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Melyssa Roy[1], Sheila M. Williams[2], Rachel C. Brown[3], Kim A. Meredith-Jones[1], Hamish Osborne[1], Michelle Jospe[1,3], and Rachael W. Taylor[1]

Departments of [1]Medicine, [2]Preventive and Social Medicine, and [3]Human Nutrition, University of Otago, Dunedin, New Zealand

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HIIT in the Real World: Outcomes from a 12-Month Intervention in Overweight Adults

Melyssa Roy[1], Sheila M. Williams[2], Rachel C. Brown[3], Kim A. Meredith-Jones[1], Hamish Osborne[1], Michelle Jospe[1,3], and Rachael W. Taylor[1]

Departments of [1]Medicine, [2]Preventive and Social Medicine, and [3]Human Nutrition, University of Otago, Dunedin, New Zealand

Address for correspondence: Professor Rachael Taylor, Department of Medicine, University of Otago, PO Box 56, Dunedin 9054, New Zealand. Email: rachael.taylor@otago.ac.nz, Phone: +64 3 470 9180

The results of this study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation. The results of the present study do not constitute endorsement by the American College of Sports Medicine. **Competing interests**: The authors declare that they have no competing interests. **Funding:** The SWIFT Study was funded by the University of Otago. RWT is partially funded by a Fellowship from the Karitane Products Society (KPS) Limited. The funders had no role in the design of the study; the collection, analysis, and interpretation of the data; the writing of the manuscript; or the decision to submit the article for publication.

Abstract

Purpose: Although high-intensity interval training (HIIT) and moderate-intensity continuous exercise have comparable health outcomes in the laboratory setting, effectiveness studies in real-world environments are lacking. The aim of this study was to determine the effectiveness of an unsupervised HIIT programme in overweight/obese adults over 12 months.

Methods: 250 overweight/obese adults could choose HIIT or current exercise guidelines of 30 minutes/day moderate-intensity exercise. HIIT participants received a single training session and were advised to independently perform HIIT 3x/week utilizing a variety of protocols. Mixed models, with a random effect for participant, compared differences in weight, body composition, blood pressure, aerobic fitness, physical activity and blood indices at 12 months, adjusting for relevant baseline variables.

Results: Forty-two percent (n=104) of eligible participants chose HIIT in preference to current guidelines. At 12 months, there were no differences between exercise groups in weight (adjusted difference HIIT vs conventional; 95% CI: -0.44kg; -2.5, 1.6) or visceral fat (-103cm^3; -256, 49), although HIIT participants reported greater enjoyment of physical activity (p=0.01). Evidence of adherence to ≥2 sessions/week of unsupervised HIIT (from heart rate monitoring) declined from 60.8% at baseline to 19.6% by 12 months. Participants remaining adherent to HIIT over 12 months (23%) were more likely to be male (67% vs 36%, p=0.03), with greater reductions in weight (-2.7kg; -5.2 -0.2) and visceral fat (-292cm^3; -483, -101) than non-adherent participants.

Conclusions: HIIT was well-accepted by overweight adults and opting for HIIT as an alternative to standard exercise recommendations led to no difference in health outcomes after 12 months. While regular participation in unsupervised HIIT declined rapidly, those apparently adherent to regular HIIT demonstrated beneficial weight loss and visceral fat reduction.

Trial Registration: Australian New Zealand Clinical Trials Registry (ACTRN12615000010594) Retrospectively registered

Key words: high-intensity interval training, adult, obesity, health

Introduction

Current public health guidelines recommend at least 30 minutes of daily exercise of moderate intensity (e.g. walking, cycling, gardening). However, studies consistently show poor adherence to guidelines (1) with lack of time often cited as a major barrier (2). An alternative approach is high intensity interval training (HIIT), defined as "brief, intermittent bursts of vigorous activity, interspersed by periods of rest or low-intensity exercise" (3). A proposed major advantage of HIIT is that it takes considerably less time than conventional moderate-intensity exercise options to obtain comparable health benefits (4). Even very small amounts of intense exercise (as little as 5-10 minutes/day or 30 minutes/once per week) improve health outcomes (5) and reduce mortality risk (6, 7). A number of meta-analyses have demonstrated that laboratory–based HIIT is at least as effective as standard continuous training for improving aerobic fitness (VO_{2max}) (8-11) and important clinical indicators such as blood pressure, glucose handling and visceral fat (3, 12, 13).

However, whether HIIT works in the real world is currently unknown (14, 15) as virtually all trials to date have been conducted in laboratory settings over less than 6 months (9-11). Although concerns have been raised regarding the safety of unsupervised HIIT in terms of cardiovascular events and injury risk (16), others argue that such concerns are unfounded, indicating that HIIT can be more enjoyable than conventional exercise (17), promote greater adherence (18), and be safe even in clinical populations (19). Certainly, longer-term outcomes from unsupervised HIIT have been evaluated in cardiac patients, who show improvements in aerobic fitness for periods up to 12 months (20, 21). However, given their motivation to adhere should theoretically be higher than the general population, it remains important to examine the feasibility of

unsupervised HIIT in non-clinical groups (22). If proven to work, such evidence will contribute to public health recommendations indicating that HIIT is a viable alternative to conventional moderate-intensity exercise. As recently highlighted (22), several issues remain in order to bridge the translational gap from the laboratory to public health policy. Real-world effectiveness studies are required that trial low-cost, accessible HIIT protocols over the long-term (22). Therefore, the aims of this study were to determine whether i) overweight individuals would choose to participate in unsupervised HIIT on a regular basis over a 12-month period, and ii) an unsupervised HIIT programme influences body composition, physical activity and health more than conventional moderate-intensity exercise recommendations.

Methods

The Support strategies for Whole-food diets, Intermittent Fasting and Training (SWIFT) study was a 12-month randomised controlled trial (RCT) investigating whether the addition of monitoring strategies (face to face contact, self-weighing, dietary monitoring, or monitoring of hunger) to dietary and exercise advice increased weight loss over 12 months compared with the provision of advice alone (23). SWIFT is registered with the Australian New Zealand Clinical Trials Registry (ACTRN12615000010594) and ethical approval was obtained from the University of Otago Human Ethics Committee (H14/024). All participants provided written informed consent. As a protocol paper (24) and main outcome findings (23) have been published, only relevant details are provided here.

Participants were recruited by advertisement and screened using an online questionnaire followed by an initial face-to-face screening visit (Figure 1). Eligible participants were aged 18+

years, had a body mass index (BMI) of ≥27 kg/m^2, and no history or symptoms of cardiovascular disease or ongoing serious medical issues. Exclusion criteria were; type 1 or 2 diabetes, inflammatory disorders, or any respiratory or musculoskeletal condition impeding ability to exercise. Women who were pregnant or breastfeeding were also excluded. Physical screening then applied further exclusions to those with previously unrecognized hyperglycemia (≥7 mmol/L) or hypertension greater than stage 1 (Figure 1). In addition to pre-participation screening, further medical assessment was provided to HIIT participants as per ACSM/AHA guidelines in 2014 (25). This was to improve safety by identifying any participants with occult heart disease or other serious disorder who could be at a higher risk of a cardiac event during exercise.

Following baseline assessments, eligible participants were able to choose whether to follow current exercise recommendations or HIIT. Both were unsupervised exercise programmes following a single intervention/training session. Those selecting the current New Zealand (NZ) guidelines option were instructed to perform "at least 30 minutes of moderate intensity physical activity on most if not all days of the week." Trained researchers (medical doctor, dietitian) spent approximately 10-20 minutes discussing with each individual how they could best meet this goal, typically using options such as brisk walking, cycling and exercise classes. A widely available brochure produced by the NZ Ministry of Health was provided and high intensity exercise was not emphasized.

HIIT participants underwent a 60-minute preparatory session, performed on a cycle ergometer in order to experience near-maximal intervals, by undertaking three intervals of up to 30 seconds in

duration, and were encouraged to attain a Rating of Perceived Exertion (RPE) of 8 or greater (10-point scale). Heart rate monitoring (Polar RC3/RCX GPS) was used to ensure participants achieved at least 80-90% of their estimated maximum heart rate (using the formula 220-age) (25). While most participants attempted maximal intervals, fitness levels varied greatly, so modification of this protocol to use sub-maximal but still high intensity intervals was occasionally necessary for tolerability and safety reasons for participants who were severely deconditioned. HIIT participants were provided with verