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High-intensity interval training: Modulating interval duration in overweight/obese men

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Abstract

Introduction—High-intensity interval training (HIIT) is a time-efficient strategy shown to induce various cardiovascular and metabolic adaptations. Little is known about the optimal tolerable combination of intensity and volume necessary for adaptations, especially in clinical populations.

Objectives—In a randomized controlled pilot design, we evaluated the effects of two types of interval training protocols, varying in intensity and interval duration, on clinical outcomes in overweight/obese men.

Methods—Twenty-five men [body mass index (BMI) > 25 kg·m^2] completed baseline body composition measures: fat mass (FM), lean mass (LM) and percent body fat (%BF) and fasting blood glucose, lipids and insulin (IN). A graded exercise cycling test was completed for peak oxygen consumption (VO_2peak) and power output (PO). Participants were randomly assigned to high-intensity short interval (1MIN-HIIT), high-intensity interval (2MIN-HIIT) or control groups. 1MIN-HIIT and 2MIN-HIIT completed 3 weeks of cycling interval training, 3 days/week, consisting of either 10 × 1 min bouts at 90% PO with 1 min rests (1MIN-HIIT) or 5 × 2 min bouts with 1 min rests at undulating intensities (80%–100%) (2MIN-HIIT).

Results—There were no significant training effects on FM (Δ1.06 ± 1.25 kg) or %BF (Δ1.13% ± 1.88%), compared to CON. Increases in LM were not significant but increased by 1.7 kg and 2.1 kg for 1MIN and 2MIN-HIIT groups, respectively. Increases in VO_2peak were also not significant for 1MIN (3.4 ml·kg^{-1}·min^{-1}) or 2MIN groups (2.7 ml·kg^{-1}·min^{-1}). IN sensitivity (HOMA-IR) improved for both training groups (Δ −2.78 ± 3.48 units; $p < 0.05$) compared to CON.

Conclusion—HIIT may be an effective short-term strategy to improve cardiorespiratory fitness and IN sensitivity in overweight males.

Keywords

Exercise; body weight; percent body fat; lifestyle; insulin; metabolism; VO_2peak

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Declaration of interest

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Introduction

The prevalence of obesity is well known with 68.2% of US adults falling into an overweight and obese classification [1]. More notable concerns are directly related to comorbidities such as diabetes mellitus, hypertension and cardiovascular disease. The benefit of exercise, independent of weight loss, is a known strategy to improve health and mitigate consequences of these comorbidities [2]. The most predictive factor for developing cardiovascular disease has been to be a result of low cardiorespiratory fitness (CRF) [3], which is one of the most modifiable strategies for primary and secondary prevention of cardiovascular disease [3]. While improvements in CRF are supported for health and disease, lack of time is cited as one of the most common barriers to exercise [4].

Moderate-intensity steady-state activity is promoted as the most effective way to improve body composition and CRF [5]. High-intensity interval training (HIIT) has gained attention as a time-efficient and effective method for improving body composition and augmenting cardiorespiratory health in a variety of populations, including the obese [6,7]. HIIT has been shown to stimulate a number of skeletal muscle adaptations that augment fat oxidation and oxygen utilization [6]. As a result of enhanced mitochondrial biogenesis and upregulated enzymes, a number of metabolic parameters are improved following interval training [7].

Weight regain and fat deposition is highly correlated with poor blood glucose levels, insulin (IN) resistance and high body fat [8]. HIIT has been shown to be a potent stimulus for improvements in these metabolic parameters, as well as a potential increase in excess post-exercise oxygen consumption [9]. When assessing health risks, well-established blood markers, such as fasting blood glucose, total cholesterol (TC), triglycerides (TG), low (LDL) and high-density lipoproteins (HDL) and IN resistance have been shown to be reliable indicators of metabolic risk [10]. Previous studies have shown as little as 2 weeks of interval training can elicit improvements in blood glucose in a type 2 diabetic group [11], whereas Skleryk et al. [12] demonstrated no effect on metabolic function. Interval training has also been shown to be an effective method to improve cholesterol [13,14] and IN sensitivity [15,16]. Further research is needed to establish the potential effects of acute interval training on metabolic function.

