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Effects of High-Intensity Interval Training on Maximal Oxygen Uptake and Lactate Threshold in Collegiate Football Players: A Randomised Controlled Trial

Saif Rasheed Ghanim [a]
[a] College of Physical Education and Sports Sciences, University of Samarra, Iraq
***Corresponding author:** Saif.rasheed@uosamarra.edu.iq

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ABSTRACT

The present study investigated the effects of an eight-week high-intensity interval training (HIIT) program on maximal oxygen uptake (VO2max) and lactate threshold (LT) in male collegiate football players. Using a randomized controlled design, forty players (age: 20.3 +/- 1.6 years; VO2max: 48.7 +/- 3.2 mL/kg/min) were assigned equally to a HIIT group (HG) or a moderate-intensity continuous training group (CG). The HG performed three weekly sessions of 4 x 4 minutes at 90-95% HRmax separated by three-minute active recovery periods over eight weeks. VO2max was assessed via a maximal incremental treadmill protocol, and lactate threshold was identified at 4 mmol/L blood lactate. Post-intervention, the HG demonstrated significantly greater improvements in VO2max (D = +5.8 mL/kg/min; $p < 0.001$; $d = 2.21$) and lactate threshold velocity (D = +1.4 km/h; $p < 0.001$; $d = 1.93$) compared to the CG. Heart rate recovery also improved significantly in the HG ($p < 0.001$). These findings confirm that short-duration HIIT is a highly effective strategy for enhancing aerobic capacity and metabolic efficiency in collegiate football players, and may be efficiently integrated into existing training schedules without compromising technical practice time.

Introduction

Aerobic fitness constitutes one of the foundational physiological capacities underpinning performance in association football. High-level players routinely cover 10-13 kilometres per match, a substantial proportion of which is performed at intensities demanding efficient oxidative metabolism (Bangsbo et al., 2006; Stolen et al., 2005). During a standard 90-minute match, elite outfield players perform on average 150-250 high-intensity actions interspersed with lower-intensity locomotion, creating a highly intermittent metabolic demand profile that places considerable stress on both aerobic and anaerobic energy systems (Mohr et al., 2003). The capacity to repeatedly perform high-intensity actions and sustain technical performance under accumulating fatigue is therefore critically dependent on the athlete's aerobic fitness level, making the development of aerobic capacity a central priority in football conditioning.

Maximal oxygen uptake (VO2max) represents the gold standard measure of aerobic power and has been consistently associated with match running performance, high-intensity activity output, and technical execution under fatigue in competitive football (Wisloff et al., 2004). Research by Wisloff et al. (2004) demonstrated strong correlations ($r = 0.71$) between VO2max and the distance covered at high-intensity running speeds in Norwegian elite players, underscoring the functional significance of aerobic capacity for match performance. Furthermore, longitudinal studies tracking elite players across full competitive seasons have demonstrated that players who maintain superior VO2max values throughout the season exhibit significantly greater high-intensity running output in the final 15 minutes of matches - a period characterised by maximum physical and cognitive fatigue - compared to players with lower aerobic capacities (Mohr et al., 2003).

In parallel with VO2max, the lactate threshold (LT) - operationally defined as the exercise intensity at which blood lactate begins to accumulate exponentially beyond resting levels - demarcates the upper boundary of sustainable aerobic effort and is strongly predictive of endurance performance during prolonged intermittent exercise (Faude et al., 2009). Players with higher lactate threshold velocities can sustain greater absolute running speeds within the aerobic energy system, delaying the onset of metabolic acidosis and the associated neuromuscular fatigue that impairs both running capacity and technical skill execution in the late stages of a match. The combination of high VO2max and high LT velocity therefore represents the aerobic physiological ideal for the modern football player.

