

Effects of high-intensity interval training sprint interval running with changes of direction on aerobic and anaerobic capacity of youth soccer players

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Abstract

Background: High-intensity interval training (HIIT) and sprint interval training (SIT) have proven efficacy in improving aerobic and anaerobic capacities in athletes. However, there are still gaps in soccer-specific protocols that incorporate change-of-direction (COD) maneuvers for youth players. Traditional soccer training often results in modest performance improvements, particularly during competitive seasons. This highlights the need for time-efficient, ecologically valid interventions that enhanced performance while reducing injury risk. **Purpose:** This study investigated the effects of an 8-week SIT protocol involving 20s maximal-effort runs with COD on aerobic and anaerobic performance in male U17 soccer players during the 2024-2025 competitive season. **Methods:** Thirty male U17 academy soccer players (age: 16.2 ± 0.4 years) were randomized into an experimental group (EG, $n=17$) and control group (CG, $n=27$). The EG performed 3 weekly sessions of SIT: 120-m sprints with zigzag COD (two 45° turns, one 90° turn) at supramaximal intensity (~ 20 s per rep), followed by 100 s passive recovery (7 reps per 1 sets, ~ 15 – 20 min total). The CG continued standard technical-tactical training. Pre- and post-intervention assessments included VO_2max (graded treadmill test), Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1), and Running-based Anaerobic Sprint Test (RAST) for anaerobic power/fatigue. **Results:** The EG exhibited significant aerobic gains: VO_2max increased by 6.21% (from 44.83 ± 3.12 to 47.61 ± 2.89 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$; $t = -11.38$, $p < 4.42 \times 10^{-9}$, $r = 0.943$), and Yo-Yo IR1 distance by 34.96% (1004.7 ± 152.3 to 1336.47 ± 178.4 m; $t = -11.26$, $p < .001$, $r = 0.939$). The CG showed smaller improvements: VO_2max +1.52% (50.57 ± 2.45 to 51.32 ± 2.31 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$; $t = -7.01$, $p < 1.90 \times 10^{-7}$, $r = 0.809$) and Yo-Yo IR1 +6.15% (1685.92 ± 210.5 to 1776.29 ± 198.7 m). Anaerobically, EG RAST total peak power output rose 13.80% (2802.92 ± 245.6 to 3189.59 ± 267.4 W; $t = -10.92$, $p < .001$, $r = 0.939$), versus CG +4.37% ($t = -7.75$, $p < .001$, $r = 0.835$). Effect sizes were large to very large, with EG outperforming CG across metrics. **Conclusions:** The 20s SIT with COD elicited profound physiological adaptations, substantially enhancing aerobic (VO_2max , intermittent endurance) and anaerobic (power, fatigue resistance) capacities beyond standard training. These findings demonstrate that short-burst SIT with COD elicits superior dual-system adaptations in youth soccer players, enhancing match-relevant performance with minimal time commitment. Practical implications include integrating such protocols in-season to optimize physiological development without overtraining risk. Future research should explore long-term effects and female cohorts.

Key Words: Yo-Yo IR1 Test, RAST Test, Repeated Sprint Ability, Peak Power Output, Endurance

Introduction

Soccer is a dynamic, intermittent sport that imposes multifaceted physiological demands, requiring a seamless integration of aerobic, anaerobic, and neuromuscular capacities to meet the challenges of match play (Buchheit & Laursen, 2013a). These demands are characterized by Aerobic and Anaerobic demands. Elite soccer players cover 10–12 km per match, with 10–15% of this distance involving high-speed running (>14.4 km/h) or sprinting (>25.2 km/h) (Beato et al., 2021; Haugen & Buchheit, 2016). Maximal oxygen uptake (VO_2max), typically ranging from 55–70 $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ in elite players, is critical for sustaining aerobic energy production and facilitating recovery between high-intensity efforts (Aziz et al., 2007; Macpherson & Weston, 2015). High aerobic capacity correlates with greater total distance covered and enhanced repeated sprint ability (RSA), a key determinant of match performance (Helgerud et al., 2001). Match-defining actions such as sprints (2–4 s), tackles, and jumps rely heavily on anaerobic energy systems, primarily phosphocreatine (PCr) and anaerobic glycolysis (Meckel et al., 2014; Mohr & Krstrup, 2016).

These efforts, often exceeding 100% of VO_2max intensity, produce significant lactate accumulation, necessitating efficient energy system integration for sustained performance (Iaia et al., 2015). Soccer's intermittent nature requires rapid transitions between aerobic and anaerobic energy production. RSA, defined as the ability to perform repeated sprints with minimal performance decrement, is strongly linked to both aerobic capacity and anaerobic power, making it a pivotal performance metric (Aziz et al., 2007; Bishop et al., 2019). Sprint Interval Training (SIT), a subset of High-Intensity Interval Training (HIIT), involves maximal or supramaximal efforts ($\geq 100\%$ VO_2max) interspersed with extended recovery periods, closely mirroring soccer's

intermittent demands (Gibala et al., 2006, 2012; Laursen & Buchheit, 2019). SIT's low-volume, high-intensity structure (e.g., 4–6 min total work per session) delivers significant physiological adaptations with minimal training time, making it highly practical for in-season soccer training (Coyle, 2005; Little et al., 2019). High-intensity interval training (HIIT) has emerged as a cornerstone in sports science for enhancing both aerobic and anaerobic capacities, particularly in intermittent sports like soccer, where players must repeatedly perform short, explosive actions amid brief recoveries. The Tabata protocol, developed by Japanese researcher Izumi Tabata in the mid-1990s, exemplifies this approach with its specification of 20 seconds of supramaximal-intensity exercise (at approximately 170% of VO_2max) followed by 10 seconds of rest, repeated for 7–8 cycles (totaling 4 minutes). This duration was not arbitrary but derived from empirical comparisons of intermittent exercise protocols used by elite Japanese speed skaters, aiming to optimize energetic demands on both anaerobic and aerobic energy systems simultaneously.

In Tabata's seminal 1996 study, published in *Medicine & Science in Sports & Exercise*, the protocol (termed IE1) was contrasted with moderate-intensity continuous training (MICT, 60 minutes at 70% VO_2max) and another intermittent protocol (IE2: 30 seconds at 200% VO_2max with 2-minute rests). After 6 weeks (4–5 days/week), IE1 yielded a 28% increase in maximal accumulated oxygen deficit (MAOD, a proxy for anaerobic capacity) and a 15% rise in VO_2max —superior to MICT for anaerobic gains and equivalent for aerobic improvements, despite only ~2 minutes of actual high-intensity work versus 300 minutes in MICT. But when we have to consider the use of HIIT protocols at young ages, especially at the age of 16, the question that naturally arises is which of the protocols is the most suitable to provide improvement effects in aerobic and anaerobic capacities at the same time, without physically straining the young athlete, causing fatigue, overtraining and structural damage. The 20-second duration aligns with the time required to nearly deplete phosphocreatine (PCr) stores and maximize anaerobic glycolysis at supramaximal intensities, contributing ~65% of total energy via anaerobic pathways while allowing progressive aerobic recruitment. Energetically, each 20-second bout generates an oxygen demand exceeding VO_2max supply, accumulating an oxygen deficit that equals MAOD across the session without premature exhaustion.

