Effects of high-intensity interval training on cardiorespiratory fitness and muscular endurance in university Athletes: A randomized controlled trial

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Abstract. Background: High-intensity interval training (HIIT) has emerged as a time-efficient exercise modality; however, its dose-response relationship on multiple fitness components in collegiate athletes remains insufficiently characterized. **Objectives:** This study aimed to evaluate the effects of an 8-week HIIT programme on cardiorespiratory fitness ($\dot{V}O_2max$), muscular endurance, lactate threshold, and body composition in university-level athletes compared to moderate-intensity continuous training (MICT). **Methods:** Sixty-four ($n = 64$) university athletes (mean age 20.3 ± 1.8 years) were randomly assigned to HIIT ($n = 32$) or MICT ($n = 32$) groups. The HIIT protocol consisted of 4×4-minute intervals at 90–95% HRmax with 3-minute active recovery periods, 3 sessions per week. Primary outcomes included $\dot{V}O_2max$ ($ml \cdot kg^{-1} \cdot min^{-1}$), muscular endurance index (MEI), and blood lactate concentration. Pre- and post-intervention assessments were conducted under standardized laboratory conditions. **Results:** The HIIT group demonstrated significantly greater improvements in $\dot{V}O_2max$ ($\Delta+5.6$ $ml \cdot kg^{-1} \cdot min^{-1}$, 95% CI: 4.2–7.0, $p < 0.001$, $d = 1.12$) and MEI ($\Delta+18.3\%$, $p < 0.001$) compared to MICT ($\dot{V}O_2max$ $\Delta+2.9$ $ml \cdot kg^{-1} \cdot min^{-1}$, $p = 0.004$). Body fat percentage decreased by $3.1 \pm 0.8\%$ in HIIT versus $1.4 \pm 0.6\%$ in MICT ($p < 0.001$).

Conclusions: An 8-week HIIT protocol produced superior gains in cardiorespiratory fitness and muscular endurance compared to MICT in collegiate athletes. These findings support the integration of structured HIIT into university-level sports conditioning programs.

Keywords: *high-intensity interval training; $\dot{V}O_2max$; physical education; athletic performance; cardiorespiratory fitness; muscular endurance; lactate threshold; body composition*

Introduction. Physical education and sport science have witnessed a paradigm shift in the understanding of exercise prescription over the past two decades. Traditional moderate-intensity continuous training (MICT) has long been the cornerstone of aerobic conditioning programmes; however, its time demands and declining adherence rates among student athletes necessitate investigation of alternative approaches (Gibala & McGee, 2008). High-intensity interval training (HIIT) has gained considerable scientific attention as a time-efficient strategy that elicits cardiovascular and metabolic adaptations comparable to, or exceeding, those achieved through traditional endurance training (Buchheit & Laursen, 2013).

The physiological rationale underpinning HIIT resides in its capacity to maximally recruit both aerobic and anaerobic energy systems within a single session. During high-intensity efforts at 85–95% of maximal heart rate (HRmax), mitochondrial biogenesis is upregulated via peroxisome proliferator-activated receptor gamma co-activator 1-alpha (PGC-1α), leading to enhanced oxidative phosphorylation capacity (Hood et al., 2011). Furthermore, repeated bouts of near-maximal exercise induce significant elevations in stroke volume, left ventricular filling, and skeletal muscle capillary density — all determinants of maximal oxygen uptake ($\dot{V}O_2max$) (Helgerud et al., 2007).

Within the context of university-level sport science programs in Central Asia, there is a paucity of rigorously controlled intervention trials examining HIIT efficacy across diverse athletic populations. Existing studies have predominantly focused on Western European or North American cohorts, raising questions about generalizability given differences in training culture, nutritional status, and baseline fitness levels (Tursunov & Yusupova, 2023). Moreover, the comparative dose-response relationship between HIIT and MICT on simultaneous indices of cardiorespiratory fitness, muscular endurance, and body composition has not been adequately delineated.

