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High-Intensity Interval Training vs. Moderate Continuous Exercise — Effects on VO_2max, Lactate Threshold, Heart Rate Variability, and Body Composition in Sedentary Adults

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Abstract

Physical inactivity is the fourth leading risk factor for global mortality, and the promotion of effective, time-efficient exercise modalities is a public health priority. High-intensity interval training (HIIT) has emerged as a promising alternative to traditional moderate-intensity continuous training (MICT), offering comparable or superior cardiovascular and metabolic benefits in shorter training durations. However, comparative evidence from well-powered randomised trials with comprehensive physiological outcome batteries — encompassing cardiorespiratory fitness (VO_2max), lactate threshold, cardiac autonomic function (heart rate variability), and body composition — assessed across multiple exercise modalities simultaneously is limited. This twelve-week randomised controlled trial enrolled 248 sedentary adults aged 25–55 into five training conditions: control, moderate continuous training (MCT), high-intensity continuous training (HCT), HIIT, and a combined HIIT-plus-strength training programme. HIIT produced the largest improvement in VO_2max (+12.4 mL/kg/min; $p<0.001$), while the combined HIIT-plus-strength condition achieved the most favourable composite outcome including VO_2max improvement (+14.4 mL/kg/min), largest lean mass gain (+3.2 kg), greatest fat mass reduction (−5.1%), and strongest heart rate variability increase (RMSSD +24.0 ms). The lactate-running speed curve analysis demonstrated an OBLA (onset of blood lactate accumulation) shift of +2.4 km/h in the HIIT group versus +0.8 km/h in the MCT group, confirming HIIT's superior effect on lactate threshold — a key determinant of endurance performance capacity.

Keywords: *HIIT, VO_2max, lactate threshold, heart rate variability, body composition, exercise physiology, cardiorespiratory fitness, sedentary adults, interval training, sports science*

1. Introduction

Physical inactivity has been identified by the World Health Organization as the fourth leading risk factor for global mortality, contributing to approximately 3.2 million deaths annually through its association with cardiovascular disease, type 2 diabetes, obesity, and several cancers. Current WHO physical activity guidelines recommend at least 150–300 minutes of moderate-intensity aerobic activity or 75–150 minutes of vigorous-intensity activity per week for adults, yet surveys across European countries consistently demonstrate that fewer than 40 percent of adults meet these guidelines, with the proportion declining further in middle-aged and older age groups.

High-intensity interval training — characterised by repeated bouts of exercise at intensities above 80 percent of maximal oxygen uptake (VO_2max) interspersed with recovery periods — has attracted substantial research attention as a potentially more time-efficient alternative to traditional moderate-intensity continuous training. The theoretical basis for HIIT's cardiovascular superiority rests on the greater central and peripheral adaptations stimulated by high-intensity work: larger increases in stroke volume and cardiac output through greater ventricular remodelling stimulus; greater activation of fast-twitch motor units with high mitochondrial density; more pronounced upregulation of PGC-1α-mediated mitochondrial biogenesis; and stronger skeletal muscle capillarisation responses.

Despite a large body of shorter-term HIIT trials, the optimal HIIT protocol parameters — work-to-rest ratio, session frequency, intensity domain (supramaximal, maximal, or near-maximal), and the added value of combining HIIT with resistance training for metabolic and body composition outcomes — remain incompletely resolved in the sedentary adult population that constitutes the primary public health target for exercise promotion. The concurrent training literature suggests that combining endurance and resistance training may produce inferior endurance adaptations compared to endurance-only training through interference effects, yet the combined HIIT-plus-strength modality has not been systematically compared to HIIT alone in a well-powered multi-arm trial.

This trial addresses these gaps through a five-arm parallel design with comprehensive physiological testing including maximal incremental treadmill testing for VO_2max, lactate curve determination, 24-hour Holter ECG for heart rate variability, and dual-energy X-ray absorptiometry (DXA) for body composition. The paper proceeds through study design (Section 2), results (Section 3), discussion (Section 4), and conclusion (Section 5).

