High-intensity Interval Training Frequency: Cardiometabolic Effects and Quality of Life

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ABSTRACT

The effects of high intensity interval training (HIIT) frequency on cardiometabolic health and quality of life were examined in 35 healthy inactive adults (age: 31.7 ± 2.6 yrs, VO_2peak: 32.7 ± 7.4 ml · kg^{-1} · min^{-1}). Participants were randomly assigned to a control (CON) and two training groups, which performed 10 × 60-s cycling at ~83 % of peak power, two (HIIT-2) or three times per week (HIIT-3) for eight weeks. Compared with CON, both training regimes resulted in similar improvements in VO_2peak (HIIT-2: 10.8 %, p = 0.048, HIIT-3: 13.6 %, p = 0.017), waist circumference (HIIT-2: -1.4 cm, p = 0.048, HIIT-3: -2.4 cm, p = 0.028), thigh cross-sectional area (HIIT-2: 11.4 cm^2, p = 0.001, HIIT-3: 9.3 cm^2, p = 0.001) and the physical health component of quality of life (HIIT-2: 8.4, p = 0.001, HIIT-3: 12.2, p = 0.001). However, HIIT-3 conferred additional health-related benefits by reducing total body and trunk fat percentage (p < 0.05, compared with CON), total cholesterol and low-density lipoprotein-cholesterol (p < 0.02, compared with CON) and by improving the mental component of quality of life (p = 0.045, compared with CON). In conclusion, performing HIIT only twice per week is effective in promoting cardiometabolic health-related adaptations and quality of life in inactive adults. However, higher HIIT frequency is required for an effect on fat deposits, cholesterol and mental component of well-being.

Introduction

Physical inactivity is one of the leading risk factors for mortality and is responsible for an estimated 9 % of premature deaths worldwide [26]. Current physical activity guidelines suggest that at least 30 min of moderate-intensity cardiorespiratory exercise, five days per week (≥ 150 min · wk^{-1}) or a minimum of three days of vigorous-intensity exercise performed at least 20 min each day (≥ 75 min · wk^{-1}), or a combination of both is required for health benefits [15]. Although the benefits of physical activity are well documented, approximately one third of the adult population remains physically inactive [17], and shortage of time is one of the main reasons given for not exercising [9].

Low-volume, high-intensity interval training (HIIT) describes exercise training sessions with ≤ 30 min duration, including ≤ 10 min of vigorous exercise interspersed with active or passive recovery periods [16]. Such protocols require lower weekly total work and training duration than the recommended public health guidelines [15], but elicit health-related adaptations such as improved cardiorespiratory fitness [31], insulin sensitivity [27] and antioxidant status [6], which are similar or even greater compared with continuous moderate-intensity training [46]. Despite the growing volume of evidence regarding the physiological adaptations to HIIT, there is limited information regarding its effect on quality of life. In a recent study, HIIT improved health-related quality of life in aging men, but this was mainly due to its effects on physical health components, and not on mental health components [25]. However, the contribution of HIIT on quality of life in inactive healthy adults and especially on the mental health function remains relatively under-examined.

In most of the previous training studies, HIIT was carried out with a frequency of three times per week. However, this frequency may not be attained by individuals who find lack of time as the main barrier for adherence in physical activity programs, and it is very interesting to determine whether reducing the frequency of exercise still offers some health benefits. In clinical and aging populations, some studies have recently used lower frequency HIIT due to the inability of the participants to follow or tolerate three sessions per week [1, 25]. However, there are limited and conflicting results regarding the efficacy of low frequency of HIIT on various health indices in healthy adults. A recent study [30] presented improvements in cardiorespiratory function and favorable adaptations in cardiac structure, after a severe-intensity interval training just once per week for three months in young healthy volunteers. However, some other studies showed no improvement in VO_2peak after interval training conducted once or twice per week [12, 23]. Therefore, it is unknown whether a low HIIT frequency may cause comparable physiological and health-related adaptations, as those achieved with higher HIIT frequencies. To date, there is no comprehensive study to evaluate the effect of different HIIT frequencies on physiological, metabolic and psychological variables associated with health and quality of life. Thus, the aim of the present study was to examine and compare the efficacy of HIIT with low and moderate training frequency (two and three times per week) on physiological, metabolic and psychological variables in healthy inactive adults. It was hypothesized that two sessions of HIIT each week may be equally effective as three sessions per week in improving VO_2peak, body composition, biochemical blood variables and quality of life, in unaccustomed individuals.

Materials and Methods

Participants

Forty-one inactive healthy adults (age range: 27–37 yrs) were initially recruited. Following medical screening by a certified physician, thirty five of them (n = 35, age: 31.7 ± 2.6 yrs, BMI: 23.7 ± 4 $kg \cdot m^{-2}$), were eligible to participate in the study and provided written informed consent after being fully informed of the research procedures. Inclusion criteria were: (a) inactive lifestyle for the past year before the study, (b) nonsmokers, (c) without diagnosed metabolic or cardiovascular diseases. Inactive lifestyle was confirmed after the completion of the short International Physical Activity Questionnaire (IPAQ short) [11], as all participants were classified into the low physical activity category (Total Physical Activity score: 326 ± 198 MET-min $\cdot wk^{-1}$). Participants also completed a detailed medical history questionnaire, to ensure their health status, before study enrollment. Ethical approval was obtained from the national bioethics committee (CNBC/RP/2015/21). All procedures were in accordance with the ethical standards of the International Journal of Sports Medicine [18].

