European Journal of Applied Physiology
https://doi.org/10.1007/s00421-018-3845-8

ORIGINAL ARTICLE

Effects of low-volume high-intensity interval training in a community setting: a pilot study

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Received: 13 November 2017 / Accepted: 13 March 2018

Abstract

Purpose High-intensity interval training (HIIT) is emerging as an effective and time-efficient exercise strategy for health promotion. However, most HIIT studies are conducted in laboratory settings and evidence regarding the efficacy of time-efficient "low-volume" HIIT is based mainly on demanding "all-out" protocols. Thus, the aim of this pilot study was to assess the feasibility and efficacy of two low-volume (≤ 30 min time-effort/week), non-all-out HIIT protocols, performed 2×/week over 8 weeks in a community-based fitness centre.

Methods Thirty-four sedentary men and women were randomised to either 2×4-min HIIT (2×4-HIIT) or 5×1-min HIIT (5×1-HIIT) at 85–95% maximal heart rate (HR_{max}), or an active control group performing moderate-intensity continuous training (MICT, 76 min/week) at 65–75% HR_{max}.

Results The exercise protocols were well tolerated and no adverse events occurred. 2×4-HIIT and 5×1-HIIT exhibited lower dropout rates (17 and 8 vs. 30%) than MICT. All training modes improved VO_{2max} (2×4-HIIT: +20%, $P<0.01$; 5×1-HIIT: +27%, $P<0.001$; MICT: +16%, $P<0.05$), but the HIIT protocols required 60% less time commitment. Both HIIT protocols and MICT had positive impact on cholesterol profiles. Only 5×1-HIIT significantly improved waist circumference ($P<0.05$) and subjective work ability ($P<0.05$).

Conclusions The present study indicates that low-volume HIIT can be feasibly implemented in a community-based setting. Moreover, our data suggest that practical (non-all-out) HIIT that requires as little as 30 min/week, either performed as 2×4-HIIT or 5×1-HIIT, may induce significant improvements in VO_{2max} and cardiometabolic risk markers.

Keywords HIIT · Real-world setting · Cardiorespiratory fitness · Cardiometabolic health · Feasibility · Time-efficient exercise

Abbreviations

2×4-HIIT	2×4 min high-intensity interval training protocol
5×1-HIIT	5×1 min high-intensity interval training protocol
ANOVA	Analysis of variance
BG	Blood glucose
CPGQ	Chronic Pain Grade Questionnaire
g	Gram
HDL	High-density lipoprotein
HIIT	High-intensity interval training
HR	Heart rate
HR_{max}	Maximal heart rate
kcal	Kilokalories
LDL	Low-density lipoprotein
MAP	Mean arterial blood pressure
MetS-Z-Score	Metabolic Syndrome *Z*-Score
μL	Microliter
MICT	Moderate-intensity continuous training
$mL·kg^{-1}·min^{-1}$	Millilitres per kilogram body mass per minute
$mmol·L^{-1}$	Millimoles per liter
O_2	Oxygen
OBLA	Onset of blood lactate accumulation
PSQ	Perceived Stress Questionnaire

Communicated by Keith Phillip George.

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Published online: 19 March 2018

TG	Triglycerides
VO_{2max}	Maximal oxygen uptake
W	Watt
WAI	Work Ability Index
WC	Waist circumference
W_{max}	Maximal power output

Introduction

There is ample evidence that regular physical activity has substantial value in preventing a broad range of health problems. It has been well documented, for example, that lack of physical activity is one of the leading preventable risk factors for developing major non-communicable diseases, including diabetes type 2, metabolic syndrome, or cardiovascular disease (Lee et al. 2012). More specifically, the degree of cardiorespiratory fitness, an objective and reproducible measure of physical activity habits, is now regarded as an independent predictor of mortality—much stronger than other well-recognised risk factors, such as smoking or obesity (Myers et al. 2015). Recent estimates suggest physical inactivity to be one of the leading risk factors for global mortality causing more than 5 million premature deaths annually (Lee et al. 2012; World Health Organization 2017). Moreover, it has been shown that regular physical activity and/or higher levels of cardiorespiratory fitness have beneficial impact on mental well-being and stress-related symptoms (Gerber et al. 2013).

Current public health guidelines recommend that adults engage in at least 150 min of moderate physical activity or 75 min of more vigorous aerobic exercise per week to maintain/improve cardiorespiratory fitness and other health-related outcomes (World Health Organization 2017). However, despite vast evidence for the numerous health benefits of physical activity, large parts of the worldwide population fail to meet these recommendations (Hallal et al. 2012). Moreover, it is frequently reported that approximately 30–50% of people who start participating in exercise programs commonly drop out after only a few weeks to months (Antoniewicz and Brand 2016; Buckworth and Dishman 2002; Kelley and Kelley 2013; Linke et al. 2011; Nam et al. 2012). The underlying reasons why individuals do not participate in regular physical activity or drop out from exercise programs are many fold and may include intrapersonal as well as environmental factors. The most commonly cited barrier to adopting and maintaining a more physically active lifestyle, however, is "a perceived lack of time" (Bauman et al. 2012). Epidemiological data suggest that physical activity levels decline substantially between the ages of 30–50 years. Individuals in this age range appear to place little priority on regular exercise due to lack of time, job commitments, and establishment of a family (Obling et al. 2013). However, it has been recognised that the first subclinical precursors of chronic diseases such as hypertension develop in this age group (National Research Council and Institute of Medicine 2013). Simultaneously, a decline of cardiorespiratory fitness is often observed to begin around age 30 years (Ciolak 2013). Therefore, effective and attractive physical activity interventions are needed from a public health perspective, especially those that can be feasibly incorporated into daily routines in a more time-efficient way.

High-intensity interval training (HIIT) has emerged as novel exercise strategy that potentially meets these characteristics. HIIT is adopted from elite sports and characterised by brief, repeated bouts of high-intensity exercise divided by recovery periods of low-intensity activity or rest (Gibala et al. 2012). Recent research has revealed the potential of HIIT to enhance cardiovascular and metabolic health in previously sedentary individuals. It was demonstrated, for example, that HIIT can improve cardiorespiratory fitness (typically quantified by maximal oxygen uptake, VO_{2max}) and various cardiometabolic risk markers, such as blood glucose concentrations, blood lipid levels, or blood pressure, effectively within only a few weeks (Gibala et al. 2012; Weston et al. 2014). Importantly, improvements in VO_{2max} and other health outcomes following HIIT were observed to be similar or even greater compared with the traditional, moderate-intensity continuous training (MICT) despite substantially lower time-effort (Connolly et al. 2017; Dunham and Harms 2012; Gibala et al. 2012; Gillen et al. 2016; Støa et al. 2017; Weston et al. 2014). Moreover, studies suggest that HIIT might also be more enjoyable than MICT due to its greater time-efficiency and varying protocol characteristics (Bartlett et al. 2011; Kong et al. 2016; Thum et al. 2017).

However, primarily, two factors limit the utility and feasibility of HIIT interventions in real-world settings (Nassis 2017). First, the majority of previous HIIT studies have been conducted in well-controlled laboratory environments, and thus, their efficacy and feasibility outside these settings is unclear. Second, the previous work on particularly time-efficient HIIT (commonly referred to as "low-volume" HIIT) has tested "all-out" sprint protocols, which demand a very high level of motivation and can lead to discomfort and safety concerns in untrained individuals. Hence, the transferability and feasibility of all-out HIIT to the general population is similarly unclear.