The feasibility of implementing HIIT into an overweight and obese population, where capacity and potentially mobility are reduced, is critical. One potential barrier is the intensity of the HIIT program [7,17]. While there is data to suggest benefit from all-out 30-s bouts of HIIT, this may not be the most feasible for an overweight cohort. Extending the duration beyond 30 s, and subsequently reduction in intensity, has been suggested to threaten the effectiveness of HIIT training [18]. However, recent data have suggested these longer intervals may be beneficial for health outcomes [11,12,16]. Therefore, the purpose of this study was to compare the effects of two types of HIIT programs with longer interval duration, and varied intensity, in overweight/obese men on various clinical outcomes. We hypothesized that both a shorter duration interval length program (short interval training (1MIN-HIIT); 1 min bouts) and a longer duration interval length (high-intensity training;

(1MIN-HIIT); 2 min bouts) would induce significant improvements compared to control, with no between group differences.

Materials and methods

This was a randomized controlled pilot trial. Participants were recruited from an Urban Southeast region in the US using e-mail and flyer recruitment materials. Following initial e-mail and telephone screening, 35 men completed an in-person screening and eligibility visit. Participants were included if they were between the ages of 18 and 50 years, had a body mass index (BMI) between 25 and 45 kg·m^2, a normal resting 12-lead electrocardiogram (EKG), and were approved by their physician. Exclusion criteria included untreated hypertension, hyperlipidemia and diabetes; previous disease history of cardiopulmonary or cardiac-related diseases, or current participation in high-intensity exercise. If potential participants had been taking anti-hypertensive, anti-depressants or lipid-lowering medications for more than 1-year, they were allowed into the study. Ten potential participants were excluded for reasons including: BMI < 25 kg·m^2, lack of correspondence from physician (assuming no clearance) or current participation in high-intensity exercise. At the screening/enrollment visit (visit 1), all participants provided a written informed consent approved by the University Biomedical Institutional Review Board, completed a medical history questionnaire and a 12-lead EKG. Informed consent was obtained from all individual participants included in the study, and all procedures were completed in accordance with the ethical standards of the Declaration of Helsinki (2013). Twenty-five overweight men were cleared to participate in this study (mean ± SD; age: 38.3 ± 11.5 years; height: 181.9 ± 7.5 cm; body mass: 103.3 ± 16.8 kg; BMI: 31.3 ± 4.9 kg·m^2). The sample consisted of equal Caucasian and African American males, with one Asian. Eligible participants completed baseline assessments for body composition (visit 2), blood lipids (visit 2) and CRF (visit 3) (Figure 1). Prior to all testing, participants were asked to refrain from caffeine and exercise for 24 h. Following baseline testing, participants were randomly assigned to one of two training interventions, or a control group (no training). The allocation ratio was set at 2:2:1 for the two training intervention and control groups, respectively. The group was randomly assigned using Random Allocation Software (Version 1.0.0, Isfahan, Iran). Within 1 week of randomization, participants completed day one of their nine supervised training sessions, conducted 3 days/week for 3 weeks. Post-testing assessments (visits 13–14) occurred between 24 and 48 h after their last training session. No adverse events were reported, and compliance was 100%.

Body composition assessments

Following an 8-h fast, dual energy X-ray absorptiometry (DXA, Hologic Discovery W, Bedford, MA) was used to measure whole body composition (Apex Software Version 3.3). Using a rectilinear fan beam, whole body fat mass (FM; kg), lean mass (LM; kg) and percent body fat (%BF; %) were measured. After removing all metal objects, participants were positioned in the center of the platform, supine, with hands facedown near their sides. If necessary, for width constraints, thumbs were slid under their legs. Participants were instructed to remain still and breathe normal for the duration of the 6-min scan. All scans were performed and analyzed by the same individual. The device was calibrated prior to

each use according to the manufacturer to ensure valid results. Testretest reliability, in a similar population, from our lab for DXA were FM: intra-class correlation (ICC) = 0.98, standard error of the mean (SEM) = 0.85 kg; LM: ICC = 0.99, SEM = 1.07 kg; %BF: ICC = 0.98, SEM = 1.06%.