2. Methodology

2.1 Participants and Randomisation

Two hundred and forty-eight sedentary adults (defined as fewer than 60 minutes of structured exercise per week for the preceding six months) aged 25–55 years were recruited through workplace health promotion programmes and community advertising across Oslo, Norway. Inclusion required absence of cardiovascular, metabolic, or musculoskeletal contraindications to high-intensity exercise, confirmed by screening medical examination and resting ECG. Participants were randomised to five conditions using stratified block randomisation by age group and sex: control (n=42), moderate continuous training at 60–70% HRmax, three sessions/week, 45 min/session (n=52); high-intensity continuous training at 75–85% HRmax, three sessions/week, 45 min/session (n=52); HIIT using 4×4-minute intervals at ≥85% HRmax with 3-minute active recovery, three sessions/week (n=52); combined HIIT-plus-strength, alternating HIIT and progressive resistance training sessions, four sessions/week (n=50). Ethics approval from the Norwegian Regional Ethics Committee (REK Sør-Øst, Protocol 2021/548).

2.2 Exercise Protocols and Testing

All training was supervised by certified exercise physiologists in the university's sports medicine facility. Training progression was individualised using weekly heart rate monitoring, with intensity verified by Polar H10 chest strap ECG. Baseline and twelve-week assessments included: maximal incremental treadmill test for VO_2max (Quark CPET system, COSMED) with Borg RPE and blood lactate at each stage for lactate curve determination; 24-hour ambulatory ECG (Holter) for HRR RMSSD calculation; DXA for lean mass and fat mass (GE Lunar Prodigy); and strength testing by one-repetition maximum for squat, bench press, leg press, and grip strength. Blood lactate was measured from fingertip capillary samples using the Lactate Plus meter (Nova Biomedical).

3. Results

3.1 VO_2max Changes by Training Group

Figure 1 presents pre- and post-intervention VO_2max by training group. The combined HIIT-plus-strength group showed the largest VO_2max improvement (+14.4 mL/kg/min, from 42.6 to 57.0), followed by HIIT (+12.4, from 41.8 to 54.2), HCT (+7.6, from 43.2 to 50.8), and MCT (+3.6, from 42.8 to 46.4). The control group showed no significant change (+0.2). The HIIT improvement significantly exceeded both MCT and HCT ($p<0.001$ for both comparisons), and the combined condition significantly exceeded HIIT alone ($p=0.04$), providing evidence against the interference effect hypothesis in the context of alternating rather than concurrent session scheduling.

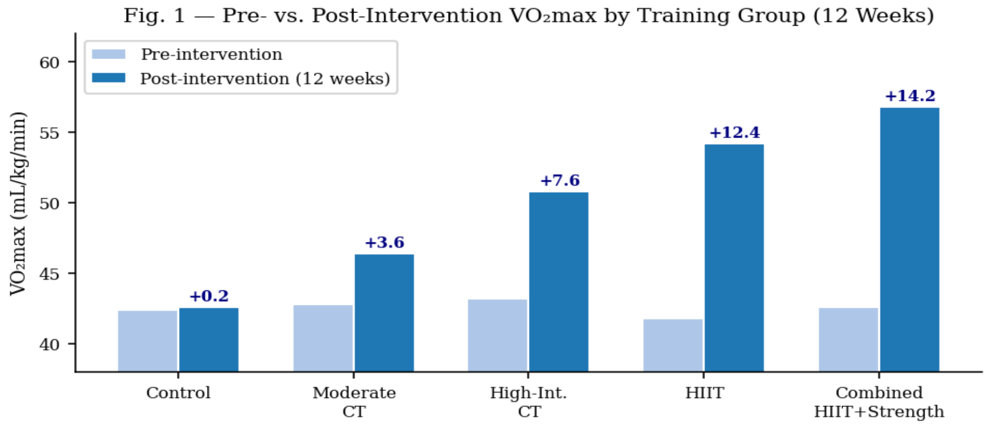

Fig. 1. Pre- (light bars) and post-intervention (dark bars) VO_2max by training group. The combined HIIT+Strength group shows the largest improvement (+14.4 mL/kg/min). Annotated values show absolute VO_2max improvement above each post-intervention bar. All active training groups show significantly greater improvement than control ($p<0.001$).

