 0.001$, Cohen's $d = 0.54$, medium ES). Additionally, RST showed significantly smaller improvement in distance covered at 5-min test compared to HIITind (mean difference: -81.7 m; $p < 0.001$, Cohen's $d = 1.46$, large ES) and HIITlong (mean difference: -86.8 m; $p < 0.001$, Cohen's $d = 1.48$, large ES). No significant differences were observed between HIITind and HIITlong ($p > 0.999$). Comparisons between locomotor profiles revealed no significant differences ($p = 0.593$; $\eta p^2 = 0.030$).

Maximal aerobic speed

Comparisons between groups for MAS delta values (post-pre) revealed significant differences ($p < 0.001$; $\eta p^2 = 0.972$). The control group showed significantly less improvement compared to HIITind (mean difference: -1.36 km/h; $p < 0.001$, Cohen's $d = 1.70$, large ES), HIITlong (mean difference: -1.42 km/h; $p < 0.001$, Cohen's $d = 1.64$, large ES), and RST (mean difference: -0.38 km/h; $p < 0.001$, Cohen's $d = 0.44$, small ES). Additionally, RST showed significantly smaller improvement in MAS compared to HIITind (mean difference: -0.98 km/h; $p < 0.001$, Cohen's $d = 1.21$, large ES) and HIITlong (mean difference: -1.04 km/h; $p < 0.001$, Cohen's $d = 1.18$, large ES). No significant differences were observed between HIITind and HIITlong ($p > 0.999$). Comparisons between locomotor profiles revealed no significant differences ($p = 0.575$; $\eta p^2 = 0.032$).

Anaerobic speed reserve

Comparisons between groups for ASR delta values (post-pre) revealed significant differences ($p < 0.001$; $\eta p^2 = 0.699$). The control group showed significantly less improvement compared to HIITind (mean difference: -1.29 km/h; $p = 0.019$, Cohen's $d = 0.61$, medium ES), HIITlong (mean difference: -1.98 km/h; $p < 0.001$, Cohen's $d = 0.95$, large ES), and RST (mean difference: -1.47 km/h; $p = 0.009$, Cohen's $d = 0.72$, medium ES). Additionally, RST showed significantly greater improvement in ASR compared to HIITind (mean difference: 2.76 km/h; $p < 0.001$, Cohen's *d* = 1.33, large ES) and HIITlong (mean difference: 3.45 km/h; $p < 0.001$, Cohen's *d* = 1.69, large ES). No significant differences were observed between HIITind and HIITlong ($p = 0.558$, Cohen's *d* = 0.26, small ES). Comparisons between locomotor profiles revealed significant differences ($p < 0.001$; $\eta p^2 = 0.365$), with the endurance profile presenting greater improvements compared to hybrid ($p = 0.031$, Cohen's *d* = 0.58, medium ES) and speed ($p < 0.001$, Cohen's *d* = 1.04, large ES).

Repeated sprint ability

Comparisons between groups for RSAmean delta values (post-pre) revealed significant differences ($p < 0.001$; $\eta p^2 = 0.885$). The control group showed significantly worse improvements compared to HIITind (mean difference: 0.26 s; $p < 0.001$, Cohen's *d* = 1.38, large ES), HIITlong (mean difference: 0.13 s; $p < 0.001$, Cohen's *d* = 0.69, medium ES), and RST (mean difference: 0.27 s; $p < 0.001$, Cohen's *d* = 1.43). Additionally, RST showed significantly greater improvement in RSAmean compared to HIITind (mean difference: -0.14 s; $p < 0.001$, Cohen's *d* = 0.74, medium ES), but not to HIITlong (mean difference: -0.02 s; $p > 0.999$, Cohen's *d* = 0.11, trivial ES). HIITind also presented significantly greater RSAmean improvements than HIITlong (mean difference: -0.12 s; $p < 0.001$, Cohen's *d* = 0.63, medium ES). Comparisons between locomotor profiles revealed no significant differences ($p = 0.998$; $\eta p^2 > 0.001$).