Study design

Participants were randomly assigned to one of the two training groups, who performed HIIT two times per week (HIIT-2: n = 14, 8 females/6 males, age: 31.5 ± 3.5yr) and three times per week (HIIT-3: n = 13, 6 females/7 males, age: 31.9 ± 2.4yr) or to a control group (CON: n = 8, 4 females/4 males, age: 31.7 ± 0.8yr). Initially, all participants of the HIIT-2 and HIIT-3 groups went through a 3-week pre-conditioning, familiarization and testing period (as described below), to avoid an abrupt increase in physical activity and exercise intensity. Afterwards, the HIIT-2 and HIIT-3 intervention groups trained two and three times per week respectively, over an 8-week period with the same HIIT protocol; whereas the participants in the CON group continued their usual daily activities for the same time period. All participants completed a series of tests at the beginning and after an 8-week period including measurement of VO_2peak, body composition, biochemical blood variables and evaluation of quality of life. Body composition, VO_2peak, and blood tests were also performed for HIIT-2 and HIIT-3 after four weeks of training.

Participants were asked to maintain their habitual lifestyle and diet habits during the intervention period. They recorded a 72-h food diary before the baseline blood testing and replicated this before subsequent tests. They were also asked to refrain from alcohol and vigorous physical activities for 48 h before the testing days. No participant withdrew from the study and no adverse events or musculoskeletal injuries were reported throughout the intervention.

Testing and training

A preconditioning phase, consisting of three training sessions that included continuous incremental cycling and 5-7 x 60-s moderate to high-intensity bouts interspersed with 60 s of low intensity exercise, served as a preparation for training and as familiarization with the testing and training procedures. The following analyses and tests were conducted over three separate visits, at least 4 days after the last preconditioning session and were repeated after training.

Blood analyses

Participants visited the laboratory after overnight fasting and venous blood samples (~ 10 mL) were taken from an antecubital vein to obtain concentrations of glucose, insulin, glycosylated hemoglobin ($HbA1_C$), C- reactive protein (CRP), total cholesterol (TC), high-density lipoprotein cholesterol (HDL-C) and triglycerides (TG). An amount of ~ 7 mL was collected in plain tubes and allowed to clot for 30 min. Then the samples were centrifuged at 4000rpm for 8 min and the serum was decanted. Insulin concentration was determined using chemiluminescent microparticle immunoassay (CMIA) technology (Abbott Architect Plus analyzer). Glucose was analyzed using the enzymatic UV test (hexokinase method) (Beckman Coulter AU 680 analyzer). The intra-assay coefficients of variation (CV) for glucose and insulin were 0.51-0.7 % and 1.9-5.2 %, respectively. TC, HDL-C and TG were determined using the enzymatic color test (Beckman Coulter AU 680 analyzer). CRP was analyzed using the immuno-turbidimetric test (Beckman Coulter AU 680 analyzer). Furthermore, ~3 mL was drawn into EDTA tubes and $HbA1_C$ was measured using the immuno-inhibition test (Beckman Coulter AU 480 analyzer). Low-density lipoprotein cholesterol (LDL-C) and very low-density lipoprotein cholesterol (VLDL-C) were calculated using the Friedwald's equations [14]. Atherogenic index was calculated as TC/HDL.

Oral glucose tolerance test (OGTT)

After ingestion of 75 g of glucose, 2-3 mL of blood was collected at 60 and 120 min later, for glucose and insulin determination. Insulin sensitivity was calculated using the insulin sensitivity index (ISI), as described by Matsuda and DeFronzo [28]. In addition, insulin resistance was calculated using the insulin resistance homeostatic model assessment (HOMA-IR) [29]. Glucose and insulin area under the curve (AUC) values were calculated using the trapezoidal rule. All participants abstained from exercise and followed a pre-recorded diet for 72h prior to OGTTs to avoid the effects of acute exercise.

Quality of life

Quality of life was assessed by the Short-form 36 Health survey (SF-36) [45]. The reliability and validity of the Greek version of SF-36 have been documented [33]. In our study, the reliability (i. e., internal consistency) of the SF-36 constructs was calculated with Cronbach's coefficient alpha, showing good internal consistency (Cronbach's alpha = 0.842). The SF-36 is a self-administrated 36 item survey that produces scores on eight constructs, which are summarized in two components: the physical health and the mental health components.

Body composition assessment

Percent of body fat was estimated using standard equations after measuring skinfold thickness [21]. Moreover, trunk fat percentage and waist circumference were measured using a validated bioelectrical impedance device (Viscan Tanita abdominal fat analyzer AB140, ICC = 0.996) [8]. Thigh circumference was measured at the midpoint of the anterior surface of the right thigh, midway between patella and inguinal fold. Thigh lean cross-sectional area (CSA) was estimated from the thigh circumference and the thigh skinfold thickness, using the multiple regression equation provided by Housh et al. [20].

Cardiorespiratory fitness assessment

Peak oxygen uptake (VO_2peak) was determined using a ramp test (15-20 $W \cdot min^{-1}$) to exhaustion on a cycle ergometer (Monark LC6 NOVO, Sweden). VO_2peak was defined as the highest 30 s average for VO_2 if at least three of the following criteria were met: a plateau in VO_2 despite increasing intensity, RER > 1.15, heart rate within 10 beats of age-predicted maximum, and a rating of perceived exertion (RPE) of 18 or greater. Wpeak was determined as the power of the last completed stage, and participants' heart rate was recorded throughout the test (Polar H6 Bluetooth smart). Coefficient of variation (CV) for the determination of VO_2peak in our laboratory is 3.9 %.

High-intensity Interval Training (HIIT)

Training was performed on a cycle ergometer (Monark LC6 Novo), set to constant watt mode at a pedal cadence of 70-80 rpm. Each HIIT session consisted of 10 x 60-s cycling intervals at an intensity of ~83 % of the Wpeak obtained during VO_2peak test, interspersed with 60 s of low intensity exercise (~30 % Wpeak at 50 rpm). Each training session included a 3-min warm-up and 2-min cool-down at 50 W. Power output was readjusted after four weeks of training according to each participant's new VO_2peak test for the remaining period, in order to maintain the target relative intensity. Training sessions were held on non-consecutive days throughout each week, and were all supervised by one of the authors.

