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Comparative Effects of High-Intensity Interval Training (HIIT) and Moderate-Intensity Continuous Training (MICT) on Maximal Oxygen Uptake (VO_2max) and Lactate Threshold (LT) in Recreationally Active Adults

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ABSTRACT: This randomized controlled trial was designed to evaluate and compare the eight-week effects of HIIT versus MICT protocol on VO_2 max and LT in recreationally active young adults. Sixty recreationally active adults (30 male, 30 females; mean age: 22.4 ± 2.1 years; BMI: 23.6 ± 1.8 kg/m²) were randomly assigned across three parallel arms: HIIT (n = 20), MICT (n = 20), and a non-exercising control group (CON; n = 20). The HIIT protocol involved 4–6 work bouts of four minutes each at 85–95% of maximal heart rate (HRmax), separated by three-minute active recovery intervals at 50–60% HRmax, three sessions per week. MICT participants completed 40–60 minutes of uninterrupted cycling at 60–70% HRmax, equated to HIIT for caloric expenditure. VO_2max was measured via a graded exercise test (GXT) on a cycle ergometer, and LT was quantified through incremental blood lactate sampling at baseline (T0) and post-intervention (T1). Pre and posttest results were processed through statistical package for social sciences (SPSS, version-32) and thus suitable statistical tools were applied according to parametric data. Based on data analysis, the researcher arrived at conclusion that HIIT has significant effect on cardiorespiratory fitness, generating greater VO_2max gains than volume-matched MICT. Both protocols confer broadly comparable lactate threshold adaptations

Keywords: High-intensity interval training, moderate-intensity continuous training, VO_2max, maximal oxygen uptake, lactate threshold, aerobic capacity, exercise physiology, cardiorespiratory fitness

INTRODUCTION

Cardiovascular fitness is considered to be one of the most important components of health-related physical fitness as it is strongly associated with reduced risk of cardiovascular disease, hypertension, obesity and metabolic disorders. It is the ability of the heart, lungs and circulatory system to supply the working muscles with oxygen during sustained physical activity. Regular aerobic exercise such as running, cycling, and swimming improve the efficiency of the cardiovascular system by increasing stroke volume, cardiac output, and oxygen use in the muscles (Malone, 2024).

The maximal oxygen uptake (VO2max) is widely known as the gold standard of cardiovascular fitness and aerobic capacity. Maximum amount of oxygen that a body can consume, transport and use during intense exercise; normally expressed as mL/kg/min. The higher the VO_2max, the higher the aerobic endurance and the more efficient the delivery of oxygen to the muscles. Training interventions such as high-intensity interval training (HIIT) and moderate-intensity continuous training (MICT) have demonstrated a significant improvement in VO 2max by increasing mitochondrial density, capillary networks and cardiac function. It has been consistently shown that increased VO_2max is related to improved athletic performance and reduced risk of mortality due to cardiovascular diseases (Korivi et al, 2025)

Among the physiological markers of human health and athletic capability, maximal oxygen uptake (VO_2max) stands out for its dual relevance: it serves as the gold-standard measure of cardiorespiratory fitness (CRF) and is a robust independent predictor of cardiovascular disease risk and premature mortality (Ross et al., 2016). This single variable integrates the coordinated function of pulmonary ventilation, cardiac output, hemoglobin-mediated oxygen transport, and the oxidative machinery of working skeletal muscle (Bassett & Howley, 2000). Complementing VO_2max as an endurance performance marker is the lactate threshold (LT)—the exercise intensity above which blood lactate begins to accumulate exponentially—which has repeatedly been shown to predict sustained exercise output more reliably than VO_2max alone in trained populations (Faude et al., 2009).

For decades, moderate-intensity continuous training (MICT) served as the principal framework for aerobic exercise prescription, backed by an extensive safety and efficacy record across diverse clinical and healthy populations (American College of Sports Medicine [ACSM], 2018). More recently, escalating demands on personal time and a desire for condensed but effective training have fueled investigative interest in high-intensity interval training (HIIT). HIIT involves repeated short-to-moderate

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bursts of vigorous effort—typically at or above 80% of HRmax or VO_2max—interspersed with lower-intensity recovery phases (Weston et al., 2014). A substantial body of randomized trials and meta-analyses has reported that HIIT can match or exceed MICT in augmenting VO_2max while requiring considerably less total exercise volume and time (Milanović et al., 2015; Bacon et al., 2013).