Cardiorespiratory fitness

Before and after training, participants performed a continuous graded exercise test on an electronically braked cycle ergometer (Corival 400, Groningen, The Netherlands) to determine peak oxygen consumption (VO_2peak) and peak power output (PO). Pedal cadence was maintained at 70 rpm, while the PO was initially set at 50 watts (W) for a 5-min warm-up, and increased by 1 W every 3 s until the participant could no longer maintain the PO (cadence dropped below 50 rpm). Respiratory gases were monitored and continuously analyzed with open-circuit spirometry using a calibrated metabolic cart (True One 2400®, Parvo-Medics, Inc., Provo, UT). Data were averaged over 15-s intervals, with the highest 15-s oxygen consumption identified as the VO_2peak and the final time of completion identified as time to fatigue (TTF). The test was considered maximal if it met a minimum of two of the following criteria: a plateau in heart rate (HR) or HR within 10% of maximal predicted HR; a plateau in VO_2 or an increase of no more than 150 $ml \cdot min^{-1}$; a respiratory exchange ratio value greater than 1.15. HR was monitored continuously during exercise by a HR monitor (Polar FS1, Polar Electro Inc. Lake Success, NY). Test-retest reliability for the VO_2peak protocol demonstrated reliable between-day testing with an ICC of 0.98 and SEM of 1.74 $ml \cdot kg^{-1} \cdot min^{-1}$.

All training was performed on an electronically braked cycle ergometer (Corival Lode, Gronigen, The Netherlands) under the supervision of trained research staff. Participants were required to train three times a week, with no more than two training sessions back to back (i.e. Mon, Tues, Thurs; Tues, Wed, Fri). There was a minimum of 24 h in between training sessions, and at least 48 h if two training sessions were completed consecutively. Respective groups consisted of: short interval training (1MIN-HIIT): 10 repetitions of 1 min bouts with 1 min rest periods at 90% of the PO obtained during VO_2peak (total of 10 min of cycling) [19]; high-intensity training (2MIN-HIIT): 5 bouts of 2 min cycling with 1 min recovery utilizing undulating intensities (80%–100% VO_2peak; Figure 1) (modified from: [16,20]), or no exercise at all (CON). The 2MIN-HIIT group alternated intensity as follows: 80% (D1), 85% (D2), 80% (D3), 90% (D4), 80% (D5), 95% (D6), 80% (D7), 100% (D8) and 80% (D9). Both training groups were equalized for training volume. HR and ratings of perceived exertion were measured and tracked to monitor intensity.

Serum blood samples were drawn at the University Hospital. All samples, excluding IN, were separated and processed by McLendon Clinical Laboratories (Chapel Hill, NC). IN was analyzed by Mayo Clinic Laboratories (Rochester MN). All samples were analyzed using established enzymatic assays for fasting blood glucose (GLU), TC, TG, HDL and IN. LDL and very low-density lipoprotein cholesterol (VLDL) were calculated using Friedwald's equations [LDL = TC-TG/2.2; VLDL = TC-(LDL+HDL)]. Furthermore, a homeostasis model assessment of IN resistance (HOMA-IR) was used to evaluate IN

resistance, and calculated as follows: fasting IN [(IU/L) × fasting plasma glucose mg/dL]/405, as described by Matthews et al. [21].

Statistical analyses

All post-testing values were examined using an analysis of covariance with the baseline scores used as the covariate following verification of the homogeneity of regression assumption. When significant interactions occurred, Bonferroni *post-hoc* pairwise comparisons were made. Non-normally distributed variables (BMI, FM) were log-transformed before analysis. Descriptive statistics are presented as mean ± SD. All statistical procedures were performed using SPSS (version 20.0, SPSS Inc., Chicago, IL). Ninety-five percent confidence intervals were constructed using the mean change from preto post-testing. Power calculations were completed using nQuery + nTerim 2.0 (Statistical Solutions, Boston, MA) based on previous data in overweight/obese population for VO_2peak with a SD of 2.5 ml·kg·min^{-1}, with the current planned sample providing a power above 0.80. Significance for all statistical analyses was determined using a two-sided alpha of 0.05.

Results

Training specific subject demographics for 2MIN-HIIT (n = 10), 1MIN-HIIT (n = 10), and CON (n = 5) are presented in Table 1. While BMI was significantly different between groups at baseline ($p = 0.021$), there were not significant differences for percent body fat ($p = 0.345$) or CRF ($p = 0.239$). *Post hoc* power calculations for primary variables were adequately powered (Vo_2peak, %BF). Lean body mass was slightly under powered (power = 0.70).