Statistical analysis

Differences in baseline values were tested with one-way Analysis of Variance (ANOVA). A mixed factor two-way analysis of covariance (time x group ANCOVA), using the pre-training values as the covariate, was employed to compare the dependent variables between and within groups. Also, to compare the responses between the three groups (CON, HIIT-2 and HIIT-3) an ANCOVA was performed using the baseline values as the covariate and the pre-post change as the dependent variable. When a significant main effect or interaction was observed ($p < 0.05$), a Tukey's post-hoc test was performed. For pairwise comparisons, the magnitude of effect sizes were determined by calculating Cohen's d (small effect = 0.20-0.49, medium effect = 0.50-0.79 and large effect ≥ 0.80). All statistical procedures were performed using SPSS version 20. Statistical significance was accepted at $p \leq 0.05$ and variables are presented as mean ± SD. Pre-post training changes for each variable are presented as mean and 90 % confidence intervals (90 %CI).

Results

There were no baseline differences between groups in any variable ($p > 0.05$) and no significant change in any variable was observed in the CON group. Adherence was the same in both training groups (97.8 %). Mean work per session (including intervals and recovery) was similar between the two training groups (HIIT-2: 107 ± 31 kJ, HIIT-3: 117 ± 27 kJ, p = 0.388), and total work was significantly higher in HIIT-3 compared to HIIT-2 (2815 ± 61 vs 1719 ± 497 kJ, $p < 0.001$). Fidelity of exercise training was calculated according to Taylor et al. [41], using a cut-point of 80 % of maximal heart rate as a criterion for satisfactory exercise intensity for all bouts. Thus fidelity was similar in both groups, with participants in the HIIT-2 group attaining the criterion in 145 of 160 bouts (90.6 %) and participants in the HIIT-3 group attaining it in 215 of the 240 bouts (89.6 %).

Body composition

No significant changes in body weight and BMI were observed for any group. After eight weeks of intervention waist circumference was significantly reduced in HIIT-2 (-1.4 cm, 90 %CI = -0.4 to -2.5 cm) and HIIT-3 (-2.4 cm, 90 %CI = -1.3 to -3.5 cm) compared with both their respective baseline values (▶ **Table 1**) and compared with the change observed in the CON group (HIIT-2: p = 0.048, d = 0.56 and HIIT-3: p = 0.028, d = 1.05) with no difference between the two HIIT groups (▶ **Table 1**). Thigh lean CSA was significantly and similarly increased in both training groups at the end of the 8-week training period (HIIT-2: 11.4 cm^2, 90 %CI = 8.5 to 14.3 cm^2; HIIT-3: 9.3 cm^2, 90 %CI = 4.9 to 13.7 cm^2, both $p < 0.01$), and this increase was greater compared with that of the CON group (HIIT-2: p = 0.001, d = 2.15 and HIIT-3: p = 0.001 and d = 1.36, respectively). Body fat was reduced by 0.7 % (90 %CI = -0.3 to -1.1 %, p = 0.033) and trunk fat percentage was reduced by 1.8 % (90 %CI = -1.0 to -2.5 %, p = 0.002) only in HIIT-3 (▶ **Table 1**). These reductions in body fat and trunk fat were greater compared with the CON condition ($p < 0.05$,

▶ **Table 1** Body composition measurements at baseline and after eight weeks of intervention for the control group (CON) and the two groups performing high intensity interval training two (HIIT-2) or three times per week (HIIT-3).

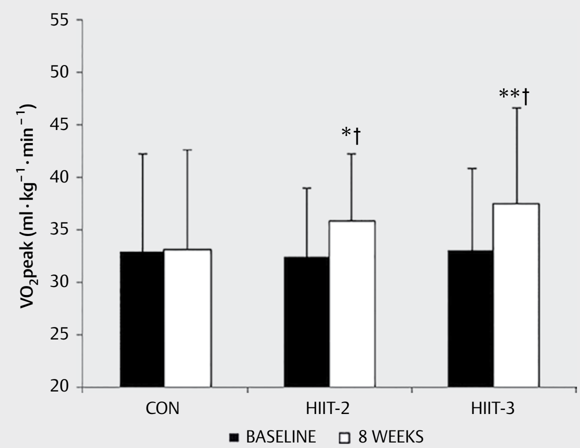
Variable	CON		HIIT-2		HIIT-3	
	Baseline	**8 weeks**	**Baseline**	**8 weeks**	**Baseline**	**8 weeks**
Weight (kg)	67.4 ± 12.2	67.4 ± 13.1	66.5 ± 18.9	66.1 ± 18.5	69.6 ± 17.6	69.2 ± 17.3
BMI ($kg \cdot m^{-2}$)	23.4 ± 3.1	23.4 ± 3.4	23.6 ± 4.6	23.4 ± 4.4	24.1 ± 4.2	24.0 ± 4.1
%Body Fat	16.6 ± 6.7	17.1 ± 6.9	18.8 ± 5.7	19.0 ± 6.2	17.0 ± 5.4	16.3 ± 5.0 * †#
Waist circumference (cm)	88.8 ± 8.7	88.5 ± 8.9	89.9 ± 12.6	88.4 ± 12.6 * †	90.2 ± 12.3	87.9 ± 12.0 * * †
%Trunk fat	25.5 ± 7.3	25.4 ± 7.6	28.3 ± 7.2	27.0 ± 7.9	26.1 ± 8.9	24.2 ± 8.8 * * †
Thigh lean CSA (cm^2)	135.6 ± 20.3	133.9 ± 21.4	122.2 ± 30.5	133.7 ± 34.3 * * ‡	133.4 ± 21.2	142.7 ± 22.2 * * ‡

* and * *: p < 0.05 and p < 0.01 from the corresponding baseline value; † and ‡: p < 0.05 and p < 0.01 from CON; #: p < 0.05 from HIIT-2

d = 1.31 and 1.33, respectively). Also, the decrease in body fat in HIIT-3 was larger than that in HIIT-2 ($p < 0.05$, d = 0.84).