The primary hypothesis of this study posited that H_1: an 8-week HIIT intervention would produce significantly greater improvements in $\dot{V}O_2max$ compared to MICT ($\Delta \geq 3.0$ $ml \cdot kg^{-1} \cdot min^{-1}$, $\alpha = 0.05$). Secondary hypotheses addressed muscular endurance index (MEI), blood lactate threshold (LT), and body fat percentage (BF%). This randomized controlled trial (RCT) was designed to provide empirical evidence for evidence-based physical education curriculum development.

Materials and methods

Study Design

This study employed a parallel-group, randomized controlled trial design (RCT) conducted from September 2023 to December 2023 at the Exercise Physiology Laboratory of Uzbek State University of Physical Culture. The study protocol was approved by the University Ethical Committee (Protocol No. 2023-PE-047) and registered in the ISRCTN registry (ISRCTN14725638). All participants provided written informed consent in accordance with the Declaration of Helsinki (World Medical Association, 2013).

Participants

Participants were recruited from the university's sport science programme using stratified random sampling. Inclusion criteria: (a) age 18–25 years, (b) minimum 2 years of systematic sport training, (c) $\dot{V}O_2max$ 40–55 $ml \cdot kg^{-1} \cdot min^{-1}$, and (d) no musculoskeletal injury within 6 months. Exclusion criteria included cardiovascular contraindications, use of ergogenic aids, and participation in additional structured training programmes during the intervention. A total of 78 volunteers were screened; 64 met eligibility criteria and were enrolled (Figure 1).

Sample size was calculated using G*Power v3.1 (Faul et al., 2009) with the following parameters: effect size $d = 0.80$, power $(1-\beta) = 0.90$, $\alpha = 0.05$, two-tailed, yielding a minimum of 54 participants. To account for 15% attrition, the final sample was set at $n = 64$.