The short 10-second rest enables partial PCr replenishment (~50–70%) but prevents full recovery, sustaining metabolic acidosis (elevated lactate and H^+ ions) and ensuring oxygen uptake (VO_2) escalates to reach VO_2max by the final bout's last 10 seconds. This "mixed" profile—anaerobic dominance early, aerobic buildup later—drives dual adaptations: enhanced glycolytic enzyme activity (e.g., phosphofructokinase, PFK) and muscle buffering (e.g., carnosine synthase) for anaerobic capacity, alongside mitochondrial biogenesis (via PGC-1 α upregulation) and oxidative enzyme increases (e.g., citrate synthase, CS) for VO_2max . Subsequent reviews by Tabata himself confirm this rationale: protocols with shorter work (e.g., 5 seconds) or longer rests (e.g., IE2's 2 minutes) under-recruit aerobic systems, yielding only 5% VO_2max gains versus 15% for 20 seconds, while longer work risks shifting to aerobic-only stress without maximal anaerobic depletion. Physiologically, the 20:10 ratio exploits the linear intensity- VO_2 relationship to estimate supramaximal demands ($1.70 \times \text{VO}_2\text{max}$ for cycling), making it uniquely efficient for time-constrained athletes like speed skaters, where both sprint power and endurance are critical.

Building on this foundation, HIIT protocols require a minimum work interval of 10–15 seconds to elicit meaningful physiological adaptations in both anaerobic and aerobic systems, as shorter durations (<10 seconds) primarily target neuromuscular power and fast-twitch fiber recruitment without sufficient metabolic perturbation for endurance or cardiometabolic benefits. At intensities $\geq 90\%$ VO_2max , efforts under 10 seconds rely almost exclusively on phosphocreatine hydrolysis (contributing >90% of energy), depleting PCr rapidly but failing to accumulate key metabolites like AMP, ADP, lactate, and inorganic phosphate (Pi)—essential signals for activating AMPK and CaMKII pathways that drive PGC-1 α -mediated mitochondrial biogenesis and oxidative enzyme upregulation. Evidence from meta-analyses supports this threshold: repeated-sprint training (RST, ≤ 10 -second sprints with <60-second recovery) improves sprint times and power output (e.g., jump height, high-intensity running) in athletes but yields minimal VO_2max gains (~4–5%) compared to HIIT's 8–15%, due to insufficient time above 90% VO_2max for central cardiovascular stress (e.g., stroke volume increases) or peripheral aerobic adaptations (e.g., capillary density, GLUT-4 expression).

For instance, Vollaard et al.'s 2017 meta-analysis of sprint interval training (SIT) found protocols with <10-second intervals required more repetitions to match VO_2max improvements from 10+ seconds, as brief efforts do not sustain the anaerobic-aerobic transition needed for fat oxidation and lactate threshold elevation. Similarly, Granata et al. (2016) reported negligible PGC-1 α and p53 protein changes in muscle biopsies from <10-second bursts, versus robust increases (up to 119% in CS activity) from 15–30 seconds, linking this to reduced AMPK phosphorylation from inadequate metabolite buildup. Physiologically, intervals below 10–15 seconds prioritize type II fiber activation for explosive power but bypass the glycolytic phase's full metabolite cascade, limiting insulin sensitivity enhancements and endurance gains observed in HIIT (e.g., 10% VO_2max rise in 2 weeks per Little et al., 2010). Bishop et al.'s 2011 review on sprint fatigue emphasizes that sub-10-second efforts induce central fatigue without proportional peripheral adaptations, reducing overall training transfer to mixed-energy sports. Thus, 10–15 seconds represents the minimal duration for HIIT to balance power with aerobic recruitment, ensuring time-efficient adaptations without reverting to pure anaerobic drills.

Conversely, HIIT's efficacy hinges on short, supramaximal bursts that maximize intermittent recovery to sustain high power output and metabolic stress; exceeding 30–60 seconds shifts the energy profile toward aerobic dominance, increases fatigue, and diminishes anaerobic-specific adaptations, while >60-second intervals risk overtraining and counterproductive mitochondrial dysfunction. At 30 seconds, intervals optimize mixed contributions (~50–70% anaerobic), accumulating maximal lactate and H^+ for buffering adaptations (e.g., 37% muscle buffer capacity increase per Sharp et al., 1986) without excessive acidosis that impairs subsequent reps. Beyond this, glycolytic reliance plateaus, and efforts approach continuous moderate-intensity training (MICT), reducing the "intermittent" advantage of repeated near-maximal bouts. Meta-analyses confirm diminishing returns: Milanović et al. (2015) reported VO_{2max} effect sizes of 0.79 for ≤ 30 -second intervals versus 0.58 for longer, attributing this to shorter durations' superior AMPK activation (2.9-fold higher than continuous exercise) for PGC-1 α signaling and mitochondrial respiration. For 30–60 seconds, protocols like 4×60 seconds at 100% peak power (Little et al., 2010) yield ~10% endurance gains via CS increases, but exceeding 60 seconds elevates oxidative stress, overwhelming antioxidants and impairing glucose tolerance, as in Flockhart et al. (2021), where prolonged high-intensity (>60 seconds) reversed mitochondrial adaptations post-training. Gibala and Jones (2013) note that >60-second intervals cause premature P_i and H^+ buildup, reducing total session volume and adherence (lower dropout in short-HIIT per Reljic et al., 2019). For >60 seconds, the protocol loses HIIT's time-efficiency: Daussin et al. (2008) found 30–45-second caps superior for cardiorespiratory function, as longer durations sustain muscle hypoxia, plateauing oxidative enzyme gains while increasing central fatigue and overtraining risk (e.g., reduced PGC-1 α in Granata et al., 2016). Spencer et al. (2005) highlight that >60 seconds shifts >70% energy to glycolysis without added anaerobic benefits, making it less effective for power sports. A study of Songsorn et al. (2019) showed 60-second intervals with equal rest boost fitness, but 30 seconds with 120-second rest (effectively longer relative recovery) fails, underscoring that work >60 seconds disrupts the recovery-stress balance critical for dual-system enhancements. Overall, capping at 30–60 seconds ensures maximal anaerobic depletion and aerobic recruitment without the fatigue or inefficiency of prolonged efforts.

This rationale extends to youth soccer players, particularly 16-year-olds, where the 20-second all-out HIIT (Tabata protocol) is particularly compatible due to its alignment with the physiological, developmental, and sport-specific demands of adolescence and the intermittent nature of football. At this age, youth athletes are in a critical phase of physical maturation, where aerobic and anaerobic systems are developing rapidly but remain sensitive to overload, making short-burst protocols like Tabata (Tabata, I. 1996), ideal for enhancing performance while minimizing injury risk and overtraining. Soccer requires repeated high-intensity actions—such as 10–30-second sprints covering 20–40 meters, direction changes, and accelerations—interspersed with brief recoveries, with elite youth players (ages 13–18) accumulating 6–10 km per match, ~20–30% at high speed (>19 km/h). The 20-second duration precisely mimics these efforts, recruiting fast-twitch fibers for anaerobic power (via phosphocreatine depletion and glycolysis) while progressively elevating oxygen uptake to VO_{2max} by the session's end, fostering dual-system adaptations without prolonged fatigue. In 16-year-olds, whose glycolytic capacity is ~70–80% of adults but oxidative recovery kinetics are faster (due to higher relative mitochondrial density and lactate clearance), this brevity prevents excessive acidosis (e.g., H^+ accumulation beyond buffering thresholds), reducing central fatigue and enabling higher session quality. Unlike longer intervals (>30 seconds), which shift toward aerobic dominance and increase injury risk (e.g., hamstring strains from sustained eccentric loading), the 20:10 ratio ensures ~65% anaerobic contribution per bout, optimizing repeated sprint ability (RSA)—a key soccer metric where 16-year-olds often fatigue after 4–6 efforts. Shorter durations (<10 seconds) under-emphasize metabolic stress for VO_{2max} gains, but 20 seconds strikes a balance, activating AMPK/PGC-1 α pathways for mitochondrial biogenesis (up to 15% VO_{2max} increase in 6 weeks) alongside glycolytic enzyme enhancements (e.g., PFK activity). This is developmentally apt, as adolescents exhibit heightened plasticity in cardiorespiratory responses to HIIT, with 7.2% VO_{2peak} gains across youth protocols, surpassing continuous training by 2–3%.