Cardiorespiratory fitness

After four weeks of training, VO_2peak significantly increased only in HIIT-3 (by 11.6 %, p = 0.002, Cohen's d = 0.47) but not in HIIT-2 (2.2 %, p > 0.05, Cohen's d = 0.11). After eight weeks of training, VO_2peak was significantly and similarly increased in HIIT-2 by 3.5 $ml \cdot kg^{-1} \cdot min^{-1}$ (90 %CI = 2.2 to 4.7 $ml \cdot kg^{-1} \cdot min^{-1}$) or 10.8 % (p = 0.017, Cohen's d = 0.56) and in HIIT-3 by 4.5 $ml \cdot kg^{-1} \cdot min^{-1}$ (90 %CI = 2.3 to 6.7 $ml \cdot kg^{-1} \cdot min^{-1}$) or 13.6 % (p = 0.001, Cohen's d = 0.55). Both increases were greater (HIIT-2: p = 0.048, d = 1.21 and HIIT-3: p = 0.017, d = 1.06, respectively) compared with the change observed in the CON group (0.2 $ml \cdot kg^{-1} \cdot min^{-1}$, 90 %CI = -1.6 to 1.9 $ml \cdot kg^{-1} \cdot min^{-1}$) (▶ **Fig. 1**).



▶ **Fig. 1** Cardiorespiratory fitness at baseline and after eight weeks of intervention for each group. * and * *: p < 0.02 and < 0.01 from baseline; †: p < 0.05 from CON

Blood biochemical parameters

Fasting blood glucose and insulin and their respective AUC were not significantly changed in any of the three groups after the intervention (▶ **Table 2**). Blood insulin concentration at the end of the OGTT was significantly reduced in both HIIT-2 and HIIT-3 (HIIT-2: -11.8 $mU \cdot L^{-1}$, 90 %CI = -5.6 to -18.0 $mU \cdot L^{-1}$, p = 0.002, Cohen's d = 0.77 and HIIT-3: -10.4 $mU \cdot L^{-1}$, 90 %CI = -4.4 to -16.4 $mU \cdot L^{-1}$, p = 0.008, Cohen's d = 0.42, respectively). However, this decrease in both training groups was not significantly different compared with the change observed in the CON group. Insulin sensitivity (ISI), HOMA-IR scores, HbA1c and CRP did not change significantly after the intervention (▶ **Table 2**).

TC and LDL-C were significantly reduced only in the HIIT-3 group (TC: -0.39 $mmol \cdot L^{-1}$, 90 %CI = -0.26 to -0.52 $mmol \cdot L^{-1}$, p = 0.008, Cohen's d = 0.58 and LDL-C: -0.32 $mmol \cdot L^{-1}$, 90 %CI = -0.21 to -0.43 $mmol \cdot L^{-1}$, p = 0.009, Cohen's d = 0.49, respectively, ▶ **Table 2**). The reductions of TC and LDL-C were significantly greater than the changes observed in the CON (TC: p = 0.017, d = 1.53 and LDL-C: p = 0.019, d = 1.62) and HIIT-2 group (TC: p = 0.032, d = 0.76 and LDL-C: p = 0.029, d = 0.84). However, HDL-C, TG, VLDL-C and atherogenic index remained unchanged (▶ **Table 2**).

Quality of life

The physical health component was improved similarly after HIIT-2 (8.4, 90 %CI = 3.5 to 13.4, p = 0.001, Cohen's d = 0.86) and HIIT-3 (12.2, 90 %CI = 5.5 to 19, p = 0.001, Cohen's d = 0.97; see ▶ **Fig. 2**). Both groups improved significantly compared with CON (HIIT-2: p = 0.001, d = 1.12 and HIIT-3: p = 0.001, d = 1.21). Mental health component was significantly elevated in both HIIT-2 (7.3, 90 %CI = -0.3 to 14.0, p = 0.003, Cohen's d = 0.54) and HIIT-3 (8.9, 90 %CI = 3.0 to 14.8, p = 0.001, Cohen's d = 0.69) compared with the baseline value. However, this improvement was significantly higher compared with the CON group only for HIIT-3 (p = 0.045, Cohen's d = 0.64) but not for HIIT-2 (p = 0.17, Cohen's d = 0.38).

Discussion

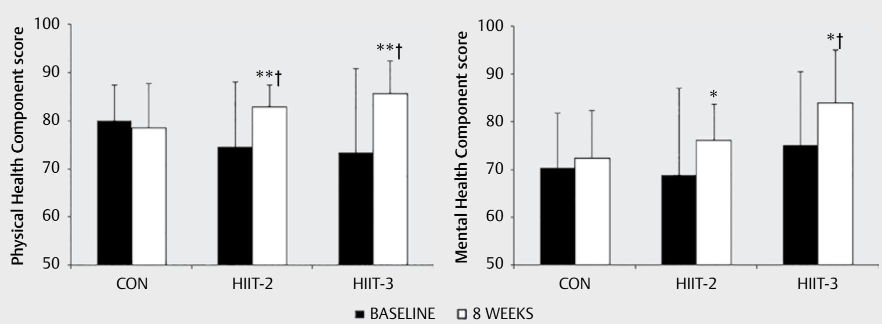
The present study demonstrated that HIIT performed either two or three times per week, leads to significant improvements in VO_2peak, waist circumference, thigh lean CSA and the physical health component of quality of life. Most importantly, the magnitude of these training-induced adaptations was unaffected by training frequency, as it was similar in the two training groups. However, there were additional health-related benefits in the group that trained three times per week, i. e., reduction of body fat and trunk fat percentage, decrease of total cholesterol and LDL-C, and improvement of the mental health component of quality of life.