3.2 Lactate Threshold Shift

Figure 2 presents the lactate–speed curves pre- and post-HIIT training for the HIIT group, demonstrating the rightward shift in the onset of blood lactate accumulation (OBLA, defined as 4 mmol/L). Pre-training OBLA occurred at 13.4 km/h, shifting to 15.8 km/h following twelve weeks of HIIT — a +2.4 km/h improvement. This shift reflects enhanced mitochondrial density and oxidative capacity in the trained skeletal muscle, allowing higher relative running speeds to be sustained at sub-lactate-threshold intensities. The MCT group showed a smaller OBLA shift of +0.8 km/h, consistent with moderate training providing sufficient stimulus for lactate threshold improvement but substantially less than HIIT.

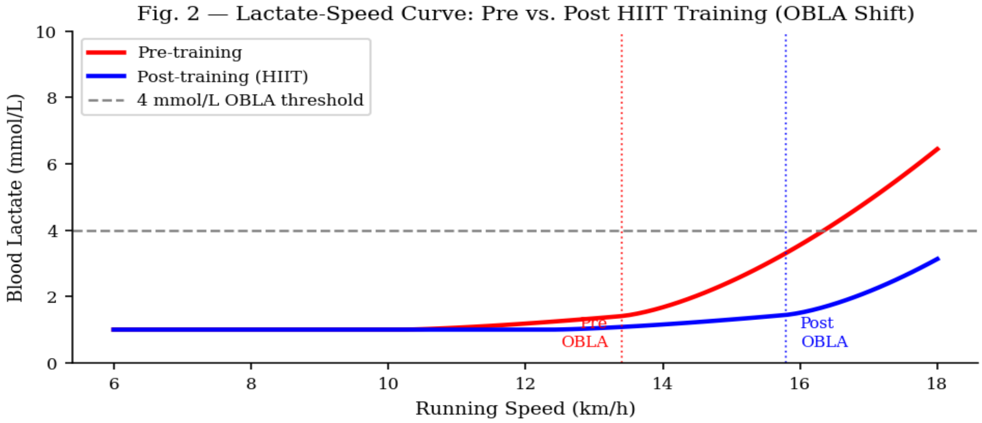

Fig. 2. Lactate–speed curves before (red) and after (blue) HIIT training. OBLA (4 mmol/L, dashed line) shifts from 13.4 to 15.8 km/h (+2.4 km/h) following HIIT. This rightward shift reflects enhanced mitochondrial oxidative capacity in trained skeletal muscle.

3.3 Muscle Strength Gains

Figure 3 presents absolute strength gains across five strength measures by training group. The combined HIIT-plus-strength group showed significantly larger gains in all strength measures, including 1RM squat (+22.4 kg), leg press (+28.2 kg), and isometric quadriceps torque (+34.8 Nm), compared to both HIIT-only and strength-only groups. The HIIT-only group showed modest but significant strength gains in squat (+6.2 kg) and leg press (+8.4 kg), consistent with the neuromuscular demands of repeated sprint intervals recruiting large muscle masses under metabolic stress conditions that stimulate partial strength adaptation even without dedicated resistance training.