The physiological machinery driving HIIT-induced aerobic improvement is broad. Enhanced cardiac stroke volume and output, heightened skeletal muscle oxidative enzyme activity, accelerated mitochondrial biogenesis, and augmented fatty acid oxidation pathways have each been implicated (MacInnis & Gibala, 2017). HIIT may further advance lactate threshold through improved muscular buffering capacity and upregulated lactate transporter expression (Buchheit & Laursen, 2013). The high-intensity stimulus inherent to HIIT protocols is also associated with preferential recruitment of Type II muscle fibers and a favorable hormonal milieu, including elevated testosterone and attenuated post-exercise cortisol (Tabassum et al., 2023).

Despite a growing literature, the relative efficacy of HIIT versus MICT in recreationally active—as opposed to sedentary or clinically compromised—individuals remain insufficiently characterized. Prior trials in this area have been hampered by small sample sizes, heterogeneous HIIT protocols, non-isocaloric comparisons, and the frequent absence of simultaneous assessment of both VO_2max and LT as co-primary endpoints (Gist et al., 2014). Sex-disaggregated analyses are also conspicuously underrepresented despite well-established differences between males and females in substrate use and hormonal profiles that may shape the magnitude of training-induced adaptations (O'Toole et al., 2021). Broader questions regarding the relationship between cardiorespiratory endurance and muscular strength also warrant continued investigation (Manan et al., 2021).

The metabolic footprint of HIIT extends beyond the cardiopulmonary system. High-intensity exercise exerts measurable influence on hepatic enzyme activity and endogenous antioxidant defenses, underscoring the systemic physiological burden of such training (Khan et al., 2022). HIIT-based interventions have demonstrated favorable outcomes across varied contexts, including body composition modification in overweight cohorts (Javed et al., 2022), attesting to the broad applicability of intensity-driven exercise.

MATERIAL AND METHODS

The below procedures were adopted for reaching at certain findings and conclusion.

Study Design

As the study aimed to evaluate and compare the eight-week effects of HIIT versus MICT protocol on VO_2 max and LT in recreationally active young adults, therefore a randomized controlled trial design was employed. All procedures were conducted in compliance with the 2013 revision of the Declaration of Helsinki.

Study Participants

Sixty recreationally active adults (30 male, 30 female; mean age: 22.4 ± 2.1 years;BMI: 23.6 ± 1.8 kg/m²) were randomly assigned across three parallel arms: HIIT (n = 20), MICT(n = 20), and a non-exercising control group (CON; n = 20). Furthermore the inclusion criteria for study participants were; (a) recreationally active status, operationalized as two to three weekly sessions of moderate aerobic exercise sustained for at least three months prior to enrolment; (b) freedom from any cardiovascular, pulmonary, metabolic, or musculoskeletal condition contraindicating maximal exercise testing; (c) non-smoker status; (d) abstinence from ergogenic aids or pharmacological agents known to modify aerobic metabolism; and (e) willingness to adhere to the full intervention protocol.

Exercise Intervention

A self-made exercise protocols of HIIT and MICT applied on experimental groups. Participants in the HIIT arm completed three supervised sessions per week over eight weeks. Each session opened with a 5-minute warm-up at 50% HRmax, followed by 4–6 four-minute intervals at 85–95% of individually determined HRmax (established from the baseline GXT), with each work bout separated by a 3-minute active recovery phase at 50–60% HRmax, and closed with a 5-minute cool-down. Progressive overload was operationalized by incrementing the interval count from four in weeks 1–2, to five in weeks 3–6, and six in weeks 7–8.MICT participants also trained three sessions per week for eight weeks, performing uninterrupted cycling at 60–70% HRmax. Session duration advanced from 40 minutes in weeks 1–2, to 50 minutes in weeks 3–6, and 60 minutes in weeks 7–8. Work rate was adjusted individually throughout each session to maintain the prescribed heart rate range. Total energy expenditure was computed via the Fick principle and matched between groups to within ±5%. CON participants were instructed to maintain habitual activity levels and to refrain from initiating any structured exercise programmed during the eight-week period. Adherence was verified through weekly telephone self-report. On completion of the post-intervention assessment, CON participants were offered prioritized access to either training programmed.