Some studies that used HIIT or sprint training with a frequency of one to two sessions per week for 4-6 weeks, reported no effect

▸ **Table 2** Blood biochemical parameters at baseline and after eight weeks of intervention for the control group (CON) and the two groups performing high intensity interval training two (HIIT-2) or three times per week (HIIT-3).

Variable	CON		HIIT-2		HIIT-3	
	Baseline	8 weeks	Baseline	8 weeks	Baseline	8 weeks
Fasting glucose (mmol · L⁻¹)	5.0 ± 0.2	5.0 ± 0.3	5.0 ± 0.3	4.9 ± 0.3	4.9 ± 0.5	4.8 ± 0.5
Fasting insulin (mU · L⁻¹)	6.2 ± 1.1	6.3 ± 1.6	6.0 ± 3.1	5.8 ± 1.7	6.3 ± 2.3	5.7 ± 2.3
Glucose at end of OGTT (mmol · L⁻¹)	4.5 ± 0.3	4.4 ± 0.8	4.6 ± 0.9	4.5 ± 1.3	4.8 ± 1.2	4.1 ± 1.1
Insulin at end of OGTT	27.3 ± 13.2	21.9 ± 10.2	35.5 ± 19.1	23.7 ± 11.9 * *	38.8 ± 24.9	28.4 ± 27.3 *
Glucose AUC (mmol · min · L⁻¹)	602 ± 77	592 ± 86	619 ± 108	595 ± 103	623 ± 178	604 ± 129
Insulin AUC (mU · min · L⁻¹)	4258 ± 2480	3795 ± 1869	4926 ± 2823	3792 ± 1281	5063 ± 3185	4370 ± 2365
ISI	8.6 ± 2.9	9.0 ± 3.2	8.5 ± 3.4	9.2 ± 3.1	9.3 ± 5.5	10.0 ± 4.8
HOMA-IR	1.4 ± 0.2	1.4 ± 0.4	1.3 ± 0.8	1.3 ± 0.4	1.4 ± 0.6	1.3 ± 0.6
HbA1c (%)	5.2 ± 0.3	5.2 ± 0.2	5.3 ± 0.3	5.1 ± 0.3	5.0 ± 0.2	5.1 ± 0.2
CRP (mg · L⁻¹)	0.9 ± 0.4	1.1 ± 0.6	1.6 ± 1.1	1.1 ± 0.7	1.0 ± 0.6	0.9 ± 0.5
TG (mmol · L⁻¹)	0.78 ± 0.15	0.71 ± 0.21	0.80 ± 0.28	0.82 ± 0.32	0.77 ± 0.32	0.73 ± 0.22
TC (mmol · L⁻¹)	4.86 ± 0.55	4.85 ± 0.72	4.76 ± 0.82	4.79 ± 0.72	5.04 ± 0.54	4.65 ± 0.59 * *
HDL-C (mmol · L⁻¹)	1.45 ± 0.23	1.41 ± 0.25	1.43 ± 0.30	1.40 ± 0.29	1.45 ± 0.28	1.40 ± 0.29
LDL-C (mmol · L⁻¹)	3.06 ± 0.58	3.12 ± 0.76	2.97 ± 0.87	3.02 ± 0.81	3.24 ± 0.45	2.92 ± 0.56 *
VLDL-C (mmol · L⁻¹)	0.35 ± 0.07	0.32 ± 0.10	0.36 ± 0.13	0.37 ± 0.14	0.35 ± 0.15	0.33 ± 0.10
Atherogenic Index	3.46 ± 0.70	3.56 ± 0.91	3.48 ± 1.00	3.58 ± 1.00	3.58 ± 0.76	3.45 ± 0.79

* and * *: $p < 0.05$ and $p < 0.01$ from the corresponding baseline value



▸ **Fig. 2** Quality of life (SF-36) physical (left panel) and mental (right panel) health component at baseline and after eight weeks of intervention for each group. * and * *: $p < 0.05$ and < 0.02 from baseline; †: $p < 0.05$ from CON

on VO_2max [12, 23]. This finding is in agreement with our result that after the initial four weeks of training, there was no improvement of cardiorespiratory fitness in HIIT-2. However, at the end of the 8-week training period, VO_2peak improved in HIIT-2 as much as in HIIT-3 group, with the later group showing no further improvement from four to eight weeks of training. This may suggest that eight sessions of HIIT, as performed by the HIIT-2 group in the first four weeks, may not be adequate for VO_{2max} improvement, and a larger number of sessions (≥ 12) is required to elicit cardiorespiratory adaptations during HIIT. Therefore, the cumulative training volume may also be important when the frequency of training is low, in order to induce cardiorespiratory adaptations. For example, Adamson et al. [1] reported an 8 % improvement in VO_2peak after eight weeks of short duration HIIT performed twice per week in middle aged untrained population. Furthermore, Nakahara et al. [30] presented an 11 % improvement in VO_2max after severe-intensity interval training performed only once a week for three months. The importance of training volume for cardiorespiratory fitness improvement during HIIT has been examined by keeping training frequency at three times per week, and manipulating the session exercise volume. For example, Tjonna et al. [42] have shown that when the frequency of HIIT training between groups was held constant (three times per week), the lower volume HIIT had a similar impact on VO_2max, compared with a 4-fold higher volume HIIT. Their findings show that training session volume may not be of prime importance for cardiorespiratory adaptations during HIIT, but our data suggest that accumulation of total HIIT volume, through different training frequencies, may influence the time course, but not the final magnitude of training adaptations. However, the relative importance of training frequency and volume, to determine the minimal effective training regime during HIIT requires further investigation.