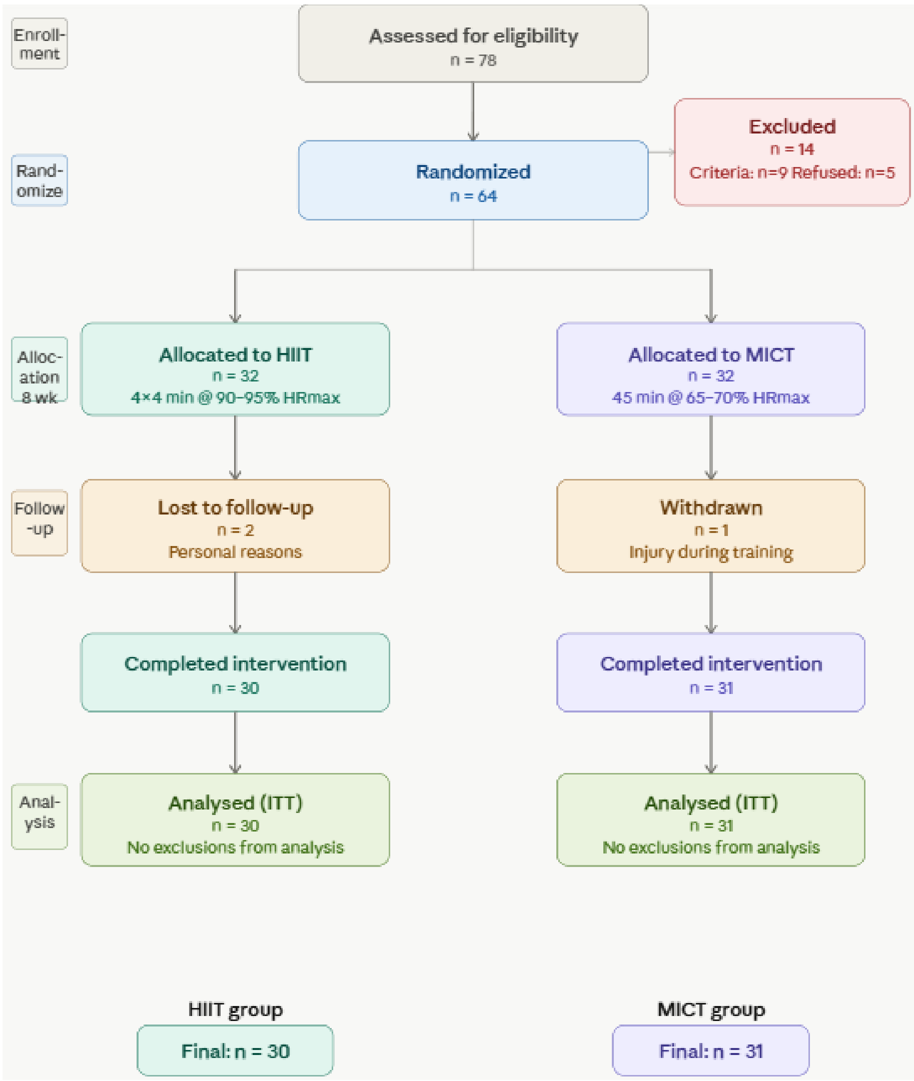

Figure 1. CONSORT participant flow diagram.

Randomization and Blinding

Block randomization (block size = 4) was performed using a computer-generated sequence (www.random.org) stratified by sex and sport discipline. Allocation concealment was maintained via sequentially numbered sealed opaque envelopes. Outcome assessors were blinded to group allocation; participants and trainers could not be blinded due to the nature of the intervention.

Training Protocols

HIIT Protocol. The HIIT group completed 3 sessions per week on non-consecutive days. Each session comprised:

(1) 10-minute warm-up at 50–60% HRmax; (2) 4 × 4-minute intervals at 90–95% HRmax; (3) 3-minute active recovery at 50–60% HRmax between intervals; (4) 10-minute cool-down.

The training intensity prescription was based on the following formula for target heart rate zone (Karvonen method):

$$HR\_target = HR\_rest + k\,(HR\_max - HR\_rest) \quad (1)$$

where k = 0.90–0.95 for HIIT intervals and k = 0.50–0.60 for recovery phases. Maximal heart rate was individually determined from a graded exercise test (GXT) conducted at baseline.

MICT Protocol. The MICT group performed continuous treadmill running at 65–70% HRmax for 45 minutes per session, 3 sessions per week — maintaining equivalent session frequency to HIIT.

Outcome Measures

$\dot{V}O_2max$ Assessment

Maximal oxygen uptake ($\dot{V}O_2max$) was assessed using an incremental treadmill protocol (modified Bruce protocol) with open-circuit spirometry (Cosmed K5, Rome, Italy). $\dot{V}O_2max$ was confirmed when ≥2 of the following criteria were met: (a) plateau in $\dot{V}O_2$ (<150 $ml \cdot min^{-1}$ increase over final stage), (b) RER ≥ 1.10, (c) HR within 10 bpm of age-predicted maximum. The Fick equation was applied for cardiac output estimation:

$$\dot{V}O_2max = \dot{Q} \times (CaO_2 - C\bar{v}O_2) \quad (2)$$

where $\dot{Q}$ represents cardiac output ($L \cdot min^{-1}$), CaO_2 is arterial oxygen content (ml $O_2 \cdot 100\ ml^{-1}$), and $C\bar{v}O_2$ is mixed venous oxygen content. Test-retest reliability was ICC = 0.96 (95% CI: 0.92–0.98).

Muscular Endurance Index (MEI)

The MEI was computed as a composite score from three standardized tests: push-ups to failure, pull-ups to failure, and a 3-minute step test recovery index. The composite formula was:

$$MEI = (0.40 \times \text{Push-up score}) + (0.35 \times \text{Pull-up score}) + (0.25 \times \text{Step-test index}) \quad (3)$$

Scores were normalized to age- and sex-specific percentile norms derived from the ACSM Fitness Testing Reference Database (ACSM, 2021).