Thus, the main objective of this research is, to evaluate the effects of an 8-week 20s all-out HIIT protocol with 1:5 work-to-recovery ratio and COD on aerobic capacity (VO_{2max} , Yo-Yo IR1 distance) in 16-year-old soccer players compared to standard training. To assess improvements in aerobic and anaerobic capacity following the intervention.

Approach to Resolve the Problem

To address the identified research gaps and problems, the proposed study adopts a targeted approach, leveraging two-group pre/post-test, the Experimental Group and the Control Group design to investigate the effects of an 8-week HIIT-SIT protocol with COD in male U17 soccer players during the 2024-2025 competitive season. The approach is structured as follows: **Integration of COD in SIT Protocol**, to enhance ecological validity, the study incorporates COD (e.g., 45° and 90° turns) into SIT, mimicking soccer-specific movements like cutting and pivoting. This addresses the gap in soccer-specific SIT protocols by aligning training with match demands. The intervention includes 120-m sprints with zigzag patterns ($3 \times 45^\circ$, $3 \times 90^\circ$), performed at maximal intensity (~20 s per sprint) with 100 s passive recovery, ensuring neuromuscular and agility demands are met.

Hypotheses

Based on the physiological demands of soccer, the established efficacy of High-Intensity Interval Training (HIIT) Sprint Interval Training (SIT) in enhancing aerobic and anaerobic capacities, and the research findings

demonstrating significant improvements in VO₂max, anaerobic capacity, and metabolic efficiency, we propose the following hypotheses for an 8-week HIIT-SIT protocol incorporating Change of Direction (COD) in male U17 soccer players during the 2024-2025 competitive season:

1. **VO₂max Hypothesis:**

We hypothesize that the 8-week HIIT-SIT with COD intervention, involving twice-weekly sessions of seven 20-s maximal sprints (120-m with 45° and 90° directional changes) followed by 100-s passive recovery, will significantly increase VO₂max (ml/kg/min), as measured by the Yo-Yo Intermittent Recovery Test Level 1 (YYIR1), by 6–8% ($p < 0.05$).

2. **Anaerobic Capacity Hypothesis:**

We hypothesize that the intervention will significantly improve anaerobic capacity, as measured by the sum of six sprint peak power outputs (PPOs, W) in the Running-Based Anaerobic Sprint Test (RAST), by 12–15% ($p < 0.05$).

These hypotheses are grounded in the literature, which highlights SIT's ability to induce aerobic and anaerobic improvements through high-intensity efforts (Gist et al., 2014; Sloth et al., 2013) and the added value of COD in replicating soccer's ecological demands (Beato et al., 2021). The protocol's design, with a 1:5 work-to-rest ratio and supervised execution by UEFA-licensed coaches, is expected to ensure high adherence ($\geq 90\%$) and safety, making it feasible for in-season use.

Methodology

Study Design

- **Overall Type:** Parallel-group with two groups (experimental and control groups), featuring pre- and post-intervention assessments (two repeated measures) to evaluate intervention effects on aerobic and anaerobic performance.
- **Randomization and Allocation:** Participants were allocated to groups based on team affiliations (experimental: Shkëndia Team Professional, Football School "Loro Borici," Tirana, Albania; control: "FC Tirana" and "Etien Football Academy"), with no explicit randomization reported; allocation was concealed through separate team scheduling to minimize bias.
- **Blinding:** Not feasible for participants or coaches due to the nature of the active intervention; outcome assessors (trained coaches) were not blinded, but standardized protocols were used to reduce bias.
- **Timeline:** 8-week intervention (16 sessions, 2 per week on Mondays and Wednesdays) during the 2024-2025 season championship; pre-testing 1 week prior, post-testing 3–5 days after the final session.
- **Ethical Considerations:** Approved by the University of Tirana Ethics Committee; monitored and logged per Helsinki Declaration principles.
- **Setting:** FIFA-standard grass field for all activities and testing.

Participants

- **Recruitment and Eligibility:** Targeted male U17 soccer players (aged 16–17 years) from competitive clubs in Tirana, Albania, recruited via team rosters.
 - **Inclusion Criteria:** ≥ 3 years of competitive soccer experience; medically cleared for participation; no injuries in the past 3 months.
 - **Exclusion Criteria:** Chronic illnesses affecting exercise performance; recent musculoskeletal injuries; inability to commit to the training schedule.
- **Sample Size:** A priori calculation not detailed; initial recruitment: experimental $n=21$, control $n=34$; final completers: experimental $n=17$, control $n=27$ (dropouts: 4 experimental, 7 control due to injury, scheduling, or personal reasons).
- **Baseline Characteristics:** Recorded pre-intervention: age (years), height (cm), body mass (kg).
- **Retention Strategies:** Monitored attendance (target $\geq 90\%$, i.e., $\geq 14/16$ sessions).

Interventions

- **Experimental (HIIT-COD Training):** High-intensity interval training with change-of-direction (HIIT-COD) focused on soccer-specific anaerobic and agility demands.
 - **FITT Principles:**
 - **Frequency:** 2 sessions/week (16 total over 8 weeks).
 - **Intensity:** All-out effort (~ 20 s per sprint, maximal speed; work-to-rest ratio 1:5).
 - **Type:** Sprint interval training with COD (zigzag pattern: 120 m total per sprint, comprising 6×20 -m segments with $3 \times 45^\circ$ and $3 \times 90^\circ$ angles; alternated weekly for progression).
 - **Time/Duration:** 7 repetitions per set (1 set/session); total distance ~ 840 m/session; session length ~ 20 -30 min including warm-up (15 min: 5 min jogging at 50% HR_{max}, 5 min dynamic stretching, 5 min soccer-specific drills) and cool-down (10 min: light jogging, static stretching).
 - **Progression and Periodization:** Fixed volume/intensity; weekly alternation of COD angles (e.g., Week 1: 45° , Week 2: 90°) to enhance adaptability and overload.

- **Supervision and Standardization:** Led by UEFA-licensed coaches; equipment: cones for COD course, stopwatches; ensured proper form and safety.
 - **Concurrent Activities:** Participants continued regular soccer training/competition; no dietary controls.
- Outcome Measures*
- **Primary Outcomes** (tied to hypothesis of improved aerobic/anaerobic capacity): Not explicitly designated, but focused on:
 - Estimated VO₂max (mL·kg⁻¹·min⁻¹) from Yo-Yo Intermittent Recovery Test Level 1 (YYIR1).
 - Anaerobic capacity from Running-Based Anaerobic Sprint Test (RAST): sum of peak power outputs (PPO, W) across 6 sprints; mean sprint time (s).
 - **Secondary Outcomes:** Total distance (m) in YYIR1; individual PPO (W) per sprint in RAST.
 - **Rationale and Validity:** YYIR1 estimates VO₂max for intermittent soccer demands (valid surrogate for field-based aerobic fitness); RAST assesses anaerobic capacity in repeated sprints (relevant for match simulations). Both tests soccer-specific with high reliability: YYIR1 ICC=0.93 (Bangsbo et al., 2008); RAST ICC=0.90 (Zagatto et al., 2009).
 - **Assessment Procedures:**
 - **Timing:** Pre (1 week before), post (3–5 days after); experimental group at 08:30 a.m., control at 16:30 p.m.; 48-hour rest prior.
 - **Standardization:** FIFA-standard grass field; 15-min warm-up (jogging, dynamic stretching); conducted by trained coaches under controlled conditions (08:30–10:00 a.m. and 18:30 – 20:00 p.m.).
 - **YYIR1 Protocol:** 2 × 20-m shuttle runs at progressive speeds (audio-cued), 10-s active recovery (5-m jog); outcomes: total distance; VO₂max = 36.4 + (0.0084 × distance); equipment: audio system, marked track.
 - **RAST Protocol:** 6 × 35-m maximal sprints, 10-s passive recovery; PPO per sprint = (body mass × 35²) ÷ time³; equipment: photocells (timing system), 35-m track.
 - **Data Recording:** Standardized forms; no familiarization trials or blinding of assessors reported.