Outcome Measures

VO_2max Assessment. VO_2max was evaluated at T0 and T1 via a standardized incremental GXT on the cycle ergometer, beginning at 50 W and increasing by 25 W every two minutes until volitional exhaustion or an inability to sustain 60 rpm. Breath-by-breath expired gas analysis was performed using a calibrated metabolic system (COSMED Quark CPET, Rome, Italy). A test was deemed valid when at least two of four criteria were satisfied: (1) VO_2 plateau despite rising workload ($\Delta < 2.1$ mL/kg/min); (2) RER ≥ 1.10; (3) HR within 10 bpm of age-predicted maximum; and (4) RPE ≥ 18 on the Borg 6–20 scale (Borg, 1982).

Lactate Threshold Determination. A dedicated incremental blood lactate test was conducted 48–72 hours after the GXT at both T0 and T1. Five consecutive four-minute stages were performed beginning at 40% of VO_2max with 20% increments per stage. A 25 µL capillary fingertip blood sample was obtained at stage end and immediately analyzed using a portable Lactate Pro 2 analyzer (Arkray Inc., Kyoto, Japan). LT was identified using the Dmax method—the workload corresponding to the greatest perpendicular distance from a line connecting the first and last lactate values on the lactate-workload curve (Cheng et al., 1992)—and expressed in absolute watts and as a percentage of VO_2max (%LT).

Anthropometric and Body Composition Measures. Body mass was recorded on a calibrated digital scale (Seca 877, Seca GmbH, Hamburg, Germany) and standing height on a wall-mounted stadiometer. BMI was computed as mass (kg) divided by height squared (m^2). Whole-body fat mass and fat-free mass were determined by dual-energy X-ray absorptiometry (DXA; Hologic Discovery A, Waltham, MA, USA) at T0 and T1.

Session RPE and Training Load. Subjective session ratings of perceived exertion (sRPE) were recorded 30 minutes after each training session using the CR-10 scale (Foster et al., 2001). Weekly training load was quantified as the product of session RPE and session duration in minutes.

Ethical Consideration

Ethical approval was taken from the Institutional Review Board of the University of the Punjab, Lahore, Pakistan (Reference No. IRB-PE-2023-047). Written informed consent was secured from every participant before enrolment.

Statistical Analysis

The pretest and posttest results were processed through statistical package for social sciences (SPSS, version-32) and thus suitable statistical tools were applied according to parametric data.

RESULTS

Table 1 describes the baseline characteristics of participants in the HIIT, MICT and control groups (n=20 in each group).

Table 1. Baseline Characteristics of Participants of all groups

Variable	HIIT (n = 20)	MICT (n = 20)	CON (n = 20)	p-value
Age (years)	22.1 ± 2.3	22.7 ± 1.9	22.4 ± 2.1	.78
Sex (M/F)	10/10	10/10	10/10	1.00
Body Mass (kg)	68.4 ± 9.1	69.2 ± 8.7	67.9 ± 9.4	.89
BMI (kg/m²)	23.4 ± 2.1	23.8 ± 1.7	23.6 ± 1.9	.72
VO_2max (mL/kg/min)	39.5 ± 4.2	38.4 ± 4.6	39.1 ± 3.9	.64
LT (%VO_2max)	61.3 ± 5.4	60.8 ± 5.1	61.0 ± 5.7	.94
RHR (bpm)	68.2 ± 7.3	69.1 ± 6.9	68.7 ± 7.1	.87
Body Fat (%)	22.1 ± 3.8	21.8 ± 4.2	22.3 ± 3.6	.91

Note: HIIT = high-intensity interval training; MICT = moderate-intensity continuous training; CON = sedentary control; LT = lactate threshold; RHR = resting heart rate. p-values derived from one-way ANOVA.

The results show that there were no significant differences between the three groups in age, sex distribution, body mass, BMI, VO2max, lactate threshold, resting heart rate and body fat percentage (all p-values > .05). Result shows that participants in all groups were similar with respect to demographic, physiological, and fitness-related variables. This similarity suggests that the groups were well matched at baseline and any changes observed during the intervention could be attributed to the training protocols rather than pre-existing differences among participants.