The magnitude of VO_2peak improvement found in the present study (3.5-4.5 ml · kg^{-1} · min^{-1}) is consistent with meta-analysis data reporting increases of 3.8 ml · kg^{-1} · min^{-1} after HIIT [4]. One potential mechanism explaining a significant part of the improvement in VO_2peak may be an increase in stroke volume, due to plasma/blood volume expansion in response to HIIT [2, 44]. Interestingly, a recent study [2] has shown that the increase in cardiac output in response to HIIT may follow different time courses, depending on the HIIT regime. In the present study, the different time-course of VO_2peak improvement in HIIT-2 and HIIT-3 may depend on either the training frequency and/or the cumulative volume of training. Thus, in HIIT-2 the low training frequency and total volume may not be adequate to increase O_2 delivery in the first four weeks of training. On the other hand, a plateau of central adaptations may explain the lack of improvement in VO_2peak in the last four weeks of training in the HIIT-3 group.

Recent meta-analyses have reported the positive impact of HIIT on body composition indices like fat mass and waist circumference [24, 47]. In the present study even though body weight remained unchanged, the percentage of total body and trunk fat, was decreased in HIIT-3. Moreover, waist circumference was reduced in both training groups (▶ **Table 1**). Similarly in the recent meta-analysis of Wewege et al. [47], it was shown that HIIT can reduce whole-body fat mass and waist circumference in the absence of body mass changes. A decrease in these indirect indices of abdominal adiposity [10] may reduce the risk of cardiovascular diseases and type 2 diabetes [13]. A possible mechanism that may promote fat loss during HIIT is the significant catecholamine response to high-intensity exercise, that enhances lipolysis [48]. The reduction in trunk fat may be explained by the increased concentration of β-adrenergic receptors in abdominal tissue compared to subcutaneous fat [36]. Another potential mechanism that could be involved in the reduction of fat mass is an increased fat oxidation following HIIT [3], that is possibly linked with increased mitochondrial biogenesis and function [5]. Additionally, post-exercise oxygen consumption (EPOC) and appetite suppression following high-intensity exercise could also be involved [19, 38]. Furthermore, in the present study, both training groups increased thigh lean CSA, indicating a gain in leg muscle mass. Increased muscle mass may elevate basal metabolic rate [39], and thus increased fat oxidation during rest, and may also improve insulin sensitivity [40].

Recently, emphasis has been placed on the effectiveness of HIIT on blood glucose regulation [4, 22]. Controversial results have been reported for healthy normal weight adults, while data from populations with impaired metabolic control show positive effects [4, 22]. In the present study, insulin at the end of the OGTT was lowered in both training groups compared with baseline, but this decrease was not significantly different compared with the CON group (▶ **Table 2**). No other significant changes were observed in other OGTT parameters, whereas HbA1c was also unaltered, possibly due to the fact that baseline values were within the normal range, indicating a healthy population [22] (▶ **Table 2**). Insulin sensitivity also failed to show significant improvements in both training groups. The lack of a significant effect on either HIIT-2 or HIIT-3 on glycemic control in healthy individuals may be explained by both the normal health status of our subjects and the possibility that a higher exercise volume and/or training duration was required. For example, a recent study by Ramos et al. [35] showed that a higher, rather than a lower HIIT volume (4 × 4 vs. 1 × 4 min, 3 times per week) was effective for improving insulin quality in participants with metabolic syndrome after 16 weeks of training.

In the present study, only HIIT-3 resulted in significant changes in total cholesterol and LDL-C (▶ **Table 2**). This is in agreement with some studies showing reductions in TC and LDL-C, after HIIT in inactive individuals [32, 37]. However, other studies failed to show improvements in blood lipids profile [27, 31]. Decreases in TC and LDL-C are important as this decreases the risk of cardiovascular diseases [34]. The fact that HIIT-2 failed to induce any influence in lipid profile may be explained by the possibility of a training volume threshold which should be surpassed to induce favorable blood lipid changes [31] and thus a longer training period of low frequency HIIT may be needed to elicit positive changes in cholesterol.

Cross-sectional studies have shown that persons attaining the recommended levels of physical activity are more likely to have better quality of life levels [7, 43]. In the present study, despite the low weekly training time commitment compared with public health guidelines, HIIT-3 improved both physical and mental health components, while HIIT-2 improved only the physical health component. Therefore, the beneficial health-related effects of HIIT on general population also include an improvement of quality of life of the participants. In the present study, the lack of an effect of HIIT-2 on the mental aspect may suggest that an increased training frequency of HIIT or a longer duration of training may be necessary to elicit positive psychological effects on quality of life in inactive adults.

In conclusion, the present study showed that HIIT-2 may improve particular cardiometabolic health indices and the physical component of quality of life following eight weeks of training in inactive men and women. However, HIIT-3 conferred additional health-related benefits by reducing total body and abdominal fat, TC and LDL-C and by improving the mental component of quality of life. Importantly, the present study adds to the existing knowledge of positive effects of HIIT and shows that despite a low training frequency (i. e., two times per week), HIIT can still promote specific health-related adaptations in inactive populations in a time-efficient way.

Conflict of Interest

The authors declare no conflict of interest.