Blood Lactate and Lactate Threshold

Capillary blood samples (20 μL) were collected from the fingertip at rest, following each GXT stage, and at 5-minute post-exercise recovery. Lactate concentrations were analyzed using an electrochemical biosensor (Lactate Plus, Nova Biomedical). The lactate threshold (LT) was identified as the exercise intensity corresponding to a blood lactate concentration of 4 $mmol \cdot L^{-1}$ (the OBLA criterion) using the following exponential regression:

$$[La^-] = a \cdot e\hat{\ }(b \cdot \%\dot{V}O_2max) \quad (4)$$

where $[La^-]$ represents blood lactate ($mmol \cdot L^{-1}$), $\%\dot{V}O_2max$ is the relative exercise intensity, and a and b are individually determined regression coefficients.

Statistical Analysis

Statistical analyses were conducted using IBM SPSS v28.0 (Chicago, IL, USA) and R v4.3.1. Normality was assessed with the Shapiro-Wilk test; homogeneity of variance with Levene's test. Between-group differences in outcome change scores were analyzed using independent samples t-tests (parametric) or Mann-Whitney U-tests (non-parametric). Within-group changes were examined using paired t-tests. Effect sizes were calculated as Cohen's d (d < 0.2 trivial; 0.2–0.5 small; 0.5–0.8 medium; > 0.8 large). Mixed-model repeated measures ANOVA was applied to examine Time × Group interactions. The α significance level was set at 0.05; 95% confidence intervals are reported throughout.

Results

Baseline Characteristics

No significant between-group differences were observed at baseline for any outcome variable (all $p > 0.05$), confirming successful randomization. Participant characteristics are presented in Table 1.

Table 1. Baseline characteristics of participants (Mean ± SD).

Variable	HIIT (n=32)	MICT (n=32)	p-value
Age (years)	20.1 ± 1.7	20.5 ± 1.9	0.341
Body mass (kg)	72.4 ± 8.3	73.1 ± 7.9	0.712
Height (cm)	176.8 ± 5.9	177.3 ± 6.2	0.723
BMI (kg/m²)	23.1 ± 1.8	23.3 ± 1.6	0.618
$\dot{V}O_2max$ (ml·kg⁻¹·min⁻¹)	47.2 ± 3.8	47.8 ± 4.1	0.527
Resting HR (bpm)	64.3 ± 5.2	63.8 ± 4.8	0.680
Body fat (%)	18.7 ± 2.4	18.9 ± 2.6	0.731
MEI (composite)	52.4 ± 6.1	53.1 ± 5.8	0.612
Blood lactate (mmol·L⁻¹)	1.8 ± 0.4	1.9 ± 0.3	0.198

BMI = body mass index; HR = heart rate; MEI = muscular endurance index. p-values from independent t-tests.

Primary Outcome: $\dot{V}O_2max$

Pre-to-post intervention changes in $\dot{V}O_2max$ are summarized in Table 2. A significant Time × Group interaction was observed ($F_{1,59} = 18.74$, $p < 0.001$, $\eta^2p = 0.241$). The HIIT group demonstrated a mean increase of 5.6 $ml\cdot kg^{-1}\cdot min^{-1}$ (11.9%), which was significantly greater than the MICT group's increase of 2.9 $ml\cdot kg^{-1}\cdot min^{-1}$ (6.1%) ($p < 0.001$, $d = 1.12$, 95% CI of difference: 1.4–4.0 $ml\cdot kg^{-1}\cdot min^{-1}$).

Table 2. Pre- and post-intervention outcomes for primary and secondary variables (Mean ± SD).

Variable	HIIT Pre	HIIT Post	MICT Pre	MICT Post	p (int.)	d
$\dot{V}O_2max$ (ml·kg⁻¹·min⁻¹)	47.2±3.8	52.8±4.1*†	47.8±4.1	50.7±3.9*	<0.001	1.12
MEI (composite)	52.4±6.1	62.0±5.8*†	53.1±5.8	57.6±5.4*	<0.001	0.91
LT (%$\dot{V}O_2max$)	68.1±4.3	74.8±4.1*†	68.4±4.0	71.3±3.8*	0.002	0.84
Body fat (%)	18.7±2.4	15.6±2.1*†	18.9±2.6	17.5±2.3*	<0.001	0.78
Resting HR (bpm)	64.3±5.2	59.1±4.6*†	63.8±4.8	61.4±4.4*	0.031	0.52