Recent studies using modified, less demanding HIIT protocols demonstrate that lower intensities can stimulate adaptations similar to all-out HIIT. Two of the most widely used more "practical" HIIT models are the 4 × 4-min protocol (Helgerud et al. 2007) and the 10 × 1-min protocol (Little et al. 2010), typically performed at intensities ranging between 85–95% of maximal heart rate (HR_{max}). Both protocols appear well tolerated and effective in improving VO_{2max} and cardiometabolic risk factors in sedentary individuals, although conflicting research results have failed to establish whether longer or shorter interval durations are more beneficial for training effects and yield higher participant enjoyment (Bækkerud et al. 2016; Martinez et al. 2015; Rønnestad et al. 2015; Tucker et al. 2015). In addition, differences in the duration of current practical HIIT protocols (30–40 min per exercise session when warm-up, HIIT, cool-down, and recovery phases are considered) are quite small compared to the traditional exercise programs. As a result, adherence to these protocols may suffer over time. A recent study suggests that a more time-efficient practical HIIT protocol with a total weekly time-effort of only 57 min was still effective in improving VO_{2max} and selected cardiometabolic risk markers in previously inactive individuals (Tjonna et al. 2013). However, given time-related adherence concerns and their relationship to health benefits, there is need to explore whether further reductions in the total volume of practical (non-all-out) HIIT models are still effective for improvements in cardiorespiratory fitness and associated health outcomes.

Therefore, the purpose of this pilot study was twofold: First, we aimed to investigate the feasibility of two practical low-volume HIIT protocols with varied interval durations [2 × 4 min at 85–95% HR_{max} (2 × 4-HIIT); and 5 × 1 min at 85–95% HR_{max}, (5 × 1-HIIT)] compared to MICT at 65–75% HR_{max} in an 8-week intervention at a community-based fitness centre. Specifically, we aimed to gain more insights regarding dropout and adherence rates, safety issues and acceptability by participants conducting low-volume practical HIIT in a real-world setting. The secondary aims were to explore the preliminary efficacy of 2 × 4-HIIT and 5 × 1-HIIT, both requiring ≤ 30 min of total time-effort per week, on VO_{2max} (primary efficacy outcome), selected cardiometabolic risk markers and self-reported outcomes including perceived stress, pain and subjective work ability in previously sedentary individuals. In addition, we aimed to assess whether the different interval durations during practical low-volume HIIT had different effects on participant-based outcomes including acceptability and exercise enjoyment. We hypothesized that (a) both HIIT protocols would be feasible for community-based health promotion and associated with less dropout compared to MICT due to the lower time-effort, (b) despite a markedly reduced exercise volume, both HIIT protocols would be effective in improving VO_{2max}, cardiometabolic risk parameters and participant-based outcomes, and (c) acceptability and exercise enjoyment would be greater in HIIT compared to MICT due to its greater time-efficiency.

Methods

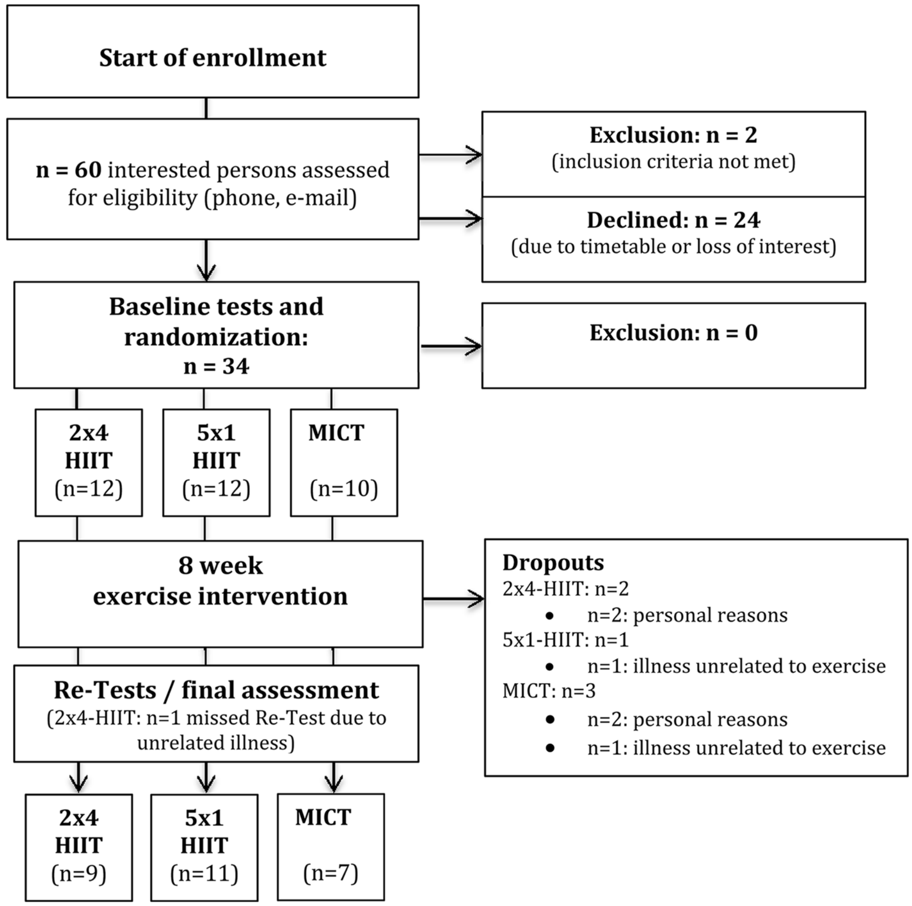
Subjects

According to recommendations regarding the appropriate sample size for pilot studies (Julious 2005) to assess feasibility and precision around the estimates to be used to design future studies, a sample size of 12 participants per HIIT group was planned. In total, 34 sedentary individuals were recruited (study flow chart, Fig. 1). Inclusion criteria were: men and women from 20 to 55 years of age, a self-reported predominantly sedentary lifestyle (defined as no specific sports training and engaging in less than 30 min of moderate physical activity three times each week) over at least 1 year prior to the study and no plans for a change in physical activity or dietary patterns during the intervention period. Exclusion criteria were: positive risk response(s) on the physical activity readiness questionnaire (PAR-Q) (Thomas et al. 1992), a self-reported medical history, or clinical diagnosis of major health problems that might preclude safe participation in the study, pregnancy, and a body mass index (BMI) > 40. Participants were asked to maintain their usual lifestyle patterns throughout the study to minimise the potential confounding effects of changes in diet and routine daily physical activity. All participants provided written informed consent. The study was approved by the local ethics committee (2015-637N-MA) and conducted in accordance with the principles outlined in the Declaration of Helsinki.

Experimental design

All procedures were carried out in a separate testing area of the fitness centre under relatively stable temperature conditions and were strictly standardised as outlined below. Outcome reassessment was repeated within the first week after completion of the exercise intervention and was performed at a similar time each day to avoid possible circadian effects. All assessments were made in a single-blinded fashion, meaning that the researchers who collected the data were not aware of the participants' group assignment. Participants were instructed to maintain their normal diet and physical activity and to refrain from alcohol and vigorous physical effort for at least 24 h prior to both baseline and follow-up testing sessions. To check for dietary compliance, participants recorded their dietary intake for 3 consecutive days prior to each testing session using standardised food records. Energy and macronutrient intakes were analysed using a nutrition analysis software system (NutriGuide®, Nutri-Science, Freiburg, Germany). Participants' routine daily physical activity was assessed

Fig. 1 Study of flow chart



using pedometers (Walking Style One 2.1, Omron, Mannheim, Germany), which were worn over 7 consecutive days prior to each test.

Resting heart rate and blood pressure measurements

Participants were instructed to consume no food or beverages (except water) for at least 3 h prior to the testing sessions. After arrival, participants initially rested for 5 min in a seated position. Subsequently, resting heart rate (HR) as well as systolic and diastolic blood pressure values were measured using an automatic upper arm blood pressure monitor (M5 professional, Omron, Mannheim, Germany). In total, three consecutive measurements were obtained at 60-s intervals and their averaged values were used in the analysis.