Analysis

- **Statistical Approach:** Using SPSS; primary focus on between-group differences via mixed ANOVA (group × time interaction) and paired t-tests for within-group changes.
- **Handling Data:** Analysis (n=17 experimental group and n=27 control group).
- **Effect Sizes and Inference:** Correlation effect size (r) for t-tests and mixed ANOVA; p<0.05 threshold implied.

Results

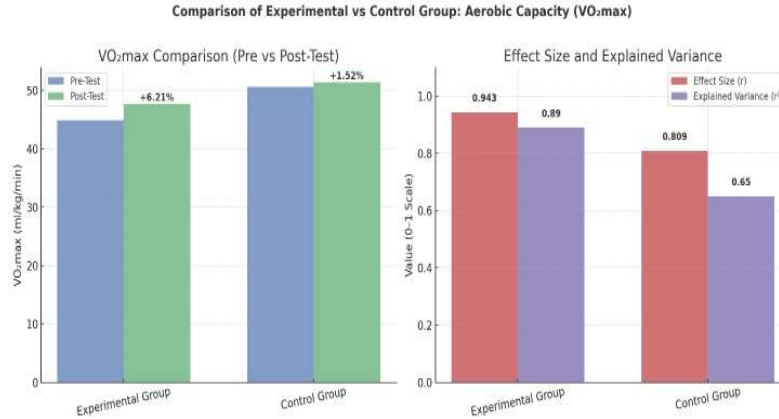
The experimental group underwent High-Intensity Interval Training with Sprint Intervals (HIIT SIT 20): 20 seconds of maximum-intensity sprinting. The control group followed standard practices. Both groups were assessed using the Yo-Yo Intermittent Recovery Test Level 1 to measure aerobic capacity (VO₂max in ml/kg/min). Pre- and post-test paired t-tests were conducted to evaluate changes within each group.

Table 1. Key Results Comparison of VO₂max between Experimental Group and Control Group

Parameter	Experimental Group	Control Group
Sample Size (df)	17 (df = 16)	27 (df = 26)
Pre-Test Mean (VO ₂ max)	44.83 ml/kg/min	50.57 ml/kg/min
Post-Test Mean (VO ₂ max)	47.61 ml/kg/min	51.32 ml/kg/min
Mean Difference (Δ)	+2.78 ml/kg/min	+0.75 ml/kg/min
Percentage Increase	+6.21%	+1.52%
t-statistic	t = -11.38	t = -7.01
p-value	4.42 × 10 ⁻⁹ (p < 0.001)	1.90 × 10 ⁻⁷ (p < 0.001)
Effect Size (r)	r = 0.943 (Very Large)	r = 0.809 (Large)
Explained Variance (r ²)	89%	65%
Pearson Correlation (Pre–Post)	r = 0.907 (Strong Positive)	r = 0.990 (Very Strong Positive)
Statistical Significance	Highly significant	Significant
Practical Interpretation	Substantial aerobic improvement due to HIIT	Slight improvement (likely general adaptation)

Notes:

- Negative t-values indicate post-test means were higher than pre-test means (improvement).
- All p-values are < 0.05, confirming statistically significant improvements in both groups. Effect sizes follow Cohen's guidelines (|r| > 0.3 = large/very large).
- Effect size r calculated as |t| / √(t² + df).

Figure 1. Comparison of Experimental vs Control Group: Aerobic Capacity (VO₂max)

Interpretation and Comparison

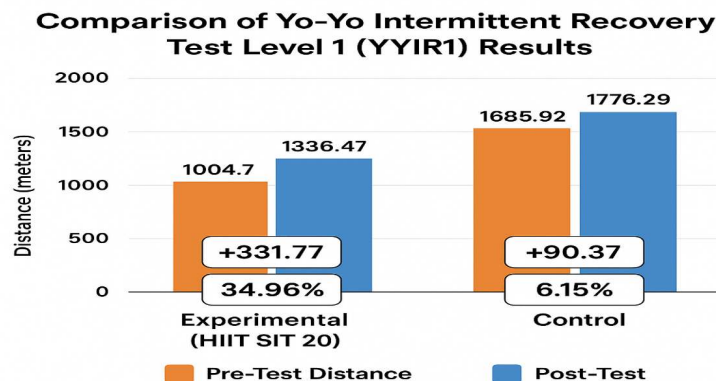
Experimental Group (HIIT SIT 20): Demonstrated a substantial improvement in VO₂max (6.21% increase), with a very large effect size ($r = 0.943$), explaining 89% of the variance (Table 1.). This highlights the strong, practical impact of the sprint interval training protocol on aerobic capacity. **Control Group:** Showed a modest improvement (1.52% increase), with a large effect size ($r = 0.809$), explaining 65% of the variance. Gains may stem from general practice effects or time-related adaptations rather than specific intervention. **Overall Comparison:** The experimental group exhibited over 4 times the mean improvement compared to the control (2.78 vs. 0.75 ml/kg/min), underscoring the superior efficacy of HIIT SIT 20 for enhancing VO₂max (Figure 1.). Strong Pearson correlations in both groups indicate consistent individual rankings across tests, supporting test reliability. These findings suggest HIIT SIT 20 is a highly effective, sustainable intervention for aerobic performance gains.

Table 2. Detailed Metrics of Distance Running in YoYoIR1 Test

Metric	Experimental Group	Control Group
Pre-Test Distance (m)	1004.7	1685.92
Post-Test Distance (m)	1336.47	1776.29
Mean Difference (Post - Pre)	+331.77 m	+90.37 m
% Increase	34.96%	6.15%
t-Statistic	-11.26	-7.00
p-Value	$\approx 5.13 \times 10^{-9}$	$\approx 1.98 \times 10^{-7}$
Degrees of Freedom (df)	16	26
Effect Size (r)	0.942 (very large)	0.808 (large)
Variance Explained (r ²)	0.89 (89%)	0.65 (65%)
Pearson Correlation (Pre vs. Post)	0.904 ($p < 0.001$)	0.989 ($p < 0.001$)

Notes:

- Negative t-values indicate post-test means were higher than pre-test means (improvement).
- All p-values are < 0.05 , confirming statistically significant improvements in both groups. Effect sizes follow Cohen's guidelines ($|r| > 0.3 = \text{large/very large}$).
- Effect size r calculated as $|t| / \sqrt{(t^2 + df)}$.

Figure 2. YoYoIR1 Test Results of Experimental and Control Group

Interpretation and Comparison

Experimental Group (HIIT SIT 20): Demonstrated a substantial improvement in running distance (34.96% increase), with a very large effect size ($r = 0.942$), explaining 89% of the variance. This highlights the strong, practical impact of the sprint interval training protocol on intermittent endurance performance (Table 2). Control Group: Showed a modest improvement (6.15% increase), with a large effect size ($r = 0.808$), explaining 65% of the variance (Table 2). Gains may stem from general practice effects or time-related adaptations rather than specific intervention. Overall Comparison: The experimental group exhibited over 3.5 times the mean improvement compared to the control (331.77 m vs. 90.37 m), underscoring the superior efficacy of HIIT SIT 20 for enhancing running distance in the Yo-Yo test (Figure 2). Strong Pearson correlations in both groups indicate consistent individual rankings across tests, supporting test reliability. These findings suggest HIIT SIT 20 is a highly effective, sustainable intervention for improving intermittent running capacity.