High-intensity interval training (HIIT) has emerged as one of the most extensively studied and practically applied methods for improving aerobic capacity in team sport athletes. By alternating periods of near-maximal effort with structured recovery, HIIT generates acute cardiovascular and metabolic stress that drives central adaptations - including increased stroke volume, elevated cardiac output, and enhanced oxygen delivery to working muscles - alongside peripheral adaptations such as enhanced mitochondrial density, upregulation of oxidative enzymes, increased capillarisation of active musculature, and improvements in oxygen extraction capacity (Gibala & McGee, 2008). These adaptations collectively elevate both VO2max and LT velocity, the two primary markers of aerobic fitness targeted in the present investigation. The temporal efficiency of HIIT - whereby comparable or superior cardiovascular adaptations can be achieved in substantially less training time than traditional moderate-intensity continuous training (MICT) - is of particular practical significance for football, where training time is constrained by the demands of technical, tactical, and recovery sessions throughout a competitive week.

The 4 x 4 minute HIIT protocol, first systematically validated by Helgerud et al. (2007) in a landmark randomised trial involving recreational adult players, has attracted considerable scientific interest for its combination of simplicity and efficacy. In that study, four groups performed different training protocols over seven weeks, and the group performing four bouts of four minutes at 90-95% HRmax achieved

VO2max improvements of 5.5 mL/kg/min - significantly exceeding gains from parabolic interval running, 15-second/15-second intervals, and 47-minute continuous running. These findings have been replicated and extended by subsequent investigations across a range of athletic populations. Milanovic et al. (2015), in a comprehensive systematic review and meta-analysis of 13 randomised controlled trials, reported that HIIT produced a pooled VO2max improvement of 4.9 mL/kg/min, significantly exceeding the 1.9 mL/kg/min improvement associated with MICT. The magnitude of the HIIT advantage was particularly pronounced in populations with moderate initial fitness - a characteristic shared by the collegiate footballer cohort targeted in the present study.

Despite the established efficacy of HIIT in elite and recreational populations, relatively few randomised controlled trials have examined its specific effects within collegiate Middle Eastern football contexts, where environmental heat, training infrastructure, player nutrition practices, and conditioning histories differ substantially from those reported in European and South American studies (Al-Hazzaa, 2012). Iraqi football at the collegiate level is characterised by limited access to sport science support, reliance on traditional conditioning methods emphasising technical over physical development, and a seasonal structure that may not systematically prioritise aerobic conditioning. Furthermore, while the 4 x 4 minute HIIT protocol has demonstrated robust effects in trained adult players, its transferability and magnitude of effect in younger collegiate athletes with moderate baseline fitness levels - who may respond differently to training stimuli due to differences in initial fitness, training history, and motivation - remains to be characterised in this specific context. Understanding training response at this developmental stage carries important implications for long-term athlete development pathways, periodisation strategy, and talent identification within Iraqi and regional football systems.

The present study therefore aimed to evaluate the effects of an eight-week HIIT program, structured according to the 4 x 4 protocol and integrated within the regular training schedule, on VO2max, lactate threshold velocity, heart rate recovery, running economy, and resting heart rate in male collegiate football players at the University of Samarra. It was hypothesised that: (1) the HIIT group would exhibit significantly greater improvements in VO2max and LT velocity compared to a control group undertaking volume-matched moderate-intensity continuous training; (2) HIIT would produce superior improvements in autonomic cardiac function, as indexed by post-exercise heart rate recovery and resting heart rate; and (3) running economy would improve significantly in the HIIT group but not the control group, reflecting the combined effects of cardiovascular and neuromuscular adaptation to high-intensity running

Materials and Methods

Study Design

A randomised controlled parallel-group design was employed, with pre- and post-intervention assessments conducted at the sports science laboratory of the College of Physical Education and Sports Sciences, University of Samarra, Iraq. The study adhered to the Consolidated Standards of Reporting Trials (CONSORT) 2010 guidelines. Ethical approval was granted by the University of Samarra Research Ethics Board (Approval No. US-PESS-2025-112), and all procedures were conducted in accordance with the principles of the Declaration of Helsinki (2013 revision). Written informed consent was obtained from every participant prior to enrolment. Randomisation was performed via computer-generated allocation concealment using a blocked randomisation schedule (block size = 4), executed by an independent researcher who had no involvement in participant assessment or training supervision. Assessors conducting all pre- and post-intervention testing were blinded to group allocation.