Blood sampling

Upon completion of the HR and blood pressure measurements, participants remained in the seated position and a total of four capillary blood samples were taken from the earlobe to determine blood glucose, triglycerides, total cholesterol (10-µL sample tubes), and HDL-cholesterol concentrations (60-µL sample tubes). Blood parameters were measured using an automated photometric analyser (Vario Photometer DP 300, Diaglobal, Berlin, Germany, photometric inaccuracy < 0.5% at $E = 1.000$). LDL-cholesterol concentration was subsequently calculated using the following formula (Friedewald et al. 1972):

$$\text{LDL-cholesterol} = \text{Total cholesterol} - \text{HDL-cholesterol} - \text{triglycerides}/5.$$

In addition, the LDL/HDL ratio was calculated by dividing the LDL value by the HDL value.

Anthropometric measurements

A multifrequency bioimpedance analyser (InBody 520, Biospace, Los Angeles, CA, USA) was used to determine body mass, fat-free mass, fat mass, the percentage of body fat, total body water, and extracellular/intracellular water. The analyser has been shown to provide reliable and valid body composition estimates and hydration measurements in men and women (Anderson et al. 2012; Salacinski et al. 2014). In addition, waist circumference was measured at the approximate midpoint between the lower margin of the last palpable rib and the upper iliac crest along the midaxillary line.

Assessment of overall cardiometabolic risk

To assess overall cardiometabolic risk in participants, the Metabolic Syndrome *Z*-Score (MetS-*Z*-Score) was calculated according to the formula suggested by Johnson et al. (2007) based on the following parameters: waist circumference (WC), triglyceride concentration (TG), HDL-cholesterol concentration (HDL), mean arterial blood pressure (MAP), and glucose concentration (BG). In detail, the MetS-*Z*-Score was calculated as follows:

MetS-*Z*-Score for women: $[(50-\mathrm{HDL})/14.1]+[(\mathrm{TG}-150)/81.0]+[(\mathrm{BG}-100)/11.3]+[(\mathrm{WC}-88)/9.0]+[(\mathrm{MAP}-100)/9.1]$.

MetS-*Z*-Score for men: $(40-\mathrm{HDL})/9.0]+[(\mathrm{TG}-150)/81.0]+[(\mathrm{BG}-100)/11.3]+[(\mathrm{WC}-102)/7.7]+[(\mathrm{MAP}-100)/9.1]$.

Exercise test

Participants performed a standardised, incremental exercise test on an electronically braked cycle ergometer (Club Bike Test, Milon, Emersacker, Germany) to determine VO_{2max}, maximal power output (W_{max}) and HR_{max}. The initial load was set at 50 W and increased stepwise every 3 min until volitional exhaustion. HR was recorded continuously in real time using a chest strap HR monitor (Polar H7 heart rate sensor, Polar Electro Oy, Kempele, Finland). VO_{2max} was measured with a semiportable metabolic analyser (Fitmax Pro, Cosmed, Rome, Italy), which has been shown to be a reliable and valid system for measuring oxygen consumption during graded exercise (Lee et al. 2011). In addition, capillary blood samples were taken from the earlobe at the end of each stage to measure lactate concentrations using an automated photometric analyser (Vario Photometer DP 300, Diaglobal, Berlin, Germany). Achieving a plateau in O_2 uptake and lactate values > 8.0 mmol L^{-1} were used as criteria for having reached maximum exertion. To assess submaximal exercise capacity, the workload corresponding to a lactate concentration of 4.0 mmol L^{-1} (onset of blood lactate accumulation, OBLA) was determined. OBLA was obtained from an interpolated and smoothed lactate curve that was created using the computer software Lactware 4.9 (Med-Tronik, Friesenheim, Germany).

Assessments of participant-based outcomes

Standardised questionnaires, which were all previously validated in the German language, were administered before and after the intervention to assess the effects of the exercise programs on self-reported outcomes. The Chronic Pain Grade Questionnaire (CPGQ) (Klasen et al. 2004) was used to assess problems with pain and the Perceived Stress Questionnaire (PSQ) (Fliege et al. 2005) was applied to examine the perception of stress among participants. Participants' subjective work ability was examined using the Work Ability Index (WAI), which covers different dimensions including individual health, skills, and work environment (Amler et al. 2015). At the end of the study, participants were asked to rate their enjoyment of the exercise intervention on a seven-point rating scale (1 = not enjoyable at all; 7 = extremely enjoyable). In addition, participants' intentions to further engage in exercise in general or to continue their assigned exercise protocol, respectively, were assessed using a four-item measure. Specifically, participants were asked: "Do you intend to further engage in any type of exercise or in the specific exercise protocol which you performed the last eight weeks?" (1 = "no"; 2 = "yes, maximum 1× per week"; 3 = "yes, 2–3 × per week"; and 4 = "yes, > 3 × per week").

Training intervention

After baseline testing, participants were randomly assigned to either the 2 × 4-HIIT, 5 × 1-HIIT or active control (MICT protocol) group. Prior to randomisation, participants were stratified into three tertiles according to their baseline VO_{2max} (< 30, 30–40, and > 40 mL kg^{-1} min^{-1}) to achieve a more balanced distribution of fitness levels across the three groups. Random assignment was achieved using a computerised random number generator and was performed independent of the researchers involved in data collection. The exercise sessions took place at a community-based fitness centre and were carried out as group-based classes on mechanically-braked indoor spinning bikes (Schwinn A.C. Performance, Core Health & Fitness, Vancouver, WA, USA). All exercise sessions were supervised by certified fitness instructors, who were trained in implementing the specific exercise protocols prior to the study. Participants were asked to attend two exercise sessions per week with at least 1-day rest between sessions during an 8-week period for a total of 16 sessions. To maximise adherence, five sessions (Monday, Tuesday, Wednesday, Friday evenings, and Sunday at noon) were offered per week. All exercise groups trained at the same time and in the same room. Participants were provided with a chest strap HR monitor (Polar H7 heart rate sensor, Polar Electro Oy, Kempele, Finland) and with individual training cards, where the target HR values to achieve during the exercise sessions were noted. Throughout each exercise session, participants were able to continuously track their individual HR values, which were transmitted to a central unit and projected on a screen in the exercise classroom (Polar Club, Polar Electro Oy, Kempele, Finland). All exercise protocols began with a brief warm-up of 2 min and concluded with a 3 min cool-down period of low-intensity cycling. Each protocol is described in detail below and summarised in Fig. 2.

High-intensity interval training (HIIT) protocols

The HIIT protocols were adapted from two practical protocols previously proven effective in improving VO_{2max} and various cardiometabolic risk factors in untrained individuals (Helgerud et al. 2007; Little et al. 2010). Specifically, the 4 × 4-min protocol (Helgerud et al. 2007) and the 10 × 1-min protocol (Little et al. 2010) were modified by reducing session volume (fewer intervals, shorter warm-up/cool-down) and weekly session frequency to minimise total time-effort to ≤ 30 min per week. Consequently, 2 × 4-HIIT consisted of two 4-min bouts alternating with 2 min of active, low-intensity activity (work-rest-ratio 2:1) and lasted a total of 15 min per session (including warm-up and cool-down), or 30 min of time-effort per week. 5 × 1-HIIT consisted of five 1-min bouts alternating with 1 min of active, low-intensity activity (work-rest-ratio 1:1) and lasted a total of 14 min per session (28 min of time-effort per week). During the first 4 weeks, participants were instructed to achieve an HR equivalent to 85–90% HR_{max} (as determined in the baseline exercise test); and during the second half of the intervention, participants were asked to increase interval intensity up to 90–95% HR_{max}, respectively. Participants were advised to adjust the pedal cadence and/or wheel resistance to reach their target HR for each interval bout and to reduce cadence/resistance during recovery periods, respectively. Participants were informed of the duration of each interval and recovery period by the instructor throughout each session.