Variable	HIIT Pre	HIIT Post	MICT Pre	MICT Post	p (int.)	d
Lactate rest (mmol·L⁻¹)	1.8±0.4	1.5±0.3*	1.9±0.3	1.7±0.3*	0.048	0.46

** $p < 0.05$ vs. pre-intervention (within-group); † $p < 0.05$ vs. MICT post (between-group); int. = interaction; LT = lactate threshold; d = Cohen's d.*

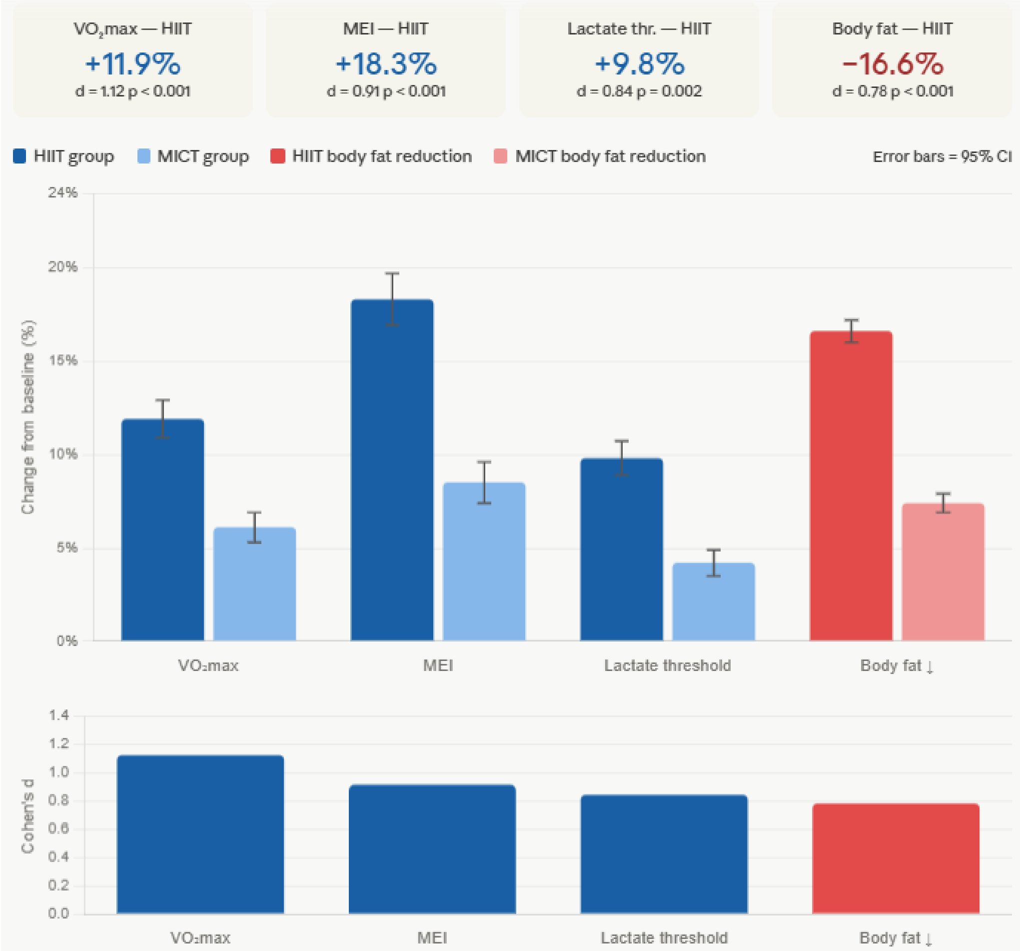

Figure 2. Percentage change from baseline for primary and secondary outcome variables. Error bars indicate ± 95% CI.