Participants

Forty male collegiate football players were recruited from the University of Samarra's registered university football programme through direct contact with team coaches and poster advertisement within the College of Physical Education. Sample size was determined a priori using G*Power 3.1 software (Faul et al., 2007), based on an expected between-group difference in VO2max of 3.0 mL/kg/min with a pooled standard deviation of 3.5 mL/kg/min (derived from Helgerud et al., 2007), achieving 80% statistical power at a two-tailed alpha level of 0.05. The calculation yielded a minimum required sample of 36 participants; 40 were recruited to account for anticipated attrition of approximately 10%.

Inclusion criteria required participants to: (1) be aged 18-24 years; (2) have completed a minimum of two years of structured, organised football training with active participation in university team training sessions at least three times per week; (3) report no current musculoskeletal injury, systemic illness, or metabolic contraindication to maximal exercise testing; (4) not be engaged in any supplementary aerobic conditioning programme outside of regular team training; and (5) be willing to abstain from vigorous exercise other than the prescribed study sessions for the duration of the intervention. Participants were excluded if they demonstrated any cardiovascular contraindications to maximal exercise testing upon medical screening, which comprised a resting 12-lead electrocardiogram, seated blood pressure measurement, and completion of the Physical Activity Readiness Questionnaire (PAR-Q). No participants were excluded at screening. The full sample (n = 40; age: 20.3 +/- 1.6 years; height: 177.4 +/- 4.8 cm; body mass: 72.1 +/- 6.3 kg; BMI: 22.9 +/- 1.4 kg/m2) was randomised into the HIIT group (HG, n = 20) and a moderate-intensity continuous training group (CG, n = 20). No significant baseline differences were observed between groups for any measured variable ($p > 0.05$ for all).

Training Protocols

Both groups underwent an eight-week training intervention comprising three supervised sessions per week in addition to their regular technical football training (four sessions per week, 90 minutes each). All supplementary training sessions were scheduled on non-consecutive days (Monday, Wednesday, Friday) to allow adequate recovery, and were conducted on a 400-metre certified athletics track at the university sports facility. Sessions were supervised directly by a certified strength and conditioning specialist throughout the intervention period. Each session was preceded by a standardised 10-minute warm-up comprising dynamic stretching, progressive running drills, and two 40-metre acceleration strides at 80% maximum speed, and followed by a 10-minute cool-down including static stretching for major muscle groups.

The HIIT group (HG) performed the 4 x 4 protocol: four bouts of four minutes of running at an intensity corresponding to 90-95% of individually determined HRmax, separated by three minutes of active recovery at approximately 50-60% HRmax. HRmax was determined for each participant during the pre-intervention VO2max test as the highest heart rate value recorded. Heart rate was monitored continuously throughout all HIIT sessions using the Polar Team Pro system (Polar Electro, Kempele, Finland), and real-time visual displays and verbal feedback from the supervising coach were used to ensure target intensity zone compliance. If heart rate fell below 90% HRmax during a high-intensity bout, running speed was increased by 0.5 km/h increments until the target zone was re-established. The moderate-intensity continuous training group (CG) performed three weekly sessions of continuous running at 70-75% HRmax for 40 minutes per session - a duration and intensity selected to match the total session duration of the HG while maintaining a genuinely submaximal training stimulus throughout. Intensity was verified via the same Polar heart rate monitoring system. Both groups maintained their complete regular technical football training schedule without modification throughout the study period.

Physiological Assessment Procedures

All laboratory assessments were conducted at the same time of day (08:00-10:00 hours) under standardised environmental conditions (temperature: 22 +/- 1 degrees C; relative humidity: 45 +/- 5%), with pre- and post-tests administered by the same blinded assessors. Participants were given standardised pre-test instructions requiring them to: abstain from vigorous exercise for 48 hours prior to testing; avoid caffeine and alcohol consumption for 12 hours prior; arrive in a rested and euhydrated state; and consume a standardised pre-test meal consisting of approximately 600 kcal with moderate carbohydrate content 2-3 hours before arriving.