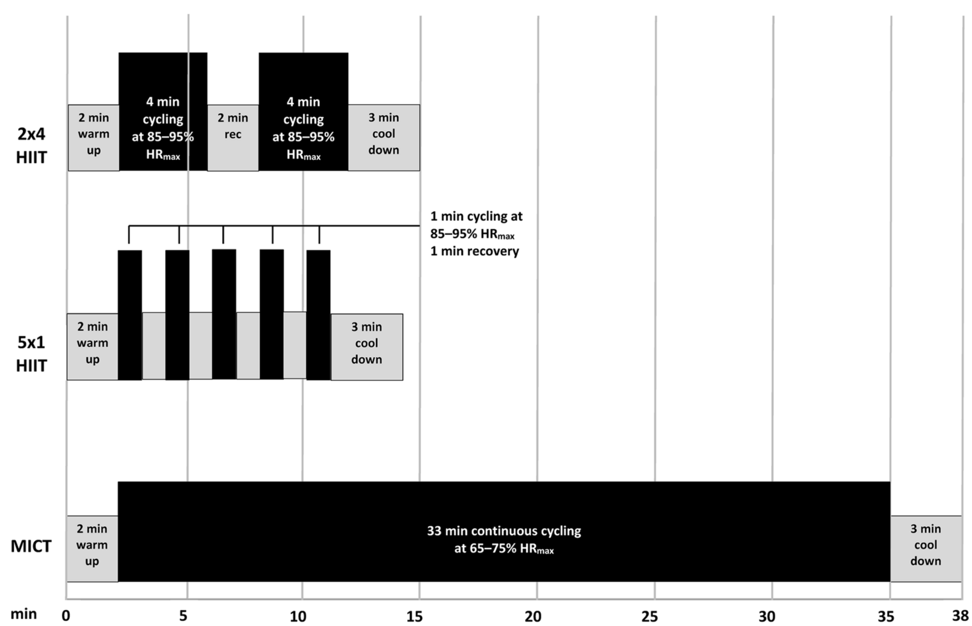
Moderate-intensity continuous training (MICT)

The MICT protocol was designed to conform to the 75 min of vigorous aerobic exercise per week recommended by the World Health Organization (2017). Each session consisted of 33 min of moderate-intensity continuous cycling, including 2 min of warm-up and 3 min of cool-down for a total session time of 38 or 76 min of exercise per week. During the first 4 weeks, participants were instructed to adjust the pedal cadence and/or resistance of the bike to achieve an HR equivalent to 65–70% HR_{max}, progressing to 70–75% HR_{max} during the last 4 weeks.

Statistical analysis

All statistical analyses were performed using SPSS version 24.0 (SPSS Inc., Chicago, IL, USA). The distribution of all data was checked using the Kolmogorov–Smirnov test and homogeneity of variance was checked with Levene's test and Box's *M* test. A two-way repeated-measures ANOVA with the between factor "group" (2 × 4-HIIT vs. 1 × 5-HIIT vs. MICT) and the repeated factor "time" (pre-intervention vs. post-intervention) were applied to analyse all data. Where significant main effects were found, paired *t* tests were performed to determine differences between pre- and post-intervention values in each group. In case of non-normally distributed data, log-transformation was used and the same analyses were applied to the transformed values. If log-transformation did not lead to data normalisation, the non-parametric Kruskal–Wallis test and Wilcoxon's matched pair tests were conducted (W_{max}, total cholesterol, fat-free mass, total body water, and participant-based outcomes). For all analyses, the significance level was set at $P < 0.05$.

Fig. 2 Illustration of the exercise protocols



All data are presented as means ± standard deviation (SD). In addition, confidence intervals (95% CI) and effect sizes (Cohen's *d* or partial eta-squared, $\acute{\eta}^2$) are included, where appropriate. Cohen's *d* effect sizes were interpreted as: small effect = 0.20–0.49, medium effect = 0.50–0.79, and large effect ≥ 0.80. $\acute{\eta}^2$ effect sizes were interpreted as: small effect = 0.02–0.12, medium effect = 0.13–0.25, and large effect ≥ 0.26 (Cohen 1988).

Results

Recruitment process and study flow

A total of 34 participants (23 females, 11 males) aged 20–52 years (mean: 30.5 ± 7.1 years) were enrolled in the study and randomly assigned to the 2 × 4-HIIT (age 29.9 ± 7.2, $n = 12$, eight females/four males), 5 × 1-HIIT (age 29.2 ± 6.0, $n = 12$, seven females/five males), and MICT (age 32.8 ± 8.4, $n = 10$, eight females/two males) groups. The most common reasons mentioned by participants for insufficient regular physical activity in the year prior to study were lack of time (85%), poor motivation (73%), lack of knowledge about how to exercise (15%), family responsibilities (12%), and physical complaints or susceptibility to injuries (8%). The average baseline $\dot{V}O_{2max}$ (29.3 ± 7.7 mL kg^{-1} min^{-1}) confirmed that the cardiorespiratory fitness level of the participants was low. Overall, six participants (2 × 4-HIIT group: one male, one female; 5 × 1-HIIT group: one male; MICT group: three females) dropped out during the exercise intervention period. Dropout rates were lower in the 5 × 1-HIIT (8%) and 2 × 4-HIIT groups (17%) compared to the MICT group (30%). Reasons for dropout are displayed in Fig. 1. There were no significant differences in the characteristics of study completers and dropouts (Table 1). One participant in the 2 × 4-HIIT group completed the intervention and provided follow-up questionnaires but was not able to take part in the post-intervention assessment due to sickness unrelated to exercise. Thus, a total of 28 participants were included in the final feasibility analysis and the data of 27 participants (Fig. 1) were used to evaluate the effects of the intervention on physiological outcomes (2 × 4-HIIT group: $n = 10$ and 9, respectively; 5 × 1-HIIT group: $n = 11$; MICT group: $n = 7$).

Table 1 Comparison of study completers and dropouts characteristics (baseline data)

Variable	Completers ($n = 28$)[a]	Dropouts ($n = 6$)
Subject characteristics and physiological data		
Age (years)	30.2 ± 7.7	32.0 ± 3.8
Body mass index (kg m^{-2})	25.4 ± 4.2	26.3 ± 5.6
Waist circumference (cm)	83.8 ± 13.5	87.3 ± 11.6
Fat mass (%)	30.2 ± 8.9	28.5 ± 9.9
$\dot{V}O_{2max}$ (mL kg^{-1} min^{-1})	29.9 ± 8.1	26.6 ± 5.1
Maximum workload capacity (W)	127 ± 33	123 ± 30
Systolic blood pressure (mmHg)	119 ± 16	119 ± 6
Diastolic blood pressure (mmHg)	82 ± 11	80 ± 6
Blood glucose (mmol L^{-1})	4.7 ± 0.8	4.8 ± 0.7
Triglycerides (mmol L^{-1})	1.4 ± 0.4	1.8 ± 0.5
Total cholesterol (mmol L^{-1})	4.4 ± 0.7	4.5 ± 1.1
HDL cholesterol (mmol L^{-1})	1.3 ± 0.2	1.1 ± 0.2
LDL-cholesterol (mmol L^{-1})	2.8 ± 0.7	3.0 ± 1.1
Subjective outcomes		
Work Ability Index (WAI)	43 ± 4	43 ± 3
Chronic pain grade (CPGQ)	0.7 ± 0.5	0.6 ± 0.5
Perceived stress (PSQ)	41 ± 10	46 ± 4
Education (highest degree)		
High school (*n*, %)	7 (25%)	3 (50%)
Technical college (*n*, %)	12 (43%)	1 (17%)
University degree (*n*, %)	7 (25%)	–
Doctoral degree (*n*, %)	2 (7%)	2 (33%)

WAI Work Ability Index Questionnaire, *CPGQ* Chronic Pain Grade Questionnaire, *PSQ* Perceived Stress Questionnaire

[a]Blood values in study completers: $n = 27$

Training data, adherence and adverse events

HR values confirmed that the prescribed level of exercise intensity was reached in all groups. Average exercise intensity in the MICT group was 74 ± 4% of HR_{max}. During the two HIIT protocols, the mean HR reached at the end of each interval bout was equivalent to 91 ± 4% of HR_{max} in the 2 × 4-HIIT group, and 95 ± 3% of HR_{max} in the 5 × 1-HIIT group. Compared to MICT, total time effort was approximately 60% lower in the HIIT protocols. Adherence rate (the percentage of the scheduled exercise sessions that the participants completed) tended to be highest in the 5 × 1-HIIT group, although the difference was not statistically significant when compared to the 2 × 4-HIIT and MICT groups. Times spent in exercising and the specific reasons for missed exercise sessions are reported in Table 2. No adverse events occurred in any of the exercise groups at any point during the study.