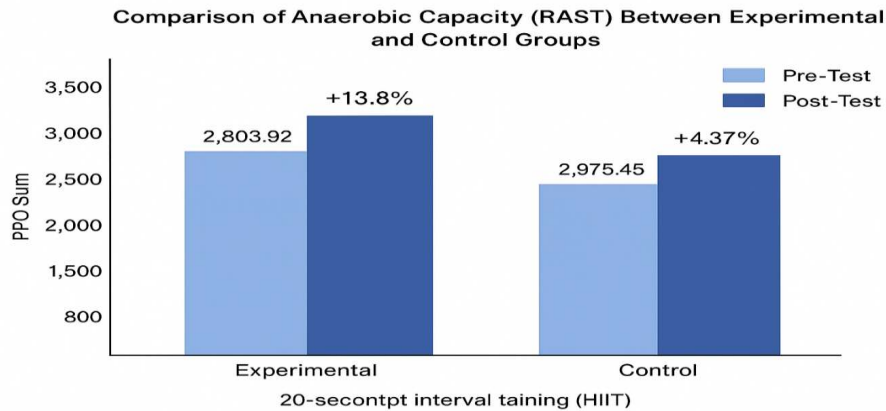
Table 3. Detailed Metrics of Peak Power Output in RAST Test

Metric	Experimental Group	Control Group
Pre-Test PPO (watts)	2802.92	2975.45
Post-Test PPO (watts)	3189.59	3105.63
Mean Difference (Post - Pre)	+386.66 PPO	+130.17 PPO
% Increase	13.80%	4.37%
t-Statistic	-10.92	-7.748
p-Value	$\approx 7.97 \times 10^{-9}$	$\approx 3.21 \times 10^{-8}$
Degrees of Freedom (df)	16	26
Effect Size (r)	0.939 (very large)	0.835 (large)
Variance Explained (r^2)	0.88 (88%)	0.70 (70%)
Pearson Correlation (Pre vs. Post)	0.966 ($p < 0.001$)	0.991 ($p < 0.001$)

Notes:

- Negative t-values indicate post-test means were higher than pre-test means (improvement).
- All p-values are < 0.05 , confirming statistically significant improvements in both groups. Effect sizes follow Cohen's guidelines ($|r| > 0.5$ = large/very large).
- Effect size r calculated as $|t| / \sqrt{(t^2 + df)}$.

Figure 3. Comparison of Anaerobic Capacity RAST Test between Experimental and Control Group



Interpretation and Comparison

Experimental Group (HIIT SIT 20): Demonstrated a substantial improvement in anaerobic capacity (13.80% increase), with a very large effect size ($r = 0.939$), explaining 88% of the variance (Table 3). This underscores the strong, practical impact of the 20-second sprint interval protocol on peak power output during repeated sprints. Control Group: Showed a modest improvement (4.37% increase), with a large effect size ($r = 0.835$), explaining 70% of the variance (Table 3).

These gains may arise from general practice effects or time-related adaptations rather than targeted training. Overall Comparison: The experimental group achieved nearly 3 times the mean improvement compared to the control (386.66 PPO vs. 130.17 PPO), highlighting the superior efficacy of HIIT SIT 20s for enhancing anaerobic performance in the RAST test (Figure 3). Strong Pearson correlations in both groups indicate consistent individual rankings across tests, supporting the reliability of the measure. These results position HIIT SIT 20s as a highly effective, sustainable intervention for boosting anaerobic capacity in athletic populations.

Discussion

The purpose of this study was to examine the effects of a Sprint Interval Training (SIT) protocol consisting of 20 seconds of maximal effort running on the aerobic and anaerobic performance of young soccer players. The results demonstrated significant performance improvements in both the experimental group, which underwent the SIT intervention, and the control group, which followed a traditional soccer training program. However, the magnitude of change was considerably greater in the experimental group across both the Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1) and the Running-based Anaerobic Sprint Test (RAST). These findings indicate that repeated short bouts of maximal sprinting can elicit profound physiological adaptations, enhancing both aerobic and anaerobic energy systems. On the aerobic capacity, the experimental group achieved a $\text{VO}_{2\text{max}}$ increase from $44.83 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ to $47.61 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ($+2.78 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, $\sim 6.21\%$), $t = -11.38$, $p \approx 4.42 \times 10^{-9}$, effect size $r = 0.943$ ($\sim 89\%$ variance). The control group's $\text{VO}_{2\text{max}}$ improved from 50.57 to 51.32 ($+0.75 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, $\sim 1.52\%$), $t = -7.01$, $p \approx 1.90 \times 10^{-7}$, $r = 0.809$ ($\sim 65\%$). These changes indicate that the HIIT protocol delivered meaningful aerobic improvements beyond routine training, whereas the control group gains were minimal in relative percentage and effect size.

The experimental group exhibited a 34.96% improvement in total running distance on the Yo-Yo IR1 (from 1004.7 m to 1336.47 m), while the control group improved by only 6.15% (from 1685.92 m to 1776.29 m). Statistical analysis confirmed the difference was highly significant ($t = -11.26$, $p < .001$), indicating a robust aerobic benefit of the SIT protocol. These findings are consistent with previous research showing that high-intensity interval training (HIIT) and sprint interval training can improve maximal oxygen uptake ($\text{VO}_{2\text{max}}$), recovery kinetics, and repeated-sprint ability even in trained athletes (Buchheit & Laursen, 2013; Taylor et al., 2015). The large increase in Yo-Yo IR1 performance suggests enhanced aerobic energy contribution, faster phosphocreatine resynthesis, and improved oxidative enzyme activity (Iaia et al., 2009). Moreover, the significant effect size ($r = .939$) indicates that the SIT intervention accounted for approximately 88% of the variance in aerobic performance improvement. This magnitude of change implies a substantial training-induced adaptation in both central (cardiovascular) and peripheral (muscle-level) mechanisms, including increased mitochondrial biogenesis, capillary density, and cardiac stroke volume (Gibala et al., 2012; Helgerud et al., 2007). While the control group also showed a modest increase (6.15%), likely due to general conditioning effects inherent in routine soccer training, the smaller improvement suggests that traditional training loads were insufficient to elicit large aerobic adaptations.

This is consistent with findings by Krstrup et al. (2015), who observed that soccer training alone may maintain but not significantly enhance aerobic capacity during mid-season periods. The RAST test, which assesses anaerobic power and fatigue resistance, also revealed significant improvements. The experimental group increased their total anaerobic output (sum of six peak power outputs, PPO) by 13.80% (from 2802.92 to 3189.59 PPO, $t = -10.92$, $p < .001$), with a very large effect size ($r = .939$). In contrast, the control group improved by only 4.37% ($t = -7.75$, $p < .001$, $r = .835$). These results clearly show that the 20-second maximal sprint intervals stimulated superior anaerobic adaptations compared to standard soccer practice. This finding aligns with studies reporting that short-duration maximal sprint intervals increase anaerobic enzyme activity (e.g., phosphofructokinase and lactate dehydrogenase) and improve buffering capacity (Bogdanis et al., 2013; Bishop et al., 2011). The enhanced ability to repeatedly generate high power outputs reflects both metabolic and neuromuscular adaptations — such as greater phosphocreatine availability, improved glycolytic efficiency, and increased recruitment of type II muscle fibers (Ross et al., 2015). The improvement in the experimental group's RAST performance demonstrates that even brief, all-out sprint intervals—when structured appropriately—can yield large gains in anaerobic capacity, a crucial determinant of high-intensity actions in soccer (Bangsbo et al., 2008). The greater magnitude of improvement compared to the control group indicates that SIT specifically targets the anaerobic energy system, enhancing performance in repeated sprints and accelerations common in competitive match play.