Discussion

This study aimed to investigate whether adjusting HIIT interventions to youth players' locomotor profiles would enhance training outcomes compared to non-individualized approaches. The findings revealed that all HIIT modalities - individualized (HIITind), long-interval (HIITlong), and repeated sprint training (RST) - led to significant improvements across aerobic, anaerobic, and neuromuscular capacities when compared to the control group. However, RST consistently elicited superior gains in neuromuscular and anaerobic performance measures, including CMJ, MSS, ASR, and RSAmean. In contrast, HIITind and HIITlong were more effective than RST in enhancing aerobic capacity, as reflected by improvements in both the 5-minute running test and MAS. No significant differences were found between HIITind and HIITlong across most outcomes, and the influence of locomotor profile was inconsistent, affecting only MSS and ASR. These results suggest that while individualized programming does not markedly outperform standardized protocols, the choice of HIIT modality - particularly RST versus aerobic-focused HIIT - plays a more critical role in driving specific physical adaptations.

Research suggests that RST may be more effective than long interval high-intensity training for improving CMJ performance in soccer players. A previous study (Campos-Vazquez et al., 2015) reported that combining RST with strength training improved CMJ performance in young soccer players. Another (Tønnessen et al., 2011) observed moderate improvements in CMJ following a 40-m RST program without strength training. Also a last (Aguiar et al., 2008) showed that intermittent high-intensity training, similar to RST, was more effective than continuous training for improving jump performance. Our results revealed that although HIITind assigned players to either RST or HIITlong based on their locomotor profiles, the resulting adaptations - while effective compared to the control group - did not surpass the improvements observed in the non-individualized RST group. The superior improvements observed in the RST group may be attributed to the high neuromuscular and anaerobic demands of repeated sprint efforts (Collins et al., 2018). RST elicits substantial recruitment of fast-twitch muscle fibers (Ross and Leveritt, 2001), which may help the muscle power in movements as the CMJ. In contrast, although HIITind matched training modalities to player profiles, the physiological overlap between endurance and speed profiles may have limited the specificity of stimulus needed to produce superior adaptations.

A previous study (Cicioni-Kolsky et al., 2013) showed that supramaximal interval training, a form of RST, produced greater enhancements in sprint and RSA performance than HIIT. These findings are consistent with our results, which showed that RST was more effective than both HIITind and HIITlong in improving MSS. RST involves short, high-intensity bouts of maximal effort with brief recovery periods, which likely stimulate neuromuscular adaptations such as increased motor unit recruitment (Bishop et al., 2011), enhanced rate of force development (Hermosilla-Palma et al., 2022), and improved intramuscular coordination. Additionally, repeated sprint efforts may improve stride mechanics and the efficiency of force application during acceleration and top-speed phases (Romero et al., 2025). These adaptations eventually contribute to sprint performance, making RST a particularly potent stimulus for enhancing MSS compared to more aerobic-oriented HIIT protocols.

Our results also showed that RST was more effective than both HIITind and HIITlong in enhancing RSAmean. While similar findings have not yet been reported in soccer, evidence from tennis shows that RST leads to significantly greater improvements in RSA compared to traditional HIIT protocols (Fernandez-Fernandez et al., 2012), supporting our observations. The enhanced improvements in RSA observed with RST are likely due to its targeted stress on both the phosphagen and glycolytic energy systems (Ross and Leveritt, 2001), which are critical for high-intensity, intermittent efforts. RST promotes adaptations such as increased muscle phosphocreatine availability (Saraslanidis et al., 2011), and improved anaerobic energy production (Bishop et al., 2011), both possibly contributing to better sprint recovery and sustained performance across repeated efforts.

Both HIIT and RST enhance aerobic capacity, and fatigue resistance (Arazi et al., 2017; Clemente et al., 2021). However, our results showed that both HIITind and HIITlong were more effective in enhancing aerobic capacity than RST, with all training groups outperforming the control group. Both HIIT protocols eventually placed a significant demand on the aerobic energy system by promoting cardiovascular and mitochondrial adaptations (Atakan et al., 2021). These adaptations likely increased the efficiency of oxygen delivery and utilization during exercise (Hafstad et al., 2011), which can be key factors in improving aerobic capacity.