Diet and habitual physical activity

No significant within- or between-group differences were found in daily energy intake and habitual physical activity (steps per day) prior to the baseline and follow-up test. There were also no significant within- or between-group differences in macronutrient intakes (Table 3).

Cardiorespiratory fitness and physical performance

There were no significant baseline and follow-up differences between groups in any fitness parameters except for baseline HR_{max}, which was significantly lower ($P < 0.05$) in the MICT group compared to both HIIT groups (Table 4). Results revealed significant main effects of time for VO_{2max}, W_{max}, time to exhaustion, and workload capacity at OBLA. All training modes improved cardiorespiratory fitness significantly after the 8-week intervention ($P < 0.001$, $\eta^2 = 0.63$); and on average, VO_{2max} increased by 27% ($P < 0.001$) in the 5 × 1-HIIT group, by 20% ($P < 0.01$) in the 2 × 4-HIIT group, and by 16% ($P < 0.05$) in the MICT group. W_{max} ($P < 0.001$, $\eta^2 = 0.57$), time to exhaustion in the exercise test ($P < 0.001$, $\eta^2 = 0.60$), as well as workload capacity at OBLA ($P < 0.001$, $\eta^2 = 0.50$) also improved significantly in all groups (Table 4). HR_{max} and maximum lactate concentrations were not significantly different between baseline and follow-up in any group, suggesting that a similar level of exertion was achieved at both time points. Average maximum lactate concentrations exceeded 8.0 mmol L^{-1} at both time points in all groups, suggesting that maximum exertion was reached pre- and post-intervention during exercise testing (Table 4).

Table 2 Training data and adherence

Variable	2 × 4-HIIT	5 × 1-HIIT	MICT
Number of weekly sessions completed (of 2 prescribed)	1.6 ± 0.4	1.7 ± 0.3	1.6 ± 0.5
Total number of sessions completed (of 16 prescribed)	13 ± 3	14 ± 3	13 ± 4
Weekly training time (min)	24 ± 6***	24 ± 5***	61 ± 17
Total training time (min)	194 ± 50***	191 ± 37***	484 ± 138
Adherence rate (%)	81 ± 21	85 ± 17	79 ± 23
Reasons for missed training sessions (%)			
Sickness unrelated to exercise	58	73	48
Shift work/job obligations	26	12	35
Lack of time/personal reasons	16	15	17

***($P < 0.001$) significantly different from MICT

Table 3 Dietary intakes and habitual physical activity prior to pre- and post-intervention exercise test

Variable	2 × 4-HIIT		5 × 1-HIIT		MICT	
	Pre	Post	Pre	Post	Pre	Post
Daily energy intake (kcal)	2183 ± 503	1921 ± 519	2148 ± 546	2341 ± 772	2355 ± 851	2318 ± 1381
Daily carbohydrate intake (g)	258 ± 54	209 ± 68	256 ± 91	245 ± 60	300 ± 109	260 ± 161
Daily fat intake (g)	76 ± 21	77 ± 25	74 ± 22	98 ± 40	80 ± 36	90 ± 48
Daily protein intake (g)	99 ± 49	85 ± 37	91 ± 21	90 ± 33	87 ± 28	101 ± 73
Daily steps	5827 ± 2280	5686 ± 2184	5571 ± 1245	5474 ± 1954	6463 ± 1950	6767 ± 2246

Dietary intakes recorded for 3 days and daily steps for 7 days, respectively, prior to pre- and post-intervention exercise test

Table 4 Exercise performance data

Variable	2×4-HIIT				5×1-HIIT				MICT			
	Pre	Post	Change (95% CI)	*d*	Pre	Post	Change (95% CI)	*d*	Pre	Post	Change (95% CI)	*d*
VO_{2max} (mL kg^{-1} min^{-1})	30.3 ± 9.1	35.3 ± 6.6**	5.0 (2.3–7.7)	0.63	29.4 ± 7.3	36.5 ± 7.3***	7.2 (3.6–10.8)	0.97	28.8 ± 8.5	32.9 ± 8.7*	4.1 (1.0–7.2)	0.48
W_{max} (W)	117 ± 26	130 ± 31*	13 (3–23)	0.45	134 ± 36	154 ± 42**	20 (8–31)	0.51	123 ± 37	145 ± 54*	22 (0–50)	0.48
Time to exhaustion (min)	11.7 ± 2.1	13.5 ± 3.0*	1.8 (0.3–3.2)	0.70	13.1 ± 3.7	15.3 ± 3.8**	2.2 (0.9–3.4)	0.59	11.7 ± 3.1	14.7 ± 3.9*	3.0 (0.3–5.4)	0.85
HR_{max} (bpm)	185 ± 6	183 ± 7	− 2 (− 7 to 3.2)	− 0.31	182 ± 9	180 ± 10	− 2 (− 6 to 1)	− 0.21	174 ± 7	172 ± 11	− 2 (− 12 to 5)	− 0.22
Lac_{max} (mmol L^{-1})	9.1 ± 2.1	9.4 ± 1.5	0.4 (− 1.4 to 2.2)	0.16	9.9 ± 1.2	9.3 ± 1.4	− 0.5 (− 1.2 to 1.0)	− 0.46	8.1 ± 2.7	9.0 ± 2.9	0.9 (− 0.4 to 2.2)	0.32
Workload at OBLA (W)	79 ± 18	90 ± 9*	11 (2–20)	0.77	84 ± 23	106 ± 25**	22 (7–37)	0.92	95 ± 29	109 ± 36*	22 (1–42)	0.43

Cohen's *d* value for effect size (ES)

VO_{2max} maximal oxygen uptake, W_{max} maximal power output, HR_{max} maximal heart rate, Lac_{max} maximal lactate concentration, *OBLA* onset of blood lactate accumulation

*($P < 0.05$), **($P < 0.01$), ***($P < 0.001$) significantly different from pre-intervention

Anthropometric indices and body composition

There were no significant between-group differences in anthropometric and body composition data before and after the intervention (Table 5). A significant main effect of time, however, was observed for waist circumference ($P < 0.05$, $\acute{\eta}^2 = 0.22$). *t* tests revealed only a significant ($P < 0.05$, $d = -0.21$) mean decrease in the 5 × 1-HIIT group by 2.0 cm (95% CI − 4.1 to 0.1), whereas changes were not significant in the 2 × 4-HIIT and MICT groups.