References

[1] Adamson S, Lorimer R, Cobley JN, Lloyd R, Babraj J. High-intensity training improves health and physical function in middle aged adults. Biology (Basel) 2014; 3: 333–344

[2] Astorino TA, Edmunds RM, Clark A, King L, Gallant RA, Namm S, Fischer A, Wood KM. High-intensity interval training increases cardiac output and V˙O2max. Med Sci Sports Exerc 2017; 49: 265–273

[3] Astorino TA, Schubert MM, Palumbo E, Stirling D, McMillan DW. Effect of two doses of interval training on maximal fat oxidation in sedentary women. Med Sci Sports Exerc 2013; 45: 1878–1886

[4] Batacan RB, Duncan MJ, Dalbo VJ, Tucker PS, Fenning AS. Effects of high-intensity interval training on cardiometabolic health: A systematic review and meta-analysis of intervention studies. Br J Sports Med 2017; 51: 494–503

[5] Bishop DJ, Granata C, Eynon N. Can we optimize the exercise training prescription to maximize improvements in mitochondria function and content? Biochim Biophys Acta 2014; 1840: 1266–1275

[6] Bogdanis GC, Stavrinou P, Fatouros IG, Philippou A, Chatzinikolaou A, Draganidis D, Ermidis G, Maridaki M. Short-term high-intensity interval exercise training attenuates oxidative stress responses and improves antioxidant status in healthy humans. Food Chem Toxicol 2013; 61: 171–177

[7] Brown DW, Balluz LS, Heath GW, Moriarty DG, Ford ES, Giles WH, Mokdad AH. Associations between recommended levels of physical activity and health-related quality of life: Findings from the 2001 Behavioral Risk Factor Surveillance System (BRFSS) survey. Prev Med 2003; 37: 520–528

[8] Browning LM, Mugridge O, Chatfield MD, Dixon AK, Aitken SW, Joubert I, Prentice AM, Jebb SA. Validity of a new abdominal bioelectrical impedance device to measure abdominal and visceral fat: Comparison with MRI. Obesity (Silver Spring) 2010; 18: 2385–2391

[9] Brownson RC, Baker Ea, Housemann Ra, Brennan LK, Bacak SJ. Environmental and policy determinants of physical activity in the United States. Am J Public Health 2001; 91: 1995–2003

[10] Clasey JL, Bouchard C, Teates CD, Riblett JE, Thorner MO, Hartman ML, Weltman A. The use of anthropometric and dual-energy X-ray absorptiometry (DXA) measures to estimate total abdominal and abdominal visceral fat in men and women. Obes Res 1999; 7: 256–264

[11] Craig CL, Marshall AL, Sjöström M, Bauman AE, Booth ML, Ainsworth BE, Pratt M, Ekelund U, Yngve A, Sallis JF, Oja P. International physical activity questionnaire: 12-country reliability and validity. Med Sci Sports Exerc 2003; 35: 1381–1395

[12] Dalleck L, Bushman TT, Crain RD, Gajda MM, Koger EM, Derksen LA. Dose-response relationship between interval training frequency and magnitude of improvement in lactate threshold. Int J Sports Med 2010; 31: 567–571

[13] Després JP. Intra-abdominal obesity: An untreated risk factor for type 2 diabetes and cardiovascular disease. J Endocrinol Invest 2006; 29: 84–89

[14] Friedewald WT, Levy RI, Fredrickson DS. Estimation of the concentration of low-density lipoprotein cholesterol in plasma, without use of the preparative ultracentrifuge. Clin Chem 1972; 18: 499–502

[15] Garber CE, Blissmer B, Deschenes MR, Franklin Ba, Lamonte MJ, Lee I-M, Nieman DC, Swain DP. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. Med Sci Sports Exerc 2011; 43: 1334–1359

[16] Gillen JB, Gibala MJ. Is high-intensity interval training a time-efficient exercise strategy to improve health and fitness? Appl Physiol Nutr Metab 2014; 39: 409–412

[17] Hallal PC, Andersen LB, Bull FC, Guthold R, Haskell W, Ekelund U, Alkandari JR, Bauman AE, Blair SN, Brownson RC, Craig CL, Goenka S, Heath GW, Inoue S, Kahlmeier S, Katzmarzyk PT, Kohl HW, Lambert EV, Lee IM, Leetongin G, Lobelo F, RJF Loos, Marcus B, Martin BW, Owen N, Parra DC, Pratt M, Puska P, Ogilvie D, Reis RS, Sallis JF, Sarmiento OL, Wells JC. Global physical activity levels: Surveillance progress, pitfalls, and prospects. Lancet 2012; 380: 247–257

[18] Harriss DJ, Atkinson G. Ethical standards in sport and exercise science research: 2016 update. Int J Sports Med 2015; 36: 1121–1124

[19] Hazell TJ, Olver TD, Hamilton CD, Lemon PWR. Two minutes of sprint-interval exercise elicits 24-hr oxygen consumption similar to that of 30 min of continuous endurance exercise. Int J Sport Nutr Exerc Metab 2012; 22: 276–283

[20] Housh DJ, Housh TJ, Weir JP, Weir LL, Johnson GO, Stout JR. Anthropometric estimation of thigh muscle cross-sectional area. Med Sci Sports Exerc 1995; 27: 784–791

[21] Jackson AS, Pollock ML. Generalized equations for predicting body density of men. Br J Nutr 1978; 40: 497–504

[22] Jelleyman C, Yates T, O'Donovan G, Gray LJ, King JA, Khunti K, Davies MJ. The effects of high-intensity interval training on glucose regulation and insulin resistance: A meta-analysis. Obes Rev 2015; 16: 942–961

[23] Kavaliauskas M, Steer TP, Babraj JA. Cardiorespiratory fitness and aerobic performance adaptations to a 4-week sprint interval training in young healthy untrained females. Sport Sci Health 2017; 13: 17–23

[24] Keating SE, Johnson NA, Mielke GI, Coombes JS. A systematic review and meta-analysis of interval training versus moderate-intensity continuous training on body adiposity. Obes Rev 2017; 18: 943–964

[25] Knowles A-M, Herbert P, Easton C, Sculthorpe N, Grace FM. Impact of low-volume, high-intensity interval training on maximal aerobic capacity, health-related quality of life and motivation to exercise in ageing men. Age (Dordr) 2015; 37: 25