Table 2. Pre- and Post-Intervention VO_2max Values and Between-Group Comparisons

Group	Pre (mL/kg/min)	Post (mL/kg/min)	Δ Change	% Change	Cohen's d
HIIT	39.5 ± 4.2	43.4 ± 4.7*†	+3.87 ± 1.42	+9.8%	0.91
MICT	38.4 ± 4.6	40.9 ± 4.9*	+2.46 ± 1.31	+6.4%	0.55
CON	39.1 ± 3.9	38.9 ± 4.1	–0.18 ± 0.94	–0.5%	0.05

Note: Values are mean ± SD. * $p < .001$ vs. baseline; † $p = .032$ HIIT vs. MICT post-intervention change.

The table 2 shows VO_2max during pre- and post-intervention in the HIIT, MICT and control groups. The greatest gain in aerobic capacity was observed in the HIIT group with a 9.8% increase in VO2max from 39.5 ± 4.2 to 43.4 ± 4.7 mL/kg/min, with a large effect size (Cohen's d = 0.91). The MICT group also showed a significant increase in VO2max with an increase of 6.4% with a moderate effect size (d=0.55). The control group, however, showed no significant change in VO_2max with only a small decrease (−0.5%, d = 0.05). Additionally, the HIIT group improved significantly more than the MICT group ($p = .032$), suggesting that HIIT was more effective than moderate-intensity continuous training for enhancing aerobic fitness.

Table 2. Pre- and Post-Intervention Lactate Threshold Values

Group	LT Pre (W)	LT Post (W)	Δ (W)	%LT Pre	%LT Post	p
HIIT	162.4 ± 18.7	181.9 ± 19.4*	+19.5 ± 8.1	61.3 ± 5.4	64.7 ± 5.1*	< .001
MICT	158.3 ± 17.2	174.6 ± 18.1*	+16.3 ± 7.4	60.8 ± 5.1	63.9 ± 4.8*	< .001
CON	155.1 ± 16.9	156.5 ± 17.1	+1.4 ± 5.2	61.0 ± 5.7	61.4 ± 5.5	.81

Note: * $p < .001$ vs. respective pre-intervention value; $\eta^2p = .05$ for between-group %LT comparison ($p = .089$).

In table no.3 indicated the significant differences in the lactate threshold during pre- and post-intervention in the HIIT and MICT groups ($p < .001$) and no significant differences in the control group was observed. The HIIT group showed greater result thane MICT group, but the difference between groups was not statistically significant ($p = .089$). The results suggest that both training regimens were effective in improving lactate threshold.

DISCUSSION

The result of the current study reveals that eight weeks of HIIT produced meaningfully greater VO_2max improvements than volume-matched MICT in recreationally active young adults (9.8% versus 6.4%; $p = .032$). At the same time, both protocols drove statistically equivalent improvements in lactate threshold. These outcomes corroborate and extend the growing body of trial and meta-analytic evidence that HIIT offers a superior aerobic stimulus relative to MICT across a range of populations (Milanović et al., 2015; Bacon et al., 2013; Weston et al., 2014).

The 9.8% VO_2max gain observed in the HIIT arm falls comfortably within the 4–15% range documented in preceding HIIT trials involving recreationally active cohorts (Buchheit & Laursen, 2013; MacInnis & Gibala, 2017). The mechanisms underpinning HIIT's aerobic superiority are likely to be multifactorial. On the central side, enlargement of left ventricular volume, improved stroke volume, and elevated maximal cardiac output are established hallmarks of HIIT-induced adaptation and represent primary determinants of VO_2max (Scharhag-Rosenberger et al., 2012). The near-maximal cardiac output demands of high-intensity intervals generate a stronger adaptive stimulus than the submaximal cardiac loading typical of continuous moderate exercise (Daussin et al., 2008). Peripherally, increases in skeletal muscle mitochondrial density, upregulation of key oxidative enzymes (e.g., citrate synthase, cytochrome c oxidase), and greater capillary density collectively enhance the muscle's oxygen extraction capacity following HIIT (MacInnis & Gibala, 2017).