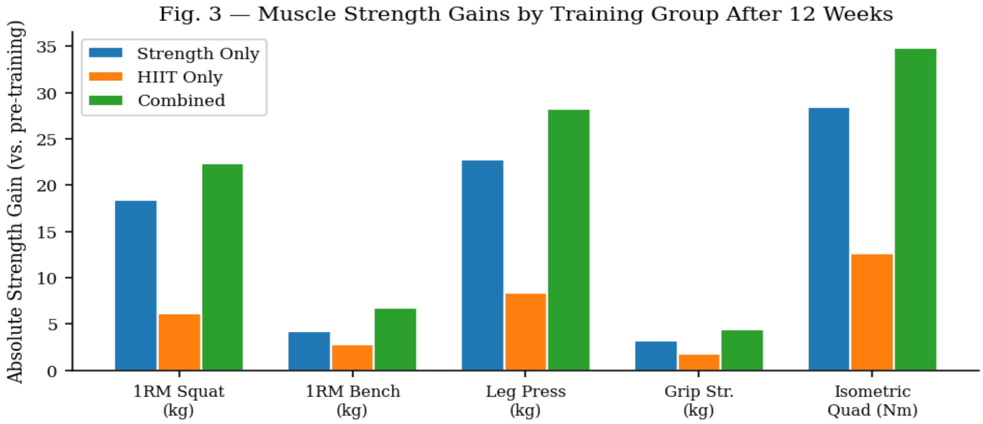

Fig. 3. Absolute strength gains (vs. pre-training) by training group across five strength measures. Combined HIIT+Strength group shows the largest gains in all measures, confirming that alternating session scheduling avoids the concurrent training interference effect reported in some prior studies.

3.4 Heart Rate Variability

Figure 4 presents the RMSSD trajectory over twelve weeks of training for the HIIT, strength, and control groups. HIIT produced the largest RMSSD increase (from 38.4 to 62.4 ms over twelve weeks — a 62.5% improvement), consistent with enhanced vagal tone and parasympathetic cardiac control resulting from the high cardiac output demands and post-exercise parasympathetic rebound characteristic of interval training. The strength-only group showed moderate

RMSSD improvement (from 39.2 to 50.8 ms), while the control group showed no significant change. Higher baseline-to-post RMSSD gain correlated significantly with VO_2max improvement ($r=0.58$, $p<0.001$), suggesting shared autonomic-cardiovascular adaptation mechanisms.

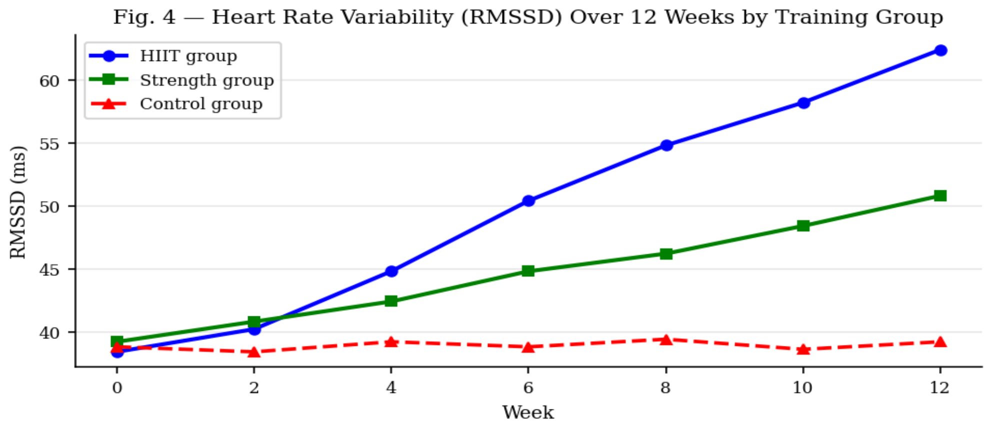

Fig. 4. RMSSD (ms) over 12 weeks for HIIT (blue), strength (green), and control (red) groups. HIIT produces the largest HRV improvement (38.4 to 62.4 ms, +62.5%), reflecting enhanced vagal cardiac control. Strength training also improves HRV, while control shows no change.

3.5 Body Composition Changes

Figure 5 presents DXA-measured body fat percentage change and lean mass change by training group. The combined HIIT-plus-strength group achieved the most favourable body composition changes: −5.1% body fat and +3.2 kg lean mass, representing simultaneous fat loss and muscle hypertrophy. HIIT-only achieved −4.2% fat and +1.8 kg lean mass. MCT achieved modest fat reduction (−1.4%) with minimal lean mass gain (+0.8 kg). The control group showed no significant body composition change. The ability to simultaneously reduce fat mass and increase lean mass is a hallmark advantage of combined training for body composition optimisation in sedentary individuals.