[26] Lee I-M, Shiroma EJ, Lobelo F, Puska P, Blair SN, Katzmarzyk PT. Effect of physical inactivity on major non-communicable diseases worldwide: An analysis of burden of disease and life expectancy. Lancet 2012; 380: 219–229

[27] Madsen SM, Thorup AC, Overgaard K, Jeppesen PB. High-intensity interval training improves glycaemic control and pancreatic β cell function of type 2 diabetes patients. PLoS One 2015; 10: e0133286

[28] Matsuda M, DeFronzo RA. Insulin sensitivity indices obtained from oral glucose tolerance testing: comparison with the euglycemic insulin clamp. Diabetes Care 1999; 22: 1462–1470

[29] Matthews DR, Hosker JP, Rudenski AS, Naylor BA, Treacher DF, Turner RC. Homeostasis model assessment: Insulin resistance and β-cell function from fasting plasma glucose and insulin concentrations in man. Diabetologia 1985; 28: 412–419

[30] Nakahara H, Ueda SY, Miyamoto T. Low-frequency severe-intensity interval training improves cardiorespiratory functions. Med Sci Sports Exerc 2015; 47: 789–798

[31] Nybo L, Sundstrup E, Jakobsen MD, Mohr M, Hornstrup T, Simonsen L, Bülow J, Randers MB, Nielsen JJ, Aagaard P, Krustrup P. High-intensity training versus traditional exercise interventions for promoting health. Med Sci Sports Exerc 2010; 42: 1951–1958

[32] O'Donovan G, Owen A, Bird SR, Kearney EM, Nevill AM, Jones DW, Woolf-May K. Changes in cardiorespiratory fitness and coronary heart disease risk factors following 24 wk of moderate- or high-intensity exercise of equal energy cost. J Appl Physiol 2005; 98: 1619–1625

[33] Pappa E, Kontodimopoulos N, Niakas D. Validating and norming of the Greek SF-36 health survey. Qual Life Res 2005; 14: 1433–1438

[34] Piepoli MF, Hoes AW, Agewall S, Albus C, Brotons C, Catapano AL, Cooney M-T, Corrà U, Cosyns B, Deaton C, Graham I, Hall MS, Hobbs FDR, Løchen M-L, Löllgen H, Marques-Vidal P, Perk J, Prescott E, Redon J, Richter DJ, Sattar N, Smulders Y, Tiberi M, van der Worp HB, van Dis I, Verschuren WMM. 2016; European guidelines on cardiovascular disease prevention in clinical practice. Eur Heart J 2016; 37: 2315–2381

[35] Ramos JS, Dalleck LC, Borrani F, Mallard AR, Clark B, Keating SE, Fassett RG, Coombes JS. The effect of different volumes of high-intensity interval training on proinsulin in participants with the metabolic syndrome: A randomised trial. Diabetologia 2016; 59: 2308–2320

[36] Rebuffé-Scrive M, Andersson B, Olbe L, Björntorp P. Metabolism of adipose tissue in intraabdominal depots of nonobese men and women. Metabolism 1989; 38: 453–458

[37] Shepherd SO, Wilson OJ, Taylor AS, Thøgersen-Ntoumani C, Adlan AM, Wagenmakers AJM, Shaw CS. Low-volume high-intensity interval training in a gym setting improves cardio-metabolic and psychological health. PLoS One 2015; 10: e0139056

[38] Sim AY, Wallman KE, Fairchild TJ, Guelfi KJ. High-intensity intermittent exercise attenuates ad-libitum energy intake. Int J Obes (Lond) 2014; 38: 417–422

[39] Speakman JR, Selman C. Physical activity and resting metabolic rate. Proc Nutr Soc 2003; 62: 621–634

[40] Srikanthan P, Karlamangla AS. Relative muscle mass is inversely associated with insulin resistance and prediabetes. Findings from the third National Health and Nutrition Examination Survey. J Clin Endocrinol Metab 2011; 96: 2898–2903

[41] Taylor KL, Weston M, Batterham AM. Evaluating intervention fidelity: An example from a high-intensity interval training study. PLoS One 2015; 10: 1–8

[42] Tjønna AE, Leinan IM, Bartnes AT, Jenssen BM, Gibala MJ, Winett RA, Wisløff U. Low- and high-volume of intensive endurance training significantly improves maximal oxygen uptake after 10-weeks of training in healthy men. PLoS One 2013; 8: e65382

[43] Vuillemin A, Boini S, Bertrais S, Tessier S, Oppert JM, Hercberg S, Guillemin F, Briançon S. Leisure time physical activity and health-related quality of life. Prev Med 2005; 41: 562–569

[44] Warburton DER, Haykowsky MJ, Quinney HA, Blackmore D, Teo KK, Taylor DA, McGavock J, Humen DP. Blood volume expansion and cardiorespiratory function: Effects of training modality. Med Sci Sports Exerc 2004; 36: 991–1000

[45] Ware JE, Kosinski M, Bayliss MS, McHorney CA, Rogers WH, Raczek A. Comparison of methods for the scoring and statistical analysis of SF-36 health profile and summary measures: Summary of results from the Medical Outcomes Study. Med Care 1995; 33: AS264–AS279

[46] Weston KS, Wisløff U, Coombes JS. High-intensity interval training in patients with lifestyle-induced cardiometabolic disease: A systematic review and meta-analysis. Br J Sports Med 2014; 48: 1227–1234

[47] Wewege M, van den Berg R, Ward RE, Keech A. The effects of high-intensity interval training vs. moderate-intensity continuous training on body composition in overweight and obese adults: A systematic review and meta-analysis. Obes Rev 2017; 18: 635–646

[48] Zouhal H, Jacob C, Delamarche P, Gratas-Delamarche A. Catecholamines and the effects of exercise, training and gender. Sports Med 2008; 38: 401–423