Body composition

There was a significant main effect for treatment for FM ($p = 0.001$), %BF ($p = 0.001$), and LM ($p = 0.001$). When evaluating *post hoc* comparisons for FM, adjusting for baseline values, there was no significant difference between 2MIN-HIIT (mean ± SD: 28.3 ± 0.96 kg) and 1MIN-HIIT (mean ± SD: 28.8 ± 0.90 kg) ($p = 0.374$); and no difference between 2MIN-HIIT and CON (mean ± SD: 29.5 ± 1.4 kg) ($p = 0.144$) or 1MIN-HIIT and CON ($p = 0.370$). Overall, there were negligible effects on FM (Figure 2*a*). For %BF, *post hoc* comparisons yielded no significant differences between training groups ($p = 0.633$) when adjusting for baseline values; 2MIN-HIIT (mean ± SD: 27.5% ± 1.0%) versus CON (*mean* ± *SD*: 28.8% ± 1.4%; $p = 0.145$), or 1MIN-HIIT (*mean* ± *SD*: 27.8% ± 1.9%) versus CON ($p = 0.276$) (Figure 2*c*). For LM, *post hoc* comparisons yielded no significant difference between 2MIN-HIIT (*mean* ± *SD*: 69.5 ± 3.4 kg) and 1MIN-HIIT (mean ± SD: 71.6 ± 3.2) ($p = 0.898$), and no significant difference between 2MIN-HIIT and CON (mean ± SD: 71.0 ± 5.4 kg) ($p = 0.751$) or 1MIN-HIIT and CON ($p = 0.811$) (Figure 2*b*). However, 2MIN-HIIT yielded an average 2.1 kg increase in LM, and 1MIN-HIIT resulted in an average 1.7 kg increase, compared to an average 0.4 kg decrease in LM for the CON, when compared to baseline values.

Cardiorespiratory fitness

There was a significant main effect for treatment on VO_2peak (p = 0.001) and TTF (p = 0.001). For VO_2peak, *post hoc* comparisons yielded no significant difference between training groups (2MIN-HIIT vs 1MIN-HIIT mean difference (Δ): −0.47 ± 2.6 ml·kg^{-1}·min^{-1}; p = 0.729) and no difference between 2MIN-HIIT and CON (Δ: 1.22 ± 3.2 ml·kg^{-1}·min^{-1}; p = 0.459) or 1MIN-HIIT and CON (Δ: 1.69 ± 3.0 ml·kg^{-1}·min^{-1}; p = 0.290) (Figure 3*a*). *Post hoc* comparisons for TTF resulted in no significant training group differences (2MIN-HIIT vs 1MIN-HIIT = Δ18.4 ± 40.0 s; p = 0.388) and no differences for 2MIN-HIIT compared to CON (Δ38.2 ± 51.4 s; p = 0.152). There was a significant increase in TTF for 1MIN-HIIT compared to CON (Δ56.6 ± 51.4 s; p = 0.040) (Figure 3*b*).

Blood analyses

Interval training had no significant effect (p = 0.076) on TC or TG (p = 0.898) (Table 2B). There was a significant treatment effect on fasting blood glucose (p = 0.009), HDL (p = 0.049), LDL (p = 0.002), IN (p = 0.001) and HOMA-IR (p = 0.001). The only *post hoc* comparisons that yielded significance were for IN and HOMA-IR (p <0.05). For both variables, 2MIN-HIIT significantly positively influenced IN (2MIN-HIIT vs CON = Δ −12.4 ± 8.4 IU/L p = 0.008) and HOMA-IR; (2MIN-HIIT vs CON Δ −4.2 ± 4.0; p = 0.049), compared to CON. There were no significant effects for 1MIN-HIIT when compared to CON for IN (Δ −7.6 ± 8.2 IU/L; p = 0.079). However, 1MIN-HIIT was significantly lower than CON for HOMA-IR (Δ −2.9 ± 4.0; p = 0.048). There were no differences between training groups.

Discussion

Traditional low-moderate intensity exercise is an efficient strategy to reduce symptoms of metabolic syndrome and improve aerobic capacity [3]; however, this type of training often does not meet time constraints. In the current pilot trial, 20 min of high-intensity exercise (10 min of work + 10 min of rest), three times per week, yielded modest improvements for IN sensitivity, and CRF in overweight and obese men. The magnitude of improvement in the current study is similar to interventions lasting 12 or more weeks [16,22,23]. It is known that lack of exercise is one of the most powerful factors for chronic disease development [2]. Integrating time-efficient, and effective, exercise protocols into routines of clinical populations, may have a widespread effect on physiological health. The current results suggest that short-term high-intensity aerobic training may be an effective method to initiate lifestyle improvements in an overweight population.

Interval style exercise has previously been shown to modulate metabolism, with an increased reliance on oxidative phosphorylation after as little as six sessions [24]. Upregulating oxidative bioenergetics, and therefore enhancing fat oxidation, following exercise may indirectly improve body composition when accumulated over time [25,26]. The present study failed to induce any changes in FM (Table 2A), and yielded no significant change in percent body fat, but resulted in modest improvements in LM. In combination with enhanced mitochondrial biogenesis, muscle protein synthesis has previously been augmented following nine sessions of interval training [27]. The current study demonstrated

non-significant increases in lean body mass from both interval duration groups (1 and 2 min); although not significant, an average 3–4 lb increase in LM can be considered clinically relevant [28]. Much of the previous data has evaluated 'all-out' short duration work bouts (30 s) [7,29], with more recent data evaluating longer (1-min and 4-min) duration bouts [11,16], which may be feasible for clinical populations. An aim of the present study was to evaluate more feasible work durations that have shown benefit in healthy populations [18,20]. In the present study, both protocols elicited similar results for body composition.

Although there is a growing body of literature demonstrating an improvement in VO_2max as a result of HIIT [30], the present study did not demonstrate a statistically significant improvement. A meta-analysis from Weston et al. [30]. reported a 6%–10% average increase in VO_2max in sedentary males with varying interval intervention lengths and training periods (2–8 weeks). The present study demonstrated an average 5% improvement in VO_2peak in the 2MIN-HIIT group and 9.5% improvement in the 1MINHIIT group. So, despite the lack of significance, the improvements in the present study are in line with previous data. The lack of statistical significance may be a result of small sample size, as well as intervention duration, as the percent increase is slightly below that shown from a 12-week of high-intensity training in a similar population [23]. The currently results could still have utility when there is a need for more rapid improvements in CRF, compared to more traditional aerobic training [31]. When cardiovascular fitness improvements from HIIT are compared to moderate-intensity longer duration exercise, an average 90% reduction in training volume from high-intensity training outweighs the 1% increase in VO_2max seen with lower intensity training [32]. The physiological mechanisms supporting consistent improvements, largely from sprint-interval "all-out" training, in oxygen uptake have been widely attributed to enhanced mitochondrial biogenesis, enhanced capillarization and arterial compliance, and upregulation of peroxisome prolifterator-activated receptor γ coactivator (PGC)-1α [29,32,33]. Enhanced activation of PGC-1α has demonstrated positive effects on oxidative capacity and glucose uptake [29,33].

In combination with cardiovascular effects, as few as six sessions of interval training, have demonstrated a positive effect on fasting glucose and IN sensitivity in overweight individuals [11,34]. The present study resulted in significant improvements in fasting blood glucose and IN sensitivity following three weeks interval training. Specifically, 2MIN-HIIT and 1MIN-HIIT resulted in a significant improvement in IN sensitivity (Table 2B). Although both training protocols were matched for total volume (10 total min), a longer duration work bout, may be more efficacious for inducing positive metabolic changes (IN and HOMA-IR) in overweight men. In type II diabetics [11], short-term high-intensity training elicited positive changes in glucose control, which was hypothesized due to improved skeletal muscle glucose transport. Richards et al. [35] and Hood et al. [34] also demonstrated improvements in IN sensitivity in inactive adults following short-term interval training. Collectively, fasting glucose and IN sensitivity data from interval training are more responsive to longer duration (12+ weeks) of training [32]. The present study was unable to demonstrate any positive effects on serum lipid outcomes. A minimum duration of 8 weeks of training has been suggested as the necessary dose-response to yield improvements in these variables, specifically for HDL [32]. Other lipid variables (TC, LDL, TG) do not seem

to be affected by interval training; instead they tend to be directly related to body composition changes [8].

Conclusion

There are limitations to all studies; this pilot trial lacks a robust control group and resulted in reduced homogeneity across groups, potentially due to randomization and relatively small sample size, and varied age of subjects. Even with these limitations, this data provides initial support for extending interval durations from an all-out 30 s approach, to a more manageable 1-min or 2-min bout protocol. Despite reducing the intensity, as cautioned by Boyd et al. [18], the two current training protocols appear to stimulate similar changes in CRF and IN sensitivity, compared to the shorter all-out protocols in overweight/obese men. More so, the practicality and cost of such intervention is minimal, with data demonstrating translation to home and community based effects [17]. Focusing on lifestyle improvements, integrating short duration, high-intensity training appears to be an effective strategy for enhancing health in a short period of time in overweight/obese men. More importantly, this style of exercise has minimal time demands (i.e. 20 total min) and was well tolerated by participants, with no adverse events reported and 100% compliance. Future studies should evaluate longer term (> 12 weeks) effects of these more tolerable protocols, in replace of ‘all-out’ maximal efforts, to evaluate the effects on chronic health concerns.