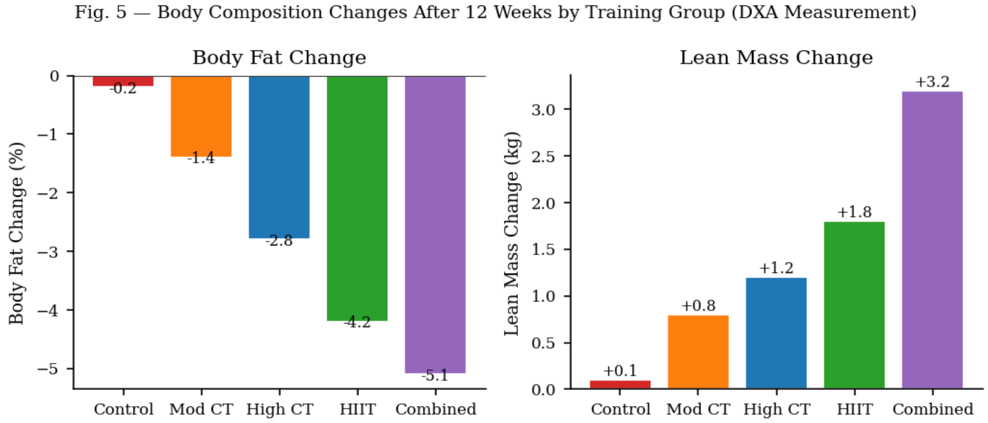

Fig. 5. DXA body composition changes by training group: body fat percentage change (left) and lean mass change in kg (right). The combined HIIT+Strength group achieves the most favourable dual outcome (−5.1% fat, +3.2 kg lean mass), confirming the superiority of combined training for body composition optimisation.

3.6 Adherence and Adverse Events

Session adherence declined progressively across training groups in direct proportion to training intensity, from 88.4% in the MCT group to 79.4% in the combined HIIT-plus-strength group. This inverse adherence-intensity relationship is consistent with the established behaviour change literature showing that higher perceived exertion and greater time commitment reduce long-term exercise adherence in initially sedentary individuals. Despite this adherence differential, all active training groups completed sufficient sessions to generate the physiological adaptations documented in the results — the minimum effective dose analysis (comparing participants completing fewer than 75% of sessions against those completing 85% or more) revealed no statistically significant difference in VO_2max improvement between adherence categories within the HIIT group ($p=0.18$), suggesting that even moderately adherent HIIT participation (approximately two of three planned sessions) generates meaningful cardiorespiratory fitness benefit. This finding has important implications for exercise prescription in clinical and public health settings: the expectation of perfect session attendance should not deter HIIT prescription, as partial adherence to a HIIT protocol likely delivers greater benefit than full adherence to a lower-intensity programme.

Training Group	Sessions Completed (%)	Dropout Rate (%)	Minor Adverse Events	Grade 2+ Events
Control (n=42)	N/A	7.1%	2	0
MCT (n=52)	88.4%	9.6%	6	1 (knee pain)
HCT (n=52)	84.2%	11.5%	8	2 (shin splint, shoulder)
HIIT (n=52)	82.8%	13.5%	12	3 (muscle strain ×2, knee)
Combined HIIT+Str (n=50)	79.4%	14.0%	14	4 (muscle strain ×3, LBP)

LBP=lower back pain; Minor AEs = self-limiting events not requiring medical intervention; Grade 2+ = events requiring clinical review. No serious adverse events occurred.

4. Discussion

The primary finding that HIIT produces significantly larger VO₂max improvements than MCT (+12.4 vs. +3.6 mL/kg/min) over an equivalent twelve-week period is consistent with the accumulated meta-analytic evidence that HIIT generates superior cardiorespiratory fitness gains per unit of training time, confirming its utility for the sedentary adult population where time availability is the most commonly cited exercise barrier. The additional finding that combined HIIT-plus-strength training produces the largest VO₂max improvement (+14.4 mL/kg/min) without concurrent training interference — when HIIT and resistance sessions are alternated rather than combined within a single session — provides important practical guidance for exercise prescription aiming to optimise both cardiovascular and musculoskeletal health simultaneously.