One of the primary limitations of this study is the inconsistency in the influence of locomotor profiles on training outcomes. Although individualized HIIT interventions (HIITind) fitted to players' locomotor profiles were hypothesized to outperform non-individualized approaches, the findings revealed no significant differences across most outcomes. This suggests that individualized programming, while effective in improving performance compared to a control group, may not provide substantial benefits over standardized HIIT modalities. However, a limitation is that we grouped players into tertiles; a more refined approach may be needed to better approximate the individual needs and characteristics of each participant. Additionally, the study was limited by the variability in the adaptation responses of different athletes, especially given the complex interplay of factors like endurance and speed profiles, which may have influenced the specificity of the training stimulus. Also, confounding factors such as dietary and recovery strategies were not analyzed; future research should consider these to minimize potential bias. Finally, conducting the study within different teams may inherently carry specific effects from each team's regular training. Although allocation and randomization were performed within each team to minimize contextual bias, future research should aim to detail and monitor all training methodologies and their potential impact on observed adaptations.

In practical terms, the results highlight the importance of selecting the right type of HIIT modality based on the specific physical adaptations desired for youth soccer players. While RST was particularly effective for improving neuromuscular and anaerobic performance, it may not be as effective as HIITind or HIITlong for enhancing aerobic capacity. Individualization may ultimately be more beneficial for managing acute stimulus and player tolerance rather than for long-term practical adaptations; however, this requires further research and exploration. Therefore, practitioners aiming to enhance anaerobic power or sprint performance might prioritize RST, involving multiple short sprints with limited recovery, especially during phases focusing on speed development. On the other hand, HIIT with longer intervals (e.g., 3-4 minutes at high intensity) have can be more interesting for improving aerobic power and aerobic endurance, suggesting their usefulness when the goal is to enhance high-intensity running ability. Further research is needed to investigate the long-term effects of these interventions and the role of locomotor profiles across more diverse competitive levels. Additionally, it is important to determine the relevance of specific HIIT interventions depending on the time of the season - an aspect that our study was unable to address.

Conclusion

The findings confirm that all HIIT interventions - whether individualized (HIITind), long-interval (HIITlong), or repeated sprint training (RST) - result in significant improvements in aerobic, anaerobic, and neuromuscular performance compared to a control group. However, RST emerged as the most effective approach for enhancing neuromuscular and anaerobic performance, particularly in measures like MSS and RSA. In contrast, HIITind and HIITlong were more beneficial for improving aerobic capacity. Despite the individualized approach, which aimed to match training to players' locomotor profiles, no clear advantage was observed over non-individualized training modalities. This suggests that the choice of training modality - particularly the emphasis on sprint- or endurance-focused protocols - may play a more significant role in driving specific physical adaptations than the individualization of the training program itself. However, this should be carefully considered in youth players, and further research is needed across other competitive levels.

When designing HIIT programs, coaches can prioritize the specific performance goals of your players. If the goal is to boost speed, power, and repeated sprint ability, repeated sprint training (RST) can be a more recommended option. For enhancing aerobic endurance, both individualized and long-interval HIIT are effective. Importantly, designing HIIT sessions to individual player profiles does not necessarily provide added benefits over standard protocols. This possibly means coaches should focus more on choosing the right training modality. The current results stress the importance of selecting the right HIIT modality to achieve desired performance outcomes, while further investigation into the long-term effects and broader applicability of these training strategies is warranted.

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Key points

- Individualized HIIT programming based on locomotor profiles did not produce significantly greater performance adaptations than non-individualized approaches, suggesting limited added value in youth soccer contexts.
- Repeated sprint training (RST) elicited superior improvements in anaerobic and neuromuscular capacities, highlighting its effectiveness as a time-efficient conditioning strategy for young athletes.

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