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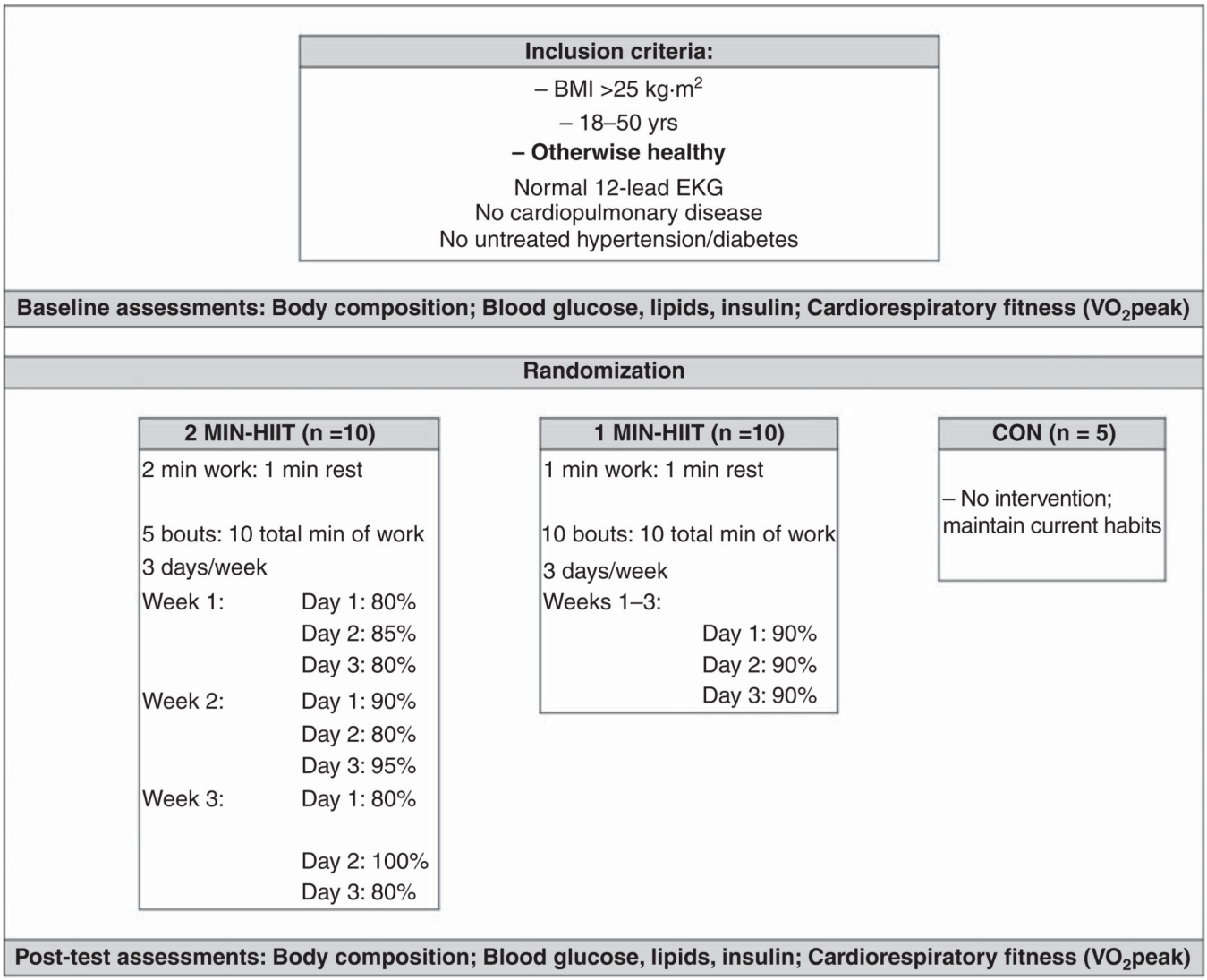

Figure 1.

Experimental design for inclusion criteria, pre-post assessments, and training protocol.