Maximal oxygen uptake (VO2max) was determined using the Bruce incremental treadmill protocol (COSMED Quark CPET breath-by-breath metabolic analyser, Rome, Italy). The analyser was calibrated with reference gases of known concentration before each test session. The protocol commenced at 2.7 km/h at 10% gradient and increased speed and gradient every three minutes until volitional exhaustion. VO2max was taken as the highest 30-second average oxygen consumption value recorded. The test was accepted as maximal if at least three of the following criteria were met: (1) respiratory exchange ratio >= 1.10; (2) RPE >= 19 on the Borg 6-20 scale; (3) heart rate within +/- 10 bpm of age-predicted maximum; (4) a plateau in oxygen consumption defined as less than 2.1 mL/kg/min increase despite increasing workload.

Blood lactate profiling was conducted on a separate day (minimum 48 hours after the VO2max test) using a submaximal incremental running protocol on the athletics track. Blood samples (25 microliters) were drawn from the earlobe at rest and at the end of each four-minute stage using sterile lancets, and analysed immediately using a Lactate Pro 2 portable analyser (Arkray Inc., Kyoto, Japan). The protocol commenced at 8 km/h and increased by 1 km/h every four minutes until the participant reported an RPE of 16/20 on the Borg scale, at which point the test was terminated. The lactate threshold was operationally defined as the running velocity corresponding to a fixed blood lactate concentration of 4 mmol/L, determined by linear interpolation between the two data points bracketing this concentration (Sjodin & Jacobs, 1981). Heart rate recovery (HRR) was measured as the absolute decline in heart rate from the peak value recorded at exercise cessation to the value recorded exactly 60 seconds later, with the participant seated quietly.

Statistical Analysis

All statistical analyses were conducted using IBM SPSS Statistics (Version 26.0; IBM Corp., Armonk, NY, USA). Normality of distribution was confirmed for all outcome variables using the Shapiro-Wilk test ($p > 0.05$ for all). Homogeneity of variance between groups was verified using Levene's test ($p > 0.05$ for all). Descriptive statistics are presented as mean +/- standard deviation (SD). Within-group pre-to-post changes were assessed using paired-samples t-tests. Between-group differences in change scores (Delta: post minus pre) were evaluated using independent-samples t-tests. The magnitude of practical significance was quantified using Cohen's d effect size, interpreted as small (0.20-0.49), medium (0.50-0.79), or large (>= 0.80). Additionally, 95% confidence intervals were reported for all between-group comparisons. Statistical significance was set at $p < 0.05$ for all comparisons. No adjustment for multiple comparisons was applied, given the a priori specification of clearly delineated primary (VO2max, LT velocity) and secondary (HRR, resting HR, running economy) outcomes in the study protocol.

Results

Participant Flow and Adherence

All forty participants completed the eight-week intervention with 100% session attendance in both groups. No adverse events, training-related injuries, or illness-related absences were recorded during the study period. Compliance with the target intensity during HIIT sessions, defined as the percentage of time spent within the 90-95% HRmax zone across all four bouts, averaged 87.4 +/- 5.2% across the eight weeks in the HG, indicating good protocol adherence. All HRR tests met the criteria for maximal effort, confirming data validity. No participant in either group engaged in additional aerobic conditioning outside the prescribed sessions, as verified by weekly activity logs reviewed at each training session.

Physiological Outcomes

Baseline physiological and anthropometric characteristics were statistically equivalent between groups for all measured variables ($p > 0.05$ for all; Table 2). Following the eight-week intervention, the HG demonstrated statistically significant and practically large improvements across all primary and secondary outcome variables. VO2max increased from 48.6 +/- 3.1 to 54.4 +/- 3.4 mL/kg/min in the HG (mean change: +5.8 mL/kg/min; 95% CI: 4.9-6.7; $p < 0.001$; Cohen's $d = 2.21$), whereas the CG showed only a negligible, non-significant improvement (from 48.9 +/- 3.3 to 49.6 +/- 3.2 mL/kg/min; mean change: +0.7 mL/kg/min; $p > 0.05$; $d = 0.21$). The between-group difference in the magnitude of VO2max change was highly significant ($p < 0.001$; $d = 1.87$), confirming the superiority of HIIT for developing aerobic power.