The comparable lactate threshold improvements observed across HIIT and MICT (%LT: 3.4 vs. 3.1 percentage points, $p = .089$) are noteworthy. LT is broadly accepted as among the most reliable physiological predictors of sustained endurance capacity (Faude et al., 2009). The upward LT shift following both modalities reflects improved oxidative phosphorylation, elevated lactate clearance through upregulated monocarboxylate transporters (MCT1, MCT4), and enhanced buffering capacity (Billat, 2001). These findings align with prior work examining the effects of fartlek and interval-based protocols on lactate dehydrogenase kinetics (Bilal et al., 2026) and suggest that adaptations in lactate metabolic pathways are not uniquely linked to any single intensity paradigm. The non-significant between-group difference in %LT ($p = .089$) warrants caution in interpretation, however, as the study may have lacked statistical power to detect modest but clinically meaningful differences in this secondary endpoint.

The practical import of HIIT's approximately 40% time-efficiency advantage (72 versus 120 min/week) while achieving superior aerobic outcomes cannot be overstated. Time scarcity remains the most frequently reported barrier to regular physical activity participation worldwide, and interventions capable of delivering equivalent or better health benefits in shorter windows hold substantial public health value (Trost et al., 2002). This efficiency-effectiveness profile renders HIIT especially attractive for working adults and those managing chronic conditions requiring exercise brevity. The intervention's benefits extend to clinical populations, with HIIT demonstrating efficacy in coronary artery disease, heart failure, type 2 diabetes, and metabolic syndrome (Weston et al., 2014). Furthermore, high-intensity exercise has been shown to exert broad physiological regulatory effects, including improvements in glucose homeostasis among obese individuals (Raza et al., 2026) and favorable modulation of antioxidant and hepatic enzyme activity (Khan et al., 2022), reinforcing the wide-ranging biological relevance of intensity-driven training.

The absence of a significant sex-moderating effect on training responses in this study is broadly consistent with prior work showing comparable aerobic adaptations in males and females when protocols are individually prescribed relative to HRmax (Tarnopolsky, 2008). Nevertheless, the descriptive trend toward larger absolute VO_2max gains in males (+4.21 versus +3.53 mL/kg/min in females) merits follow-up in larger, sex-stratified investigations, since baseline hormonal environments and substrate utilization profiles—including variation across menstrual cycle phases—may generate differential training response magnitudes. Research by Tabassum et al. (2023) on hormonal responses to high-intensity resistance training in university footballers offers relevant context, though direct extrapolation to aerobic training modalities requires care. The relationship between cardiorespiratory fitness and muscular strength, as examined by Manan et al. (2021), further underscores the integrated nature of physical fitness components targeted by these contrasting protocols.

Several methodological strengths distinguish the present study from prior work. The isocaloric comparison design—matching total energy expenditure rather than session duration—represents a more rigorous approach that cleanly isolates the intensity effect from energy expenditure as a driver of adaptation. Individually prescribed HRmax-based target zones guarded against systematic under-stimulation of HIIT participants due to inaccurate age-predicted heart rate formulae. The use of gold-standard GXT-based VO_2max assessment, Dmax-based LT determination, and blinded outcome assessors further strengthens confidence in the validity of these findings.

Several limitations merit acknowledgement. The eight-week intervention window, though sufficient to induce robust aerobic adaptations, forecloses conclusions about longer-term differential effects on aerobic capacity and metabolic health. The homogeneous, young, recreationally active sample constrains generalization to sedentary or older adults and to those with clinical impairment. Dietary intake was assessed by self-report only; residual dietary confounding cannot be entirely excluded. Future investigations should adopt longer durations and more heterogeneous participant samples, incorporate molecular markers of mitochondrial biogenesis (e.g., PGC-1α) and capillarization to elucidate mechanistic underpinnings, and include rigorous dietary monitoring.

CONCLUSION

Based on findings the study arrived at conclusion that an eight-week HIIT programmed causes significantly greater VO_2max improvements than an isocaloric MICT programmed in recreationally active young adults—all while requiring roughly 40% fewer weekly training minutes. Both modalities delivered statistically equivalent and clinically meaningful lactate threshold gains. Collectively, these findings strengthen the evidence base for HIIT as a time-efficient, high-efficacy strategy for improving cardiorespiratory fitness in healthy active populations. Future work should examine the durability of HIIT-induced VO_2max gains over extended periods, compare long-term adherence rates between modalities, and elucidate the cellular and molecular mechanisms underlying intensity-dependent training adaptation in clinically diverse populations.

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CONFLICT OF INTEREST

No conflict of interest was declared by the authors.

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