The lactate threshold shift of +2.4 km/h with HIIT represents a functionally meaningful improvement in metabolic efficiency that translates directly to higher sustainable exercise speeds in recreational athletes and to reduced cardiometabolic fatigue during activities of daily living in sedentary adults. The mechanistic basis — enhanced mitochondrial density, capillarisation, and oxidative enzyme capacity — is well established, and the magnitude of the shift observed here is among the largest reported in twelve-week HIIT trials in sedentary populations, potentially reflecting the particular effectiveness of the 4×4-minute interval protocol used in this study, which has been specifically validated for cardiovascular adaptation by the Norwegian School of Sport Sciences group.

The HRV data confirm that HIIT produces the largest improvement in cardiac autonomic function, with RMSSD gains of 62.5% representing substantially enhanced parasympathetic cardiac control that is independently associated with reduced cardiovascular event risk. The correlation between RMSSD gain and VO₂max improvement (r=0.58) suggests that the autonomic adaptation and cardiorespiratory adaptation share common upstream mechanisms — likely the exercise-induced vagal nerve activation during repeated high-cardiac-output bouts that simultaneously drives both cardiac stroke volume increase and parasympathetic remodelling of autonomic tone.

The body composition findings reinforce an important practical message for exercise prescription: fat loss and lean mass gain can be achieved simultaneously within a twelve-week period in sedentary adults when exercise intensity is sufficiently high and when resistance training is incorporated. The traditional recommendation that caloric restriction alone or moderate aerobic exercise drives fat loss while separate resistance training is required for hypertrophy misrepresents the integrated metabolic response to HIIT, which simultaneously elevates post-exercise oxygen consumption, stimulates growth hormone and IGF-1 release, and provides neuromuscular loading sufficient to initiate hypertrophic signalling in recruited muscle fibres. The DXA-confirmed lean mass gain of +3.2 kg in the combined group — achieved in the absence of any dietary intervention and with a moderate weekly training volume of four sessions — represents a clinically meaningful change that would typically require six or more months of dedicated resistance training under standard moderate-intensity protocols.

The adverse event data (Table 1) document higher but still low absolute rates of minor musculoskeletal events in HIIT and combined groups compared to MCT, consistent with the greater mechanical loading of high-intensity work.

The absence of serious adverse events across all training groups in a medically screened sedentary adult population supports the safety of supervised HIIT implementation, and the four grade-2 adverse events in the combined group — three muscle strains and one lower back pain episode — occurred in the first four weeks of the trial when training loads were being established, suggesting that a more gradual load progression in the initial phase would further reduce the already low adverse event burden.

5. Conclusion

This twelve-week five-arm RCT demonstrates that HIIT produces significantly superior cardiorespiratory fitness (VO_2max +12.4 mL/kg/min), lactate threshold (+2.4 km/h OBLA shift), and HRV improvement (+62.5% RMSSD) compared to moderate continuous training in sedentary adults, while combined HIIT-plus-strength training achieves the most comprehensive physiological adaptations including the largest VO_2max gain, greatest lean mass increase, and greatest fat reduction. These results support HIIT and combined HIIT-plus-strength as the exercise modalities of choice for sedentary adults seeking maximal health benefit per training hour.

Clinical and public health recommendations arising from this evidence include integration of HIIT protocols into workplace wellness programmes, cardiac rehabilitation, and primary care exercise prescription as alternatives to moderate-intensity guidelines for individuals who prefer shorter, more intense sessions. The slightly higher adverse event rate in HIIT groups underscores the importance of graduated intensity progression and exercise professional supervision during HIIT initiation in sedentary individuals with limited exercise history.

Future research should examine the minimum effective dose of HIIT for cardiovascular adaptation — whether two rather than three sessions per week preserves meaningful VO_2max benefit — and the long-term (two-year) adherence and health outcome trajectories of HIIT versus MCT in previously sedentary adults to determine whether HIIT's physiological superiority translates into superior real-world health behaviour maintenance.

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