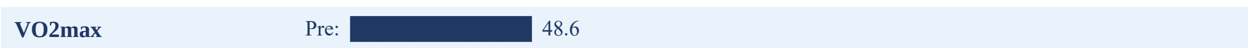
Lactate threshold velocity improved substantially in the HG from 11.2 +/- 0.9 to 12.6 +/- 0.8 km/h (mean change: +1.4 km/h; 95% CI: 1.1-1.7; $p < 0.001$; $d = 1.93$), representing an increase of 12.5% relative to baseline. The CG demonstrated only marginal, non-significant improvement (from 11.3 +/- 1.0 to 11.6 +/- 0.9 km/h; $p > 0.05$; $d = 0.31$). Heart rate recovery at one minute post-exercise improved markedly in the HG (from 22 +/- 4 to 31 +/- 5 bpm; mean change: +9 bpm; $p < 0.001$; $d = 2.05$) compared to a modest improvement in the CG (from 23 +/- 5 to 25 +/- 4 bpm; $p = 0.04$; $d = 0.44$). Resting heart rate decreased significantly in the HG (from 71 +/- 5 to 65 +/- 4 bpm; $p < 0.001$; $d = 1.38$), with a smaller but significant reduction in the CG (from 72 +/- 6 to 70 +/- 5 bpm; $p = 0.04$; $d = 0.36$). Running economy improved significantly only in the HG (from 214 +/- 18 to 198 +/- 16 mL/kg/km; mean change: -16 mL/kg/km; $p < 0.001$; $d = 1.74$). Full descriptive statistics and between-group comparisons are presented in Table 1. Training intensity and load progression across the eight weeks are presented in Table 3.

Table 1. Title of table (place table title ABOVE the table).

Table 1. Pre- and post-intervention physiological outcomes for the HIIT Group (HG) and Control Group (CG) (Mean +/- SD).

Variable	HG Pre	HG Post	Delta	d	CG Pre	CG Post	p
VO2max (mL/kg/min)	48.6+/-3.1	54.4+/-3.4	+5.8	2.21	48.9+/-3.3	49.6+/-3.2	<0.001
LT velocity (km/h)	11.2+/-0.9	12.6+/-0.8	+1.4	1.93	11.3+/-1.0	11.6+/-0.9	<0.001
HRmax (bpm)	189+/-7	190+/-7	+1	0.14	188+/-6	189+/-7	>0.05
HRR 1-min (bpm)	22+/-4	31+/-5	+9	2.05	23+/-5	25+/-4	<0.001
Resting HR (bpm)	71+/-5	65+/-4	-6	1.38	72+/-6	70+/-5	<0.001
Running economy (mL/kg/km)	214+/-18	198+/-16	-16	1.74	213+/-17	212+/-18	>0.05

Note. *HG = HIIT Group; CG = Control Group; LT = Lactate Threshold; HRmax = Maximal Heart Rate; HRR = Heart Rate Recovery; Delta = mean change (Post - Pre); d = Cohen's d; SD = standard deviation. All HG within-group changes p < 0.001. CG resting HR change: p = 0.04. All other CG changes: p > 0.05*