Cardiometabolic risk markers

Groups did not differ significantly on any cardiometabolic marker at baseline or following the intervention. One participant in the MICT group was diagnosed with pre-diabetes; and therefore, the abnormal data from the subject were excluded from all blood analyses. A significant time-effect was observed for resting HR ($P < 0.05$, $\acute{\eta}^2 = 0.18$), but subsequent paired *t* tests did not reveal significant changes in any group. Moreover, a significant time-effect was found for LDL-cholesterol ($P < 0.001$, $\acute{\eta}^2 = 0.40$) and the LDL/HDL ratio ($P < 0.001$, $\acute{\eta}^2 = 0.39$). Post hoc analyses revealed significant reductions in LDL concentrations in the 2 × 4-HIIT ($P < 0.05$, $d = -0.65$) by 0.42 mmol L^{-1} (95% CI − 0.81 to − 0.03) and 5 × 1-HIIT ($P < 0.05$, $d = -0.48$) groups by 0.26 mmol L^{-1} (95% CI − 0.52 to − 0.01). The LDL/HDL ratio decreased significantly in the 2 × 4-HIIT ($P < 0.05$, $d = -0.76$) by 0.41 (95% CI − 0.72 to − 0.10) and MICT ($P < 0.05$, $d = -0.47$) groups by 0.45 (95% CI − 0.79 to − 0.10) (Table 5). Results revealed a trend towards improved MetS-*Z*-Scores after the exercise intervention; however, the main effect of time did not reach statistical significance ($P = 0.054$, $\acute{\eta}^2 = 0.15$) (Table 5).

Participant-based outcomes

With the exception of an improvement in WAI in the 5 × 1-HIIT group ($P < 0.05$, $\acute{\eta}^2 = 0.22$) after the intervention, there were no significant differences in participant-based outcomes pre- and post-intervention between groups (Table 6). The percentage of participants who reported that the assigned protocol was helpful to overcome perceived barriers to regular exercise was 100% in the 2 × 4-HIIT group, 92% in the 5 × 1-HIIT group, and 86% in the MICT group.

Discussion

The purpose of the present pilot study was to determine the feasibility and efficacy of two low-volume, practical HIIT protocols, implemented in a real-world setting, in

Table 5 Anthropometric indices, body composition, and cardiometabolic risk data

Variable	2×4-HIIT		5×1-HIIT		MICT	
	Pre	Post	Pre	Post	Pre	Post
Height (m)	1.67 ± 0.11	–	1.73 ± 0.10	–	1.72 ± 0.13	–
Body mass (kg)	71.0 ± 14.2	71.4 ± 13.7	75.6 ± 15.4	74.9 ± 14.5	76.7 ± 22.8	76.2 ± 23.1
BMI (kg m^{-2})	25.8 ± 5.3	25.9 ± 5.1	24.9 ± 3.0	24.7 ± 2.9	25.6 ± 5.0	25.3 ± 5.1
Fat-free mass (kg)	48.0 ± 9.0	48.4 ± 9.5	52.8 ± 11.0	52.8 ± 10.8	52.8 ± 16.1	52.9 ± 15.1
Fat mass (kg)	23.1 ± 12.0	23.0 ± 11.9	22.8 ± 7.9	22.2 ± 7.2	24.0 ± 9.6	23.3 ± 9.6
Fat mass (%)	31.4 ± 11.9	31.3 ± 12.2	29.9 ± 7.2	29.3 ± 6.9	30.6 ± 7.7	29.7 ± 6.5
Total body water (L)	35.9 ± 6.7	36.2 ± 6.9	38.5 ± 8.4	38.4 ± 8.3	38.7 ± 12.8	38.7 ± 12.1
Extracellular water (L)	13.6 ± 2.4	13.3 ± 2.4	14.6 ± 3.2	14.6 ± 2.9	14.8 ± 4.9	14.8 ± 4.3
Intracellular water (L)	22.3 ± 4.3	22.0 ± 4.5	23.9 ± 5.3	24.0 ± 4.9	23.9 ± 7.9	24.0 ± 6.7
Waist circumference (cm)	83.1 ± 14.9	81.8 ± 13.6	82.3 ± 10.5	80.2 ± 9.2*	90.4 ± 19.5	89.1 ± 20.6
Resting heart rate (bpm)	79 ± 9	77 ± 10	81 ± 18	78 ± 14	81 ± 14	73 ± 13
Systolic BP (mmHg)	115 ± 7	112 ± 9	119 ± 21	120 ± 19	122 ± 15	118 ± 14
Diastolic BP (mmHg)	79 ± 7	80 ± 6	80 ± 10	81 ± 10	89 ± 13	81 ± 15
Blood glucose (mmol L^{-1})	4.55 ± 0.66	4.35 ± 0.43	4.67 ± 1.16	4.46 ± 0.42	4.70 ± 0.48	4.65 ± 0.53
TG (mmol L^{-1})	1.37 ± 0.39	1.24 ± 0.45	1.34 ± 0.51	1.78 ± 0.98	1.46 ± 0.41	1.70 ± 0.82
TC (mmol L^{-1})	4.30 ± 0.78	4.00 ± 0.55	4.22 ± 0.65	4.04 ± 0.49	4.71 ± 0.54	4.55 ± 0.44
HDL-C (mmol L^{-1})	1.35 ± 0.21	1.51 ± 0.21	1.28 ± 0.18	1.27 ± 0.31	1.19 ± 0.22	1.28 ± 0.22
LDL-C (mmol L^{-1})	2.67 ± 0.82	2.25 ± 0.42*	2.68 ± 0.67	2.41 ± 0.44*	3.21 ± 0.59	2.93 ± 0.59
LDL/HDL ratio	1.94 ± 0.64	1.53 ± 0.41*	2.09 ± 0.67	2.02 ± 0.71	2.85 ± 1.00	2.40 ± 0.93*
MetS-Z-Score	−4.41 ± 3.31	−5.71 ± 2.70	−4.10 ± 2.34	−3.90 ± 2.20	−2.26 ± 3.02	−3.31 ± 4.07

BMI body mass index, *BP* blood pressure, *TG* triglycerides, *TC* total cholesterol, *HDL-C* high-density lipoprotein cholesterol, *LDL-C* low-density lipoprotein cholesterol, *MetS-Z-Score* Metabolic Syndrome Z-Score

*($P < 0.05$) significantly different from pre-intervention

previously sedentary individuals. The main findings of this study are that: (a) the application of low-volume HIIT in a community-based fitness centre setting is well tolerated and accepted by sedentary individuals and appears to be a feasible and effective approach for public health promotion, (b) all training modes induced significant increases in cardiorespiratory fitness but the adaptations to the HIIT protocols were evoked for a substantially lower time commitment compared to MICT, (c) there were no significant differences in exercise enjoyment between the three exercise protocols, and (d) preliminary data suggest that 2×4-HIIT and 5×1-HIIT induce similar cardiorespiratory and cardiometabolic adaptations in previously sedentary individuals.

A number of well-controlled laboratory studies have already demonstrated that HIIT can be an effective and time-efficient exercise strategy to induce various physiological adaptations that are linked to improved health outcomes (Gibala et al. 2012; Weston et al. 2014). However, to date, data on the feasibility and efficacy of HIIT implemented in real-world settings are sparse. The few studies addressing this issue have yielded conflicting results. Lunt et al. (2014) reported low adherence rates and only modest improvements in cardiorespiratory fitness during a 12-week HIIT intervention, consisting of walking/running uphill intervals in a community park. In contrast, Shepherd et al. (2015) observed significant improvements in VO_{2max} after 10 weeks of HIIT carried out on indoor spinning bikes in a gym setting plus greater adherence among participants in the HIIT group compared with those who performed MICT. Two more recent studies investigating the effects of an intense stair climbing exercise intervention over 6 weeks (Allison et al. 2017) or a 4-week home-based program consisting of equipment-free high-intensity exercises (Blackwell et al. 2017) have also found significant increases in VO_{2max} and provide indication that HIIT may be a viable exercise option outside of laboratory conditions. Our results support these recent findings and strongly suggest that the concept of HIIT can be feasibly translated into real-world exercise programs. Participants in the present study were recruited via community-based channels (flyers and intranet postings in surrounding companies) and almost 60% of interested persons who responded were ultimately included in the study. The dropout rates in both HIIT groups (5×1-HIIT: 8% and 2×4-HIIT: 17%) were substantially lower than those in the MICT group (30%) and than those typically reported for the traditional exercise programs (30–50%) (Antoniewicz and Brand 2016; Buckworth and Dishman 2002; Kelley and Kelley 2013; Linke et al. 2011; Nam et al. 2012). Consistent