Abbreviation: HIIT = High-intensity interval training.

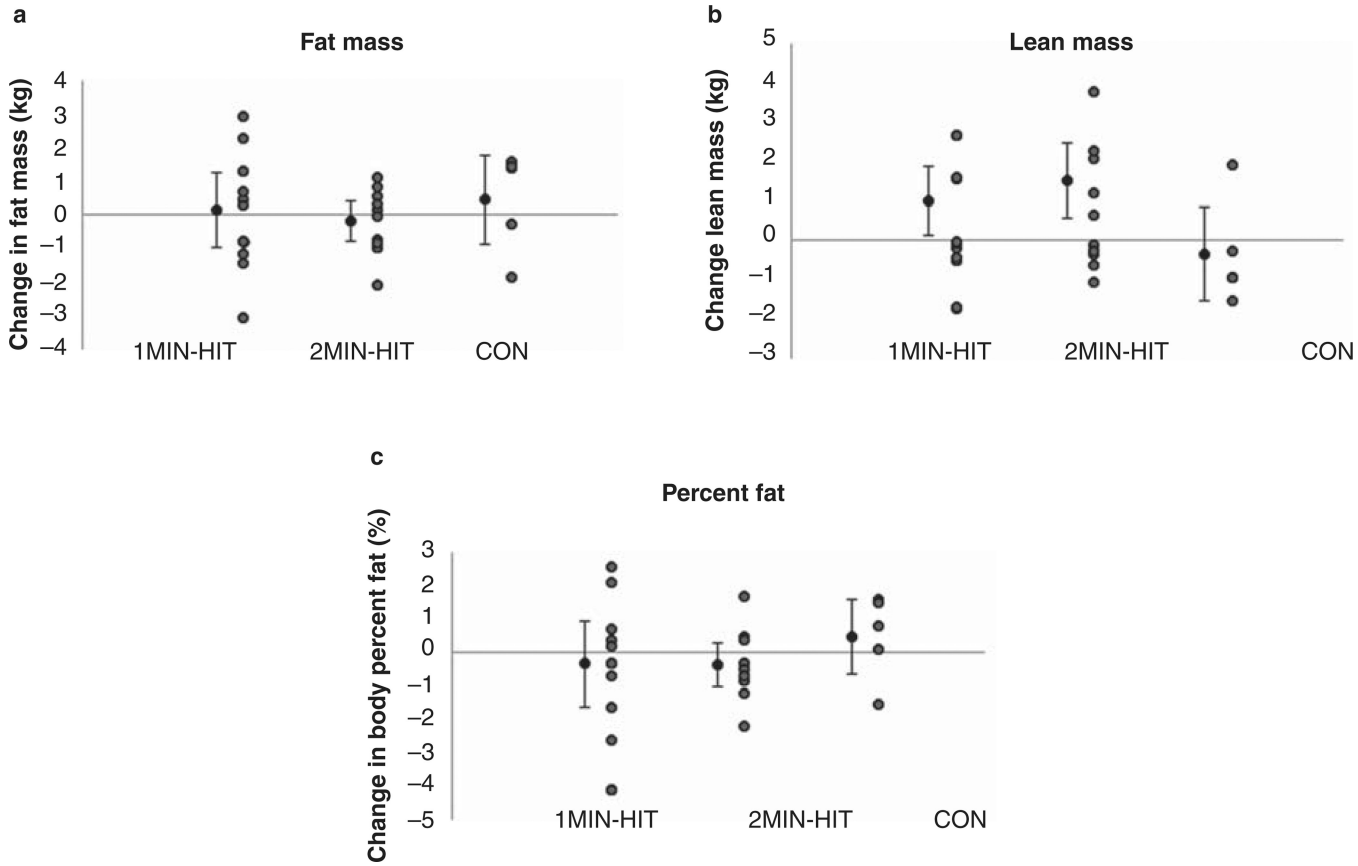

Figure 2.

Mean ± 95% confidence intervals and individual responses for the change in (*a*) Fat mass (kg), (*b*) Lean mass (kg), and (*c*) Percent body fat (%) for 1MIN-HIIT, 2MIN-HIIT, and CON from pre- to post-training.

Abbreviation: HIIT = High-intensity interval training.