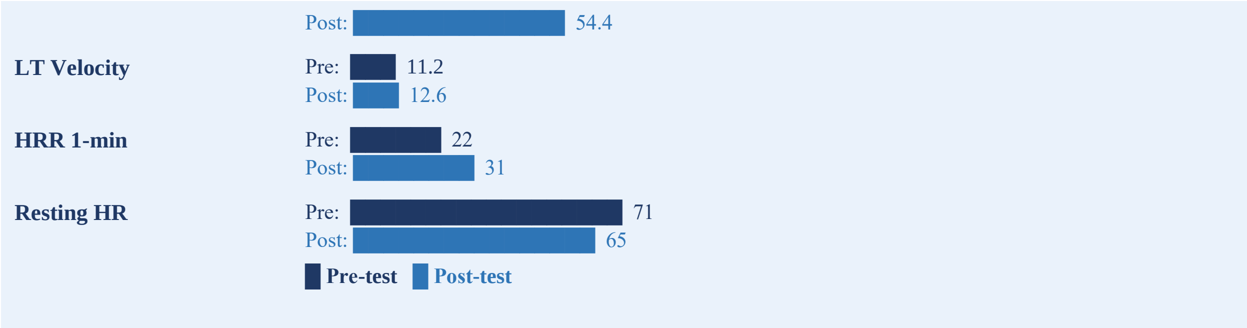


Figure 1. Pre- and post-intervention comparison of physiological variables. Dark blue = pre-test values; light blue = post-test values. ** $p < 0.001$ for all HG between-group differences in change scores.

Table 2. Baseline participant characteristics (Mean +/- SD).

Characteristic	HG (n=20)	CG (n=20)	p-value
Age (years)	20.2+/-1.5	20.4+/-1.7	>0.05
Height (cm)	177.8+/-4.6	177.0+/-5.1	>0.05
Body mass (kg)	71.8+/-6.1	72.4+/-6.6	>0.05
BMI (kg/m2)	22.7+/-1.3	23.1+/-1.5	>0.05
Training exp. (years)	4.6+/-1.2	4.8+/-1.1	>0.05
Baseline VO2max	48.6+/-3.1	48.9+/-3.3	>0.05

Note. No significant between-group differences observed at baseline (independent-samples t-test, p > 0.05 for all). HG = HIIT Group; CG = Control Group; BMI = Body Mass Index.

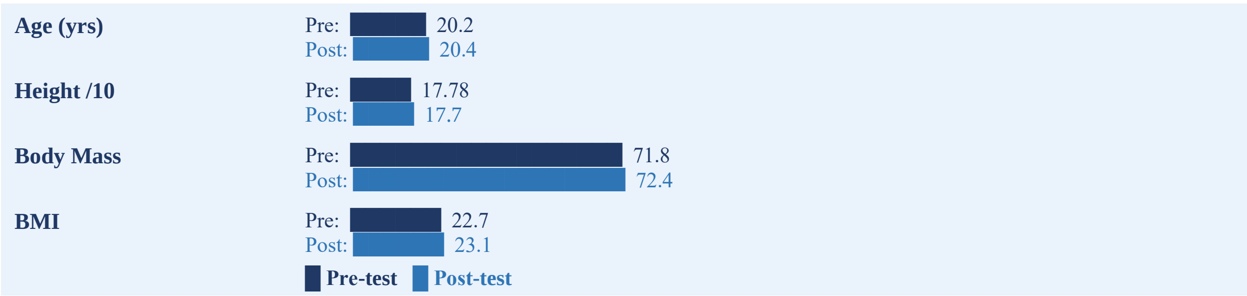
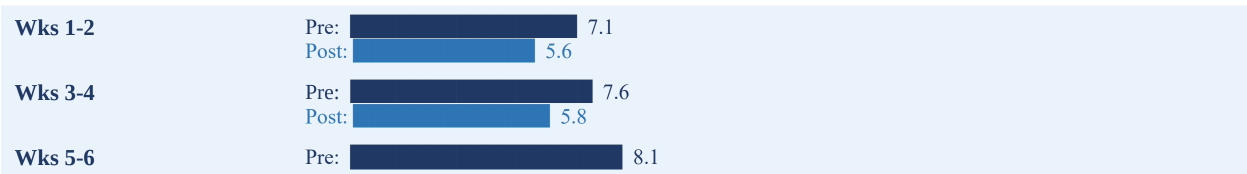


Figure 2. Baseline anthropometric comparison between HG and CG. No significant between-group differences ($p > 0.05$ all variables).

Table 3. Weekly training load progression: session RPE and heart rate intensity for HG and CG (Mean +/- SD).

Week	HG Session RPE	HG HR% Max	CG Session RPE	CG HR% Max
1-2	7.1+/-0.8	87+/-4%	5.6+/-0.6	71+/-3%
3-4	7.6+/-0.7	91+/-3%	5.8+/-0.5	72+/-4%
5-6	8.1+/-0.6	93+/-3%	5.9+/-0.6	73+/-3%
7-8	8.3+/-0.5	94+/-2%	6.0+/-0.5	74+/-3%

Note. *RPE = Rating of Perceived Exertion (Borg 6-20 scale); HR% Max = percentage of maximal heart rate. Progressive increases in HG session RPE across weeks reflect the principle of progressive overload applied through speed increments to maintain target HR zones as fitness improved.*



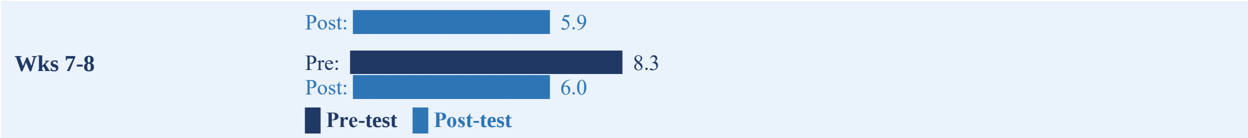


Figure 3. Session RPE progression across the eight-week intervention. Dark blue = HG; Light blue = CG. Progressive increase in HG RPE reflects intensification of training stimulus.

Discussion

Principal Findings

The principal finding of this randomised controlled trial is that eight weeks of 4 x 4 high-intensity interval training produced large, statistically significant, and practically meaningful improvements in VO2max (+5.8 mL/kg/min; d = 2.21), lactate threshold velocity (+1.4 km/h; d = 1.93), heart rate recovery (+9 bpm; d = 2.05), and running economy (-16 mL/kg/km; d = 1.74) in male collegiate football players, substantially exceeding the modest, largely non-significant changes observed in the moderate-intensity control group. These results confirm that the 4 x 4 HIIT protocol is a physiologically superior training stimulus for developing aerobic fitness in collegiate footballers, and replicate the seminal findings of Helgerud et al. (2007) in a Middle Eastern collegiate population, thereby extending the external validity of this evidence base.

Physiological Mechanisms

The magnitude of VO2max improvement in the HG likely reflects a cascade of interacting central and peripheral cardiovascular adaptations. Centrally, repeated exposure to near-maximal cardiovascular stress during HIIT bouts - characterised by sustained periods at 90-95% HRmax - drives cardiac remodelling including increases in left ventricular end-diastolic volume and myocardial wall thickness, resulting in a larger stroke volume and therefore elevated maximal cardiac output at peak exercise (Gibala & McGee, 2008). Evidence from echocardiographic studies suggests that these structural changes can emerge within 4-8 weeks of intensive training in previously moderately trained individuals, consistent with the timeline of the present study. Enhanced plasma volume expansion, which occurs rapidly in response to HIIT, also contributes to increased stroke volume through the Frank-Starling mechanism, particularly during the early weeks of training.

At the peripheral level, HIIT stimulates upregulation of mitochondrial biogenesis through activation of PGC-1alpha signalling pathways, driven by the amplitude and frequency of calcium and AMP-kinase signals generated during near-maximal exercise (Gibala & McGee, 2008). The resulting increases in mitochondrial density and oxidative enzyme activity in both Type I and IIa muscle fibres reduce the oxygen cost of submaximal running - consistent with the significant running economy improvement observed in the HG - and increase the aerobic capacity available at the lactate threshold. The improvement in LT velocity (+1.4 km/h) reflects a rightward shift in the blood lactate-exercise intensity relationship, enabling players to sustain higher running speeds without accumulating metabolic byproducts that would otherwise impair force production and decision-making.