Table 6 Participant-based outcomes

Variable	2×4-HIIT		5×1-HIIT		MICT	
	Pre	Post	Pre	Post	Pre	Post
Work Ability Index (WAI)	41.7±4.1	44.0±3.5	44.1±3.9	45.5±3.6*	41.3±4.1	42.0±4.3
Chronic pain grade (CPGQ)	0.80±0.42	0.70±0.67	0.55±0.52	0.64±0.50	0.86±0.69	1.43±1.27
Chronic pain intensity (CPGQ)	18.6±13.2	16.6±18.1	13.4±14.8	10.3±10.7	23.1±22.0	24.7±24.5
PSQ—worries	24.7±21.8	22.0±16.0	10.9±12.4	7.9±10.3	22.9±23.1	22.9±21.7
PSQ—tension	35.3±24.3	40.0±23.7	33.3±15.8	29.7±15.3	35.2±22.0	37.2±31.7
PSQ—joy	68.7±26.7	67.4±25.6	72.7±18.5	75.2±18.9	53.3±27.7	61.9±22.4
PSQ—demands	41.3±27.5	42.7±21.1	40.6±18.0	41.8±21.5	48.6±30.7	56.2±31.7
PSQ—total	42.5±12.2	43.0±9.1	39.2±8.0	38.6±8.6	40.0±11.0	44.5±15.5
Exercise enjoyment (1–7)	–	6.0±0.5	–	5.9±0.8	–	5.4±0.5
Intentions to continue with assigned exercise protocol						
No (*n*, %)		1 (10%)		1 (9%)		0 (0%)
Yes, 1× per week (*n*, %)		2 (20%)		2 (18%)		2 (29%)
Yes, 2–3× per week (*n*, %)		6 (60%)		8 (73%)		4 (57%)
Yes, >3× per week (*n*, %)		1 (10%)		0 (0%)		1 (14%)
Intentions to continue with exercise in general						
No (*n*, %)		0 (0%)		0 (0%)		0 (0%)
Yes, 1× per week (*n*, %)		1 (10%)		2 (18%)		2 (29%)
Yes, 2–3× per week (*n*, %)		6 (60%)		9 (82%)		5 (71%)
Yes, >3× per week (*n*, %)		3 (30%)		0 (0%)		0 (0%)

WAI Workability Index Questionnaire (higher values indicate higher experienced work ability), *CPGQ* Chronic Pain Grade Questionnaire (higher values indicate higher pain severity), *PSQ* Perceived Stress Questionnaire (higher total values indicate higher subjectively experiences stress)

*($P<0.05$) significantly different from pre-intervention

with the previous work (Bauman et al. 2012) the main reason for insufficient physical activity reported by participants was a "perceived lack of time". After the intervention, 96% of participants in the HIIT groups perceived that the exercise protocol was helpful in overcoming this crucial barrier and 100% of participants intended to continue to engage in regular exercise. Thus, it is reasonable to assume that low-volume HIIT implemented in a real-world setting may—at least temporarily—circumvent perceived time-related barriers to exercise and may be helpful in increasing physical activity patterns over time. It is also important to note that no adverse events occurred during the present study, suggesting that HIIT, as performed in this intervention, may be safely administered in previously untrained populations under real-world conditions. The dropout rates in the present investigation were similar to those found in the study of Shepherd et al. (2015) (9%), whereas Lunt et al. (2014) reported substantially more dropouts (44%) as well as the occurrence of exercise-related injuries. This discrepancy could potentially be attributed to the selected type of exercise. HIIT, in the form of running exercise as performed in the study of Lunt et al. (2014), may have placed higher mechanical stress on the musculoskeletal system in previously untrained individuals compared to non-weight-bearing exercise modes like cycling, and may, therefore, have led to a higher injury risk and dropout prevalence. This interpretation is supported by a study, indicating that intensified running exercise over a short-term period induced substantially more muscle damage, soreness, and systemic inflammation when compared to cycling (Nieman et al. 2014). In line with this, it has recently been suggested that cycle-based HIIT may be a viable exercise mode for individuals with musculoskeletal conditions such as knee osteoarthritis (Keogh et al. 2017). In contrast, a recent study demonstrated that intense stair climbing was also well tolerated and may be used as a practical model of HIIT (Allison et al. 2017); however, it is to note that the subjects in this study were sedentary but otherwise healthy normal weight young women. Exercise and health professionals planning to develop and implement HIIT-based exercise programs for previously sedentary individuals should, therefore, carefully consider the exercise type to maximise tolerability.

Time efficiency is typically considered a major advantage of HIIT compared to traditional exercise methods. However, the true timesaving of previous practical (non-all-out) HIIT protocols is quite small when warm-up, cool-down, and recovery phases are added to the net HIIT time. As a result, the current research has focused on developing more time-efficient HIIT protocols, typically referred to as "low-volume" HIIT (Gibala et al. 2012; Metcalfe et al. 2012). A recent study, for example, demonstrated that an HIIT protocol involving only 3 × 20-s all-out cycling bouts (10-min total session time, including warm-up, cool-down, and recovery phases) performed three times per week (30-min total weekly time-effort) improved VO_{2max}, insulin sensitivity, and skeletal muscle mitochondrial content in sedentary men (Gillen et al. 2016). The all-out HIIT protocols used in most studies applying low-volume HIIT; however, typically require specialized laboratory cycle-ergometers, at costs impeding large-scale rollout, rendering them impractical for broad uptake in population-based health promotion interventions. Moreover, all-out HIIT protocols, such as the classical Wingate protocol, are considered extremely demanding and potentially unsuitable for untrained individuals (Gibala et al. 2012). The low-volume HIIT protocols applied in the present study were performed at more tolerable exercise intensities and, similar to all-out protocols, also required approximately 30 min of time-effort per week. Thus, these protocols could easily be incorporated into community-based exercise programs or adopted for time-efficient exercise workouts at home. Given that well-rounded exercise programs should ideally also include resistance training in addition to aerobic training (World Health Organization 2017), the present low-volume HIIT protocols may allow sufficient time for implementation of combined exercise programs to improve overall fitness. The ideal combination of practical low-volume HIIT with strength exercise, however, remains to be explored in future studies.

Low cardiorespiratory fitness is an independent and powerful predictor for cardiovascular disease and all-cause mortality (Myers et al. 2015). It was suggested that higher levels of cardiorespiratory fitness, regardless of health status and the presence of cardiometabolic risk factors, reduce the overall risk for cardiovascular disease and mortality (Myers et al. 2015). Estimates indicate, for example, that an increase in cardiorespiratory fitness by 1 MET (corresponding to an increase in VO_{2max} by 3.5 mL kg^{-1} min^{-1}) is associated with a 10–25% reduction in premature mortality (Myers et al. 2015). Thus, the mean increase in VO_{2max} by 5.0 mL kg^{-1} min^{-1} (20%) and 7.2 mL kg^{-1} min^{-1} (27%) induced by 2 × 4-HIIT and 5 × 1-HIIT, respectively, can be considered highly clinically relevant. These improvements in VO_{2max} are comparable to those found in recent studies with sedentary adults who also performed more practical low-volume HIIT protocols. Tjonna et al. (2013) observed a VO_{2max} increase by 5.0 mL kg^{-1} min^{-1} after 10 weeks of a HIIT program that required 57 min of time-effort per week. Astorino et al. (2016) reported a mean increase in VO_{2max} by approximately 6.4 mL kg^{-1} min^{-1} following a 12-week HIIT-regime that involved a total of approximately 70 min per week. However, to the best of our knowledge, the present study is the first to indicate that as little as 30 min of (non-all-out) practical HIIT can still effectively improve VO_{2max}, W_{max}, and submaximal exercise capacity at OBLA.

Although the increase in VO_{2max} did not significantly differ between the three exercise groups, it is of high interest that the cardiorespiratory adaptations to the HIIT protocols involved substantially less time-effort compared to MICT. Moreover, it is to note that the average 11% (3 mL kg^{-1} min^{-1}) greater improvement in VO_{2max} following 5 × 1-HIIT when compared to MICT can be considered clinically meaningful. The finding that the HIIT protocols improved VO_{2max} to a greater (although not statistically significant) extent than MICT is consistent with the previous investigations (Gibala et al. 2012; Weston et al. 2014; Helgerud et al. 2007), and supported by a recent study, suggesting that exercise intensity appears to be the more critical factor for improving cardiorespiratory fitness than exercise volume (Ross et al. 2015).

The significant reduction in waist circumference observed in the 5 × 1-HIIT group is also in line with the previous research, indicating that HIIT may be more effective at reducing abdominal fat than other types of exercise (Boutcher 2011). Possible mechanisms for the potential superiority of HIIT for reducing abdominal fat discussed in the literature include increased fat oxidation during and after exercise as well as reduced post-exercise appetite (Boutcher 2011). Given the relationship between waist circumference and morbidity, the finding that a weekly time commitment of ~ 30 min to a practical HIIT protocol may effectively decrease obesity-related disease risks is important from a public health point of view. Moreover, the significantly reduced LDL-cholesterol blood levels following both HIIT interventions are also consistent with the literature (Weston et al. 2014) and further indicate that fat metabolism may be improved following HIIT. For other cardiometabolic risk factors, like blood pressure, blood glucose, or total cholesterol, only small, statistically non-significant improvements were found. This could be due to the low sample size of the study. Future studies with larger sample sizes are, therefore, required to allow for a more definitive conclusion regarding the effects of practical low-volume HIIT protocols on single cardiometabolic risk factors. It is to note that the trend towards improved MetS-*Z*-Scores (effect size, $\acute{\eta}^2 = 0.15$) might provide an indication of the potential of low-volume (non-all-out) HIIT to decrease overall cardiometabolic risk, which, however, needs to be clarified in further studies.

Studies attempting to compare the effects of HIIT protocols consisting of either longer or shorter intervals have yielded conflicting results. A recent study comparing the widely used 4 × 4-min protocol vs. the 10 × 1-min HIIT protocol, for example, found that 4-min intervals were superior to 1-min interval in improving VO_{2max}. This finding was attributed to an increase in oxygen supply by greater stroke volume after the 4-min interval protocol (Martinez et al. 2015). In contrast, another recent study suggested that shorter intervals induced superior training adaptations compared with longer intervals (Rønnestad et al. 2015). The authors of this study speculated that shorter intervals might provide a more effective stimulus for multiple adaptations, including neuromuscular function, buffering capacity, cardiovascular functions, and muscular oxygen potential. The influence of differing interval durations on cardiometabolic risk markers is still poorly understood. It was recently suggested that a longer interval duration may be potentially more beneficial in improving distinctive health-enhancing benefits (Weston et al. 2014). In the current study, both HIIT protocols showed favourable improvements in VO_{2max} and cardiometabolic risk markers and our data do not provide indications of whether longer or shorter interval durations induce superior improvements in these outcomes.

It has been previously reported that HIIT may have a positive impact on well-being and quality-of-life outcomes (Weston et al. 2014). To our knowledge, the effects of HIIT on perceived work ability have not yet been investigated. Our results indicate that HIIT may positively affect work ability as became evident by significant (5 × 1-HIIT) and small (2 × 4-HIIT) increases in WAI among participants. This finding is of high practical relevance for exercise and health professionals interested in implementing feasible and effective exercise programs within workplace settings. Given that most adults spend many hours a day at work, the workplace represents an ideal setting in which to promote physical activity (Jakobsen et al. 2015). However, given perceived time barriers among workers and a potential reluctance among employers to provide paid time during the work day for exercise programs, worksite interventions need to be both time-efficient and effective if they are likely to yield significant health benefits. Thus, the low-volume HIIT protocols applied in this study may be an interesting option for worksite health promotion settings. Future studies in this area may wish to examine the feasibility of low-volume practical HIIT implemented directly in the workplace.

Regarding exercise enjoyment, Martinez et al. (2015) reported higher values during shorter intervals than during longer intervals, whereas in a study of Tucker et al. (2015), no significant differences were found in this respect. In the present study, we did not detect any significant impact of interval duration on exercise enjoyment. Given that both protocols were extremely time-efficient, it could, therefore, be speculated that enjoyment responses are less affected by interval duration if total time-effort is low and similar between HIIT protocols, respectively.

There are several limitations that should be considered when interpreting our results. First, the present study is an initial pilot study with a relatively small group of participants. Thus, all results related to the efficacy of the applied low-volume HIIT protocols should be regarded as preliminary and it should be noted that other clinically meaningful changes pre-/post-intervention and differences between groups, respectively, were potentially not detected due to a small sample size. However, the preliminary data obtained in this pilot study provide important estimates for future power calculations for larger studies, which are needed to reach more definitive conclusions on efficacy. Second, given the work obligations of the participants, it was not possible to standardise the scheduling of testing, so that it followed an overnight fast. Although this could have potentially resulted in some variability of blood values, all participants were instructed to fast for at least 3 h prior to the testing session and this has been demonstrated to be sufficient for obtaining reliable measurements of the type of blood parameters examined in this study (Moebus et al. 2011; Sidhu and Naugler 2012). Third, we are aware of the limitations associated with convenience sampling used in this study, such as the possibility of volunteer bias and limited generalisation to the overall population, although we do not feel this had meaningful effects on the assessment of our outcomes. Fourth, given that we only recruited previously sedentary/untrained but otherwise healthy subjects, the results of this study cannot be generalised to other populations such as individuals with chronic diseases. Therefore, further research is needed to explore whether the present low-volume HIIT protocols can be feasibly translated into clinical settings. Fifth, given that the present study lasted 8 weeks, long-term adherence to the applied HIIT protocols remains unclear. Future studies involving longer intervention and follow-up periods are needed to answer such questions.

Conclusion

The results of the present pilot study indicate that low-volume HIIT can feasibly be implemented in the real world. Furthermore, our preliminary data suggest that practical (non-all-out) HIIT regimens that require as little as 30 min/week—corresponding to only a fifth of the general physical activity recommendations—may induce significant improvements in VO_{2max} and cardiometabolic risk markers. Given that both 2 × 4-HIIT and 5 × 1-HIIT were found to be feasible and effective in improving VO_{2max} and selected cardiometabolic risk markers, without differences in participant-based outcomes, the interval duration appears to be of minor importance for the implementation of low-volume HIIT in real-world settings. Further confirmation of our findings is needed to assess the role of practical low-volume HIIT protocols in population-based studies to reduce the burden of chronic disease.

Acknowledgements No funding was received for this study. We would like to thank the Pfitzenmeier Premium Club Mannheim Neckarau headed by Haki Kadria and Tobias Kleine-Nathland for their outstanding cooperation. In particular, we thank Esther Giesewetter, André Luqueba, Stephan Steinicke, Danijel Ber, Paula Rosenfelder, and Daniel Lambor for supervising the exercise classes. We would also like to thank Wiebke Würdemann and Irina Peil for their professional assistance during data collection. We thank David Litaker for his valuable assistance and proofreading the manuscript. We are especially grateful to all study participants for their willingness to participate in this study.

Author contributions DR and JF conceived and designed research. DR and FW conducted measurements and exercise tests. DR analyzed data. DR wrote the manuscript. All authors read and approved the manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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