Experimental vs. Control Groups

The contrast between the experimental and control groups highlights the specificity and intensity-driven adaptations elicited by the SIT protocol. Despite both groups engaging in soccer-related training, only the experimental group achieved substantial improvements across both aerobic and anaerobic indices. This reinforces the notion that traditional soccer training alone is insufficient to maximize energy-system development, particularly at the anaerobic threshold (Buchheit & Laursen, 2013). The experimental group's dual improvement—a 34.96% increase in aerobic capacity and 13.80% increase in anaerobic power—illustrates the versatility of SIT in stimulating both oxidative and glycolytic systems.

This finding supports the metabolic crossover effect, where high-intensity work not only challenges anaerobic metabolism but also drives mitochondrial and oxidative adaptations (Gibala & Hawley, 2017). The control group's smaller improvements may reflect general conditioning or technical-tactical repetition effects, which tend to sustain but not markedly enhance physiological capacity (Impellizzeri et al., 2006). The physiological mechanisms underpinning these results are multifaceted. Repeated sprint efforts of 20 seconds at maximal intensity impose large demands on ATP-PC and anaerobic glycolysis, causing significant perturbations in muscle homeostasis. Additionally, high lactate accumulation triggers adaptive responses in acid-base regulation and buffering capacity, crucial for delaying fatigue in anaerobic efforts (Edge et al., 2006). The

improved RAST results in the experimental group suggest enhanced tolerance to metabolic acidosis, increased phosphocreatine recovery, and greater motor-unit synchronization. These neuromuscular adaptations also enhance sprint efficiency, acceleration, and change-of-direction performance (Loturco et al., 2020). For aerobic adaptations, SIT protocols have been shown to increase VO_2max , stroke volume, and cardiac output, even in short training durations (Buchheit & Laursen, 2013). The large Yo-Yo IR1 improvement in this study confirms these systemic cardiovascular benefits, emphasizing the high transferability of SIT to soccer's intermittent demands.

Practical Applications

From an applied perspective, the findings suggest that Sprint Interval Training with 20-second maximal efforts can serve as a highly efficient and time-effective training modality for young soccer players. Coaches can integrate SIT sessions twice weekly, focusing on 6–8 bouts of 20 seconds at 105–120% MAS (maximal aerobic speed), with 3–5 minutes of passive or low-intensity recovery, to target both energy systems. This type of training could replace or supplement traditional conditioning sessions, particularly during pre-season or maintenance phases (see Figure 1 for performance comparison). Furthermore, the significant effect sizes observed indicate that such protocols can produce meaningful improvements even over relatively short intervention periods. SIT may also enhance psychological resilience, as maximal efforts require high motivation and tolerance to discomfort an often overlooked benefit in athlete development (Taylor et al., 2019).

Limitations and Future Research

Despite the strong results, several limitations should be acknowledged. The sample size, though adequate for detecting large effects, limits generalizability. Future studies should include larger and more diverse samples, potentially across different age groups and competitive levels. The study's design also did not control for dietary intake or recovery quality, both of which can influence performance outcomes.

Future Research Directions

- **Randomized Controlled Trials:** Comparing HIIT-SIT with COD to traditional training or other HIIT formats (e.g., small-sided games) would strengthen causal inferences.
- **Long-Term Effects:** Longitudinal studies could assess whether these adaptations persist and influence match performance.
- **Female and Mixed-Sex Cohorts:** Including female U17 players would broaden applicability, as sex-specific responses to SIT are underexplored.
- **Neuromuscular and Psychological Outcomes:** Incorporating agility tests and psychological measures (e.g., enjoyment, adherence) would provide a holistic view of SIT with COD.
- **Protocol Optimization:** Varying sprint durations, recovery periods, or COD angles could identify the most effective SIT design for youth soccer.
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Conclusion

This study provides evidence that an 8-week Sprint Interval Training (SIT) protocol, featuring 20-second maximal sprints integrated with soccer-specific changes of direction (COD), is a highly effective and efficient method for simultaneously enhancing the aerobic and anaerobic capacities of youth soccer players during the competitive season. The primary and most critical finding to be remembered is that this specific intervention produced **superior, large-magnitude physiological adaptations compared to standard technical-tactical training alone**. The experimental group demonstrated a **6.21% increase in VO_2max** and a remarkable **34.96% improvement in Yo-Yo Intermittent Recovery Test (IR1) distance**, underscoring a profound boost in aerobic power and high-intensity intermittent endurance. Concurrently, anaerobic capacity, as measured by peak power output in the Running-Based Anaerobic Sprint Test (RAST), surged by **13.80%**. These gains were not only statistically significant (with very large effect sizes, $r > 0.93$) but also substantially greater than the modest improvements observed in the control group (1.52%, 6.15%, and 4.37%, respectively). The research successfully bridges a gap in soccer-specific conditioning by demonstrating that brief, supramaximal efforts **20-second (1:5 work-to-rest ratio) is optimally effective for this age group and sport**, developing physiology benefits from such time-efficient stimuli. This duration is scientifically justified: it is sufficient to maximally stress the phosphocreatine and glycolytic systems, elicit significant metabolic perturbation (lactate accumulation, oxygen deficit), and yet is brief enough to allow for high-quality repetitions without excessive systemic fatigue or injury risk for adolescent athletes. The incorporation of zigzag COD maneuvers enhanced the protocol's specificity, ensuring adaptations were directly transferable to the multidirectional, stop-start nature of soccer. The proven and credible solution offered by this research is a **time-efficient (15-20 minute session), highly applicable training model that drives dual-energy system development**. The theoretical contribution lies in validating and applying the principles of the Tabata protocol (20s:10s), within a soccer-specific, field-based context for youth athletes, demonstrating that the potent physiological mechanisms—including mitochondrial biogenesis, oxidative enzyme upregulation, enhanced buffering capacity, and neuromuscular efficiency—can be successfully triggered in a sport-specific manner. Practically, this protocol represents an evolution in the field by providing coaches with a **structured, evidence-based tool to overcome the "in-season plateau,"** where traditional soccer training often yields only maintenance-level adaptations. It enables targeted

performance enhancement without overburdening the athlete's schedule, aligning perfectly with the need for high-quality, low-volume conditioning during busy competitive periods.

Declaration of generative AI and AI-assisted technologies in the writing process.