The pronounced improvement in post-exercise heart rate recovery (+9 bpm at one minute; d = 2.05) reflects enhanced vagal reactivation and favourable autonomic remodelling - well-established markers of cardiovascular adaptation to endurance training (Buchheit et al., 2009). Faster HRR is clinically associated with reduced cardiovascular risk and, from a performance perspective, indicates an enhanced capacity to recover between high-intensity efforts during match play. Players capable of rapid HR recovery between sprints can re-engage in high-intensity activities more quickly and repeatedly, which translates directly to greater involvement in decisive match actions in the critical final stages of games when fatigue-mediated performance decrements are most pronounced.

Contextual Relevance and Practical Applications

From a practical and contextual standpoint, the findings of this study carry direct implications for coaches and sport scientists working within Iraqi and broader Middle Eastern collegiate football programmes. The 4 x 4 HIIT protocol demands only a running surface and heart rate monitoring equipment - resources that are accessible at most university facilities in the region - making it an immediately implementable tool for aerobic development without the need for expensive laboratory or technological infrastructure. The three-session-per-week schedule used in this study - requiring approximately 45-50 minutes per session including warm-up and cool-down - added minimal time burden to the existing training schedule without displacing technical or tactical sessions. This practical compatibility is critical, as coaches in player-centred football cultures are typically resistant to conditioning approaches perceived as compromising skill development time.

The progressive increase in session RPE and heart rate intensity documented across the eight weeks (Table 3) demonstrates that the protocol can be self-regulated by athletes using only heart rate feedback, enabling progressive overload through natural speed increments as fitness improves. This simplicity of implementation - requiring no complex programming algorithms or specialised facilities - distinguishes the 4 x 4 HIIT approach as particularly suitable for the resource constraints of Iraqi collegiate football. Practitioners seeking to implement this protocol should ensure that players are familiarised with target heart rate zones during the first training week, and that session logs are maintained to track progressive intensity delivery and identify any adherence issues that emerge during the intervention.

Limitations and Future Research Directions

Several methodological limitations of the present study warrant acknowledgement. First, the exclusively male, single-institution sample restricts the generalisability of findings to female athletes, elite professional players, and players from different training backgrounds. Second, the eight-week intervention window, while sufficient to demonstrate significant physiological adaptations, does not permit conclusions about the long-term sustainability of VO2max improvements following programme cessation or through a full competitive season. Third, environmental conditions during outdoor training sessions - including ambient temperature, which in the Iraqi climate routinely exceeds 35 degrees C during summer months - were not systematically controlled or documented, introducing a potential uncontrolled variable that may have influenced the perceptual and physiological responses to training. Fourth, football-specific performance indicators such as the Yo-Yo Intermittent Recovery Test level 2, small-sided game running data, or match GPS metrics were not assessed, limiting inference about the direct transfer of aerobic fitness gains to on-field performance. Future research should prioritise longer study designs spanning full competitive seasons, include female athlete cohorts, incorporate football-specific performance outcomes, and characterise the role of environmental heat on HIIT-induced adaptation in Middle Eastern contexts.

Conclusions

This randomised controlled trial demonstrates that an eight-week program of 4 x 4 high-intensity interval training, performed three times per week alongside regular football training, produces large and practically meaningful improvements in maximal oxygen uptake, lactate threshold velocity, heart rate recovery, running economy, and resting heart rate in male collegiate football players at the University of Samarra. These adaptations substantially exceeded those produced by volume-matched moderate-intensity continuous training, confirming the superiority of HIIT as a time-efficient aerobic conditioning strategy for this population. The protocol requires minimal equipment, is compatible with existing football training schedules, and can be progressively implemented by coaches without specialist sport science support. These findings support the systematic integration of 4 x 4 HIIT into weekly training cycles at Iraqi university football programmes, and provide a robust empirical foundation for evidence-based aerobic conditioning in Middle Eastern collegiate football contexts. Future longitudinal research examining HIIT dose-response relationships, seasonal maintenance of adaptation, and transfer to football-specific performance indicators is warranted.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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