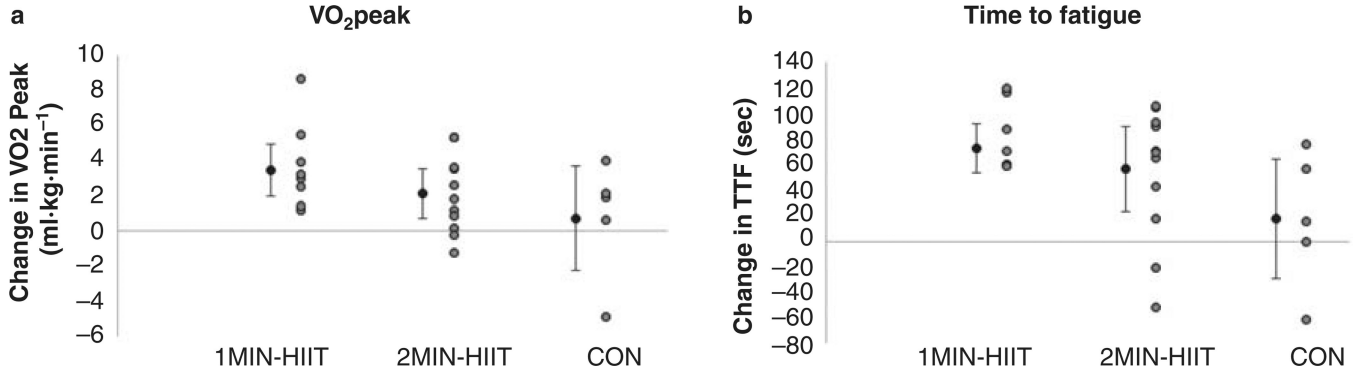

Figure 3.

Mean ± 95% confidence intervals and individual responses for the change in (*a*) VO_2peak ($ml \cdot kg \cdot min^{-1}$) and (*b*) TTF, s.

Abbreviation: TTF = Time to fatigue.

Table 1

Baseline descriptive characteristics for high-intensity interval (2MIN-HIIT), short-intensity interval (1MIN-HIIT), and control (CON) groups.

	Age (years)	Height (cm)	Weight (kg)	BMI (kg·m^2)
2MIN-HIIT (n = 10)	40.6 ± 12.1	181.8 ± 9.2	94.1 ± 10.8	28.4 ± 1.3
1MIN-HIIT (n = 10)	36.5 ± 12.3	180.4 ± 6.7	104.0 ± 12.3	32.1± 4.4
CON (n = 5)	37.2 ± 9.9	184.9 ± 5.2	120.5 ± 22.6	35.4 ± 7.4[a]

[a] Indicates significant difference between groups.

Abbreviations: BMI = Body mass index; HIIT = High-intensity interval training.

Table 2

Pre and post-testing values for fasting blood variables. Values are presented as Mean ± SD for the raw data.

	2MIN-HIIT		1MIN-HIIT		CON	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**
Glucose (mmol/L)	98.9 ± 36.8	91.7 ± 16.3	88.9 ± 6.5	88.1 ± 7.6	90.3 ± 3.9	100.0 ± 26.9
Cholesterol (mg/dL)	200.1 ± 48.4	175.3 ± 76.2	185.3 ± 42.6	177.7 ± 38.0	184.5 ± 40.8	163.2 ± 35.9
Triglycerides (mg/dL)	197.4 ± 133.4	121.2 ± 66.7	105.2 ± 47.9	111.0 ± 27.5	120.0 ± 33.7	129.0 ± 48.3
HDL (mg/dL)	43.5 ± 10.1	44.9 ± 7.7	42.9 ± 12.6	44.3 ± 11.8	43.8 ± 2.4	41.2 ± 5.7
LDL (mg/dL)	116.5 ± 45.3	123.1 ± 39.3	121.4 ± 32.5	111.1 ± 30.6	116.8 ± 35.2	96.2 ± 28.8
Insulin (IU/L)	16.9 ± 15.6	9.8 ± 5.0[a]	13.7 ± 8.6	12.7 ± 6.1[a]	14.4 ± 6.2	21.8 ± 13.7
HOMAIR (units)	8.0 ± 13.3	3.3 ± 3.8[a]	3.0 ± 1.8	2.7 ± 1.3[a]	3.2 ± 1.3	5.6 ± 6.4

[a]Indicates significant difference from CON from analysis of covariance adjusted for baseline differences ($p < 0.05$).

Abbreviations: HDL = High-density lipoprotein; HIIT = High-intensity interval training; LDL = Low-density lipoprotein.