The Use of Generative AI statement

During the preparation of this work the author(s) used GEMINI AI/SERVICE ENGLISH LANGUAGE CERTIFICATION in order to improve the standards of English writing. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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References

- Aziz, A. R., Teh, K. C., & Chia, M. Y. (2005). The relationship between maximal oxygen uptake and repeated sprint performance indices in field hockey and soccer players. *Journal of Sports Medicine and Physical Fitness*, 45(3), 304–310.
- Bangsbo, J., Iaia, F. M., & Krstrup, P. (2012). The Yo-Yo intermittent recovery test: A useful tool for evaluation of physical performance in intermittent sports. *Sports Medicine*, 38(1), 37–51. <https://doi.org/10.2165/00007256-200838010-00004>
- Beato, M., Bianchi, M., Coratella, G., Merlini, M., & Drust, B. (2021). A single session of repeated wingate anaerobic test increases peak power in young soccer players. *International Journal of Environmental Research and Public Health*, 18(23), 12144. DOI: [10.1519/JSC.00000000000003369](https://doi.org/10.1519/JSC.00000000000003369)
- Bishop, D., Girard, O., & Mendez-Villanueva, A. (2011). Repeated-sprint ability-Part II: Recommendations for training. *Sports Medicine*, 41(9), 741–756. <https://doi.org/10.2165/11590560-000000000-00000>
- Bishop, D., Spencer, M., Duffield, R., & Lawrence, S. (2001). Predictors of repeated-sprint ability in elite female hockey players. *Journal of Science and Medicine in Sport*, 4(2), 199–209. [https://doi.org/10.1016/s1440-2440\(03\)80255-4](https://doi.org/10.1016/s1440-2440(03)80255-4)
- Bishop, D. J., Botella, J., & Granata, C. (2019). CrossTalk opposing view: Exercise training volume is more important than training intensity to promote increases in mitochondrial content. *Journal of Physiology*, 597(16), 4115–4118. <https://doi.org/10.1113/JP277634>
- Bogdanis, G. C., Nevill, M. E., Boobis, L. H., Lakomy, H. K., & Nevill, A. M. (1995). Recovery of power output and muscle metabolites following 30 s of maximal sprint cycling in man. *Journal of Physiology*, 482(2), 467–480. doi: [10.1113/jphysiol.1995.sp020533](https://doi.org/10.1113/jphysiol.1995.sp020533)
- Bogdanis, G. C., Stavrinou, P., Fatouros, I. G., Philippou, A., Chatzinikolaou, A., Draganidis, D., Ermidis, G., & Maridaki, M. (2013). Short-term high-intensity interval exercise training attenuates oxidative stress responses and improves antioxidant status in healthy humans. *Food and Chemical Toxicology*, 61, 171–177. <https://doi.org/10.1016/j.fct.2013.05.046>
- Buchheit, M., & Laursen, P. B. (2013a). High-intensity interval training, solutions to the programming puzzle: Part I: Cardiopulmonary emphasis. *Sports Medicine*, 43(5), 313–338. <https://doi.org/10.1007/s40279-013-0029-x>
- Buchheit, M., & Laursen, P. B. (2013b). High-intensity interval training, solutions to the programming puzzle: Part II: Anaerobic energy, neuromuscular load and practical applications. *Sports Medicine*, 43(10), 927–954. DOI: [10.1007/s40279-013-0066-5](https://doi.org/10.1007/s40279-013-0066-5)
- Coyle, E. F. (2005). Very intense exercise-training is extremely potent and time efficient: A reminder. *Journal of Applied Physiology*, 98(6), 1983–1984. <https://doi.org/10.1152/japplphysiol.00215.2005>
- Daussin, F. N., Zoll, J., Dufour, S. P., Ponsot, E., Lonsdorfer-Wolf, E., Doutreleau, S., Mettauer, B., Piquard, F., Geny, B., & Richard, R. (2008). Effect of interval versus continuous training on cardiorespiratory and mitochondrial functions: Relationship to aerobic performance improvements in sedentary subjects. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*, 295(1), R264–R272. <https://doi.org/10.1152/ajpregu.00875.2007>
- Edge, J., Bishop, D., & Goodman, C. (2006). The effects of training intensity on muscle buffer capacity in females. *European Journal of Applied Physiology*, 96(1), 97–105. <https://doi.org/10.1007/s00421-005-0068-6>
- Flockhart, M., Nilsson, L. C., Tais, S., Ekblom, B., Apró, W., & Larsen, F. J. (2021). Excessive exercise training causes mitochondrial functional impairment and decreases glucose tolerance in healthy volunteers. *Cell Metabolism*, 33(5), 957–970.e6. DOI: [10.1016/j.cmet.2021.02.017](https://doi.org/10.1016/j.cmet.2021.02.017)
- Gibala, M. J., & Hawley, J. A. (2017). Sprinting toward fitness. *Cell Metabolism*, 25(5), 988–990. <https://doi.org/10.1016/j.cmet.2017.04.030>

- Gibala, M. J., & Jones, A. M. (2013). Physiological and performance adaptations to high-intensity interval training. *Nestle Nutrition Institute Workshop Series*, 76, 51–60. <https://doi.org/10.1159/000350256>
- Gibala, M. J., Little, J. P., MacDonald, M. J., & Hawley, J. A. (2012). Physiological adaptations to low-volume, high-intensity interval training in health and disease. *Journal of Physiology*, 590(5), 1077–1084. <https://doi.org/10.1113/jphysiol.2011.224725>
- Gibala, M. J., Little, J. P., van Essen, M., Wilkin, G. P., Burgomaster, K. A., Safdar, A., Raha, S., & Tarnopolsky, M. A. (2006). Short-term sprint interval versus traditional endurance training: similar initial adaptations in human skeletal muscle and exercise performance. *Journal of Physiology*, 575(Pt 3), 901–911. <https://doi.org/10.1113/jphysiol.2006.112094>
- Gibala, M. J., McGee, S. L., Garnham, A. P., & Hargreaves, M. (2011). Effect of high-intensity interval exercise on signaling proteins involved in skeletal muscle remodelling in humans. *Applied Physiology, Nutrition, and Metabolism*, 36(6), 771–777.
- Gist, N. H., Fedewa, M. V., Dishman, R. K., & Cureton, K. J. (2014). Sprint interval training effects on aerobic capacity: A systematic review and meta-analysis. *Sports Medicine*, 44(2), 269–279. <https://doi.org/10.1007/s40279-013-0115-0>
- Granata, C., Oliveira, R. S., Little, J. P., Renner, K., & Bishop, D. J. (2016). Training intensity modulates changes in PGC-1 α and p53 protein content and mitochondrial respiration, but not markers of mitochondrial content in human skeletal muscle. *FASEB Journal*, 30(2), 959–970. <https://doi.org/10.1096/fj.15-276907>
- Songsorn, P., Lambeth-Mansell, A., Mair, J. L., Haggett, M., Sicilia, A., & Vollaard, N. B. J. (2019, December 17). Exercise timing matters for increasing aerobic capacity: 60-second intervals with 60-second recovery are effective whereas 30-second intervals with 120-second recovery are not.
- Haugen, T., & Buchheit, M. (2016). Sprint running performance monitoring: Methodological and practical considerations. *Sports Medicine*, 46(5), 641–656. <https://doi.org/10.1007/s40279-015-0446-0>
- Helgerud, J., Engen, L. C., Wisløff, U., & Hoff, J. (2001). Aerobic endurance training improves soccer performance. *Medicine & Science in Sports & Exercise*, 33(11), 1925–1931. <https://doi.org/10.1097/00005768-200111000-00019>
- Helgerud, J., Høydal, K., Wang, E., Karlsen, T., Berg, P., Bjerkaas, M., Simonsen, T., Helgesen, C., Hjorth, N., Bach, R., & Hoff, J. (2007). Aerobic high-intensity intervals improve VO₂max more than moderate training. *Medicine & Science in Sports & Exercise*, 39(4), 665–671. <https://doi.org/10.1249/mss.0b013e3180304570>
- Iaia, F. M., Fiorenza, M., Perri, E., Alberti, G., Millet, G. P., & Bangsbo, J. (2015). The effect of two speed endurance training regimes on performance of soccer players. *PLoS One*, 10(9), e0138096. <https://doi.org/10.1371/journal.pone.0138096>
- Iaia, F. M., Hellsten, Y., Nielsen, J. J., Fernström, M., Sahlin, K., & Bangsbo, J. (2009). Four weeks of speed endurance training reduces energy expenditure during exercise and maintains muscle oxidative capacity despite a reduction in training volume. *Journal of Applied Physiology*, 106(1), 73–80. <https://doi.org/10.1152/japplphysiol.90676.2008>
- Iaia, F. M., Thomassen, M., Kolding, H., Gunnarsson, T., Wendell, J., Rostgaard, T., Nordsborg, N., Krstrup, P., Nybo, L., Hellsten, Y., & Bangsbo, J. (2008). Reduced volume but increased training intensity elevates muscle Na⁺-K⁺ pump α 1-subunit and NHE1 expression as well as short-term work capacity in humans. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*, 294(3), R966–R974. <https://doi.org/10.1152/ajpregu.00666.2007>
- Impellizzeri, F. M., Rampinini, E., Castagna, C., Bishop, D., Ferrari Bravo, D., Tibaudi, A., & Wisloff, U. (2006). Physiological and performance effects of generic versus specific aerobic training in soccer players. *International Journal of Sports Medicine*, 27(6), 483–492. <https://doi.org/10.1055/s-2005-865839>
- Impellizzeri, F. M., Rampinini, E., Coutts, A. J., Sassi, A., & Marcora, S. M. (2004). Use of RPE-based training load in soccer. *Medicine & Science in Sports & Exercise*, 36(6), 1042–1047. <https://doi.org/10.1249/01.mss.0000128199.23901.2f>
- Krstrup, P., Bradley, P. S., Christensen, J. F., Castagna, C., Jackman, S., Connolly, L., Randers, M. B., Mohr, M., & Bangsbo, J. (2015). The Yo-Yo IE2 test: physiological response for untrained men versus trained soccer players. *Medicine & Science in Sports & Exercise*, 47(1), 100–108. <https://doi.org/10.1249/MSS.0000000000000377>
- Krstrup, P., Mohr, M., Nybo, L., Jensen, J. M., Nielsen, J. J., & Bangsbo, J. (2006). The Yo-Yo IR2 test: Physiological response, reliability, and application to elite soccer. *Medicine & Science in Sports & Exercise*, 38(9), 1666–1673. <https://doi.org/10.1249/01.mss.0000227538.20799.08>
- Krstrup, P., Mohr, M., Steensberg, A., Bencke, J., Kjaer, M., & Bangsbo, J. (2006). Muscle and blood metabolites during a soccer game: Implications for sprint performance. *Medicine & Science in Sports & Exercise*, 38(6), 1165–1174. <https://doi.org/10.1249/01.mss.0000222845.89262.cd>
- Laursen, P. B., & Buchheit, M. (2019). *Science and application of high-intensity interval training*. Human Kinetics.

- Little, J. P., Langley, J., Lee, M., Myette-Côté, E., Jackson, G., Durrer, C., Gibala, M. J., & Jung, M. E. (2019). Sprint exercise snacks: a novel approach to increase aerobic fitness. *European Journal of Applied Physiology*, 119(5), 1203–1212. <https://doi.org/10.1007/s00421-019-04110-z>
- Little, J. P., Safdar, A., Wilkin, G. P., Tarnopolsky, M. A., & Gibala, M. J. (2010). A practical model of low-volume high-intensity interval training induces mitochondrial biogenesis in human skeletal muscle: Potential mechanisms. *Journal of Physiology*, 588(6), 1011–1022. <https://doi.org/10.1113/jphysiol.2009.181743>
- Loturco, I., Pereira, L. A., Freitas, T. T., Alcaraz, P. E., Zanetti, V., Bishop, C., & Jeffreys, I. (2020). Maximum acceleration performance of professional soccer players in linear sprints: Is there a direct connection with change-of-direction ability? *PLoS One*, 15(5), e0233194. <https://doi.org/10.1371/journal.pone.0216806>
- Macpherson, T. W., & Weston, M. (2015). The effect of low-volume sprint interval training on the development and subsequent maintenance of aerobic fitness in soccer players. *International Journal of Sports Physiology and Performance*, 10(3), 332–338. DOI: [10.1123/ijsp.2014-0075](https://doi.org/10.1123/ijsp.2014-0075)
- Yoav Meckel, Avner Einy, Roni Gottlieb, Alon Eliakim, (2014). Repeated Sprint Ability in Young Soccer Players at Different Game Stages. *The Journal of Strength and Conditioning Research* 28(9). DOI:10.1519/JSC.0000000000000383
- Y Meckel, U Harel, Y Michaely, A Eliakim, (2014). Effects of a very short-term preseason training procedure on the fitness of soccer players *J Sports Med Phys Fitness* 54(4):432-40.
- Milanović, Z., Sporiš, G., & Weston, M. (2015). Effectiveness of high-intensity interval training (HIT) and continuous endurance training for VO2max improvements: A systematic review and meta-analysis of controlled trials. *Sports Medicine*, 45(10), 1469–1481. <https://doi.org/10.1007/s40279-015-0365-0>
- Mohr, M., & Krstrup, P. (2014). Yo-Yo intermittent recovery test performances within an entire football league during a full season. *Journal of Sports Sciences*, 32(4), 315–327. <https://doi.org/10.1080/02640414.2013.824598>
- Reljic, D., Wittmann, F., & Fischer, J. (2019). Effects of low-volume high-intensity interval training in a community setting: A pilot study. *European Journal of Applied Physiology*, 119(11-12), 2701–2710. <https://doi.org/10.1007/s00421-018-3845-8>
- Ross, A., Leveritt, M., & Riek, S. (2001). Neural influences on sprint running: Training adaptations and acute responses. *Sports Medicine*, 31(6), 409–425. <https://doi.org/10.2165/00007256-200131060-00002>
- Sharp, R. L., Costill, D. L., Fink, W. J., & King, D. S. (1986). Effects of eight weeks of bicycle ergometer sprint training on human muscle buffer capacity. *International Journal of Sports Medicine*, 7(1), 13–17. <https://doi.org/10.1055/s-2008-1025727>
- Sloth, M., Sloth, D., Overgaard, K., & Dalgas, U. (2013). Effects of sprint interval training on VO2max and aerobic exercise performance: A systematic review and meta-analysis. *Scandinavian Journal of Medicine & Science in Sports*, 23(6), e341–e352. <https://doi.org/10.1111/sms.12092>
- Spencer, M., Bishop, D., Dawson, B., & Goodman, C. (2005). Physiological and metabolic responses of repeated-sprint activities: Specific to field-based team sports. *Sports Medicine*, 35(12), 1025–1044. <https://doi.org/10.2165/00007256-200535120-00003>
- Tabata, I. (1996). Effects of moderate-intensity endurance and high-intensity intermittent training on anaerobic capacity and VO2max. *Medicine & Science in Sports & Exercise*, 28(10), 1327–1330. <https://doi.org/10.1097/00005768-199610000-00018>
- Taylor, J. M., Macpherson, T. W., Spears, I. R., & Weston, M. (2015). The effects of repeated-sprint training on field-based fitness measures: A meta-analysis of controlled and non-controlled trials. *Sports Medicine*, 45(6), 881–891. DOI: [10.1007/s40279-015-0324-9](https://doi.org/10.1007/s40279-015-0324-9)
- Vollaard, N. B. J., Metcalfe, R. S., & Williams, S. (2017). Effect of number of sprints in an SIT session on change in V'O2max: A meta-analysis. *Medicine & Science in Sports & Exercise*, 49(6), 1147–1156. DOI: [10.1249/MSS.0000000000001204](https://doi.org/10.1249/MSS.0000000000001204)
- Zagatto, A. M., Beck, W. R., & Gobatto, C. A. (2009). Validity of the running anaerobic sprint test for assessing anaerobic power and predicting short-distance performances. *Journal of Strength and Conditioning Research*, 23(6), 1820–1827. DOI: [10.1519/JSC.0b013e3181b3df32](https://doi.org/10.1519/JSC.0b013e3181b3df32)