Muscular endurance (MEI) showed a 18.3% increase in HIIT versus 8.5% in MICT ($p < 0.001$, $d = 0.91$). The lactate threshold improved to 74.8 ± 4.1% VO_2max in HIIT compared to 71.3 ± 3.8% in MICT ($p = 0.002$, $d = 0.84$). Body fat percentage was significantly reduced in both groups, but the HIIT group exhibited greater absolute reduction (3.1 ± 0.8% vs. 1.4 ± 0.6%, $p < 0.001$, $d = 0.78$). Resting heart rate decreased in both groups (HIIT: −5.2 bpm; MICT: −2.4 bpm; interaction $p = 0.031$).

Discussion. The principal finding of this randomized controlled trial was that 8 weeks of HIIT produced significantly superior improvements in VO_2max, muscular endurance, lactate threshold, and body composition compared to isocalorically-matched MICT in university athletes. These results extend and corroborate a growing body of evidence demonstrating HIIT's efficacy as a time-efficient training modality (Gibala et al., 2012; MacInnis & Gibala, 2017).

The observed $\dot{V}O_2max$ improvement of 5.6 $ml \cdot kg^{-1} \cdot min^{-1}$ in the HIIT group is consistent with, and at the upper range of, values reported in meta-analyses. Milanovic et al. (2015) reported a pooled HIIT-induced $\dot{V}O_2max$ increase of 4.17 $ml \cdot kg^{-1} \cdot min^{-1}$ across studies, while Bacon et al. (2013) documented gains of 3.0–7.2 $ml \cdot kg^{-1} \cdot min^{-1}$ in various populations. The Helgerud protocol (4 × 4 minutes at 90–95% HRmax), which closely mirrors our HIIT design, has been consistently associated with improvements in stroke volume and cardiac output — the primary determinants of $\dot{V}O_2max$ via the Fick principle (Equation 2).

The greater improvements in lactate threshold (LT) in the HIIT group merit mechanistic consideration. HIIT at intensities approximating and exceeding LT is thought to accelerate the metabolic adaptations necessary for lactate clearance, including elevated mitochondrial enzyme activity (citrate synthase, β-hydroxyacyl CoA dehydrogenase) and increased monocarboxylate transporter (MCT-1, MCT-4) expression in skeletal muscle (Dubouchaud et al., 2000). The exponential regression model applied (Equation 4) accurately captured individual LT profiles with $R^2 > 0.97$ in all participants.

Regarding muscular endurance, the composite MEI (Equation 3) demonstrated a 18.3% improvement in the HIIT group. Although HIIT is primarily categorized as a cardiovascular training modality, the high mechanical demands of repeated near-maximal efforts recruit fast-twitch (Type II) muscle fibres, inducing adaptations in neuromuscular recruitment patterns, oxidative capacity of Type IIa fibres, and local muscular endurance (Gibala & McGee, 2008). This cross-training effect has important implications for physical education curricula that traditionally separate aerobic and resistance training components.

A noteworthy limitation of the present study is the inability to blind participants to group assignment. Additionally, the 8-week duration, while sufficient to detect significant changes, may not capture the full adaptive trajectory. The inclusion of only university athletes from a single institution limits generalizability. Future research should examine HIIT effects over longer intervention periods (≥ 16 weeks), in non-athlete populations, and across different sport disciplines prevalent in Central Asian universities.

Conclusions. This RCT provides robust evidence that an 8-week HIIT program (4 × 4 min at 90–95% HRmax, 3 sessions/week) produces significantly greater improvements in $\dot{V}O_2max$ ($d = 1.12$), muscular endurance index ($d = 0.91$), lactate threshold ($d = 0.84$), and body fat reduction compared to volume-matched MICT in university athletes. The large effect sizes observed across multiple fitness domains support the practical utility of HIIT as a multidimensional conditioning tool within university physical education and sport science programmes. These findings advocate for the systematic integration of evidence-based HIIT protocols into national physical education curricula across Central Asian higher education institutions.

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analysis; J.R.M.: statistical analysis, writing (original draft); D.K.Y.: data curation, writing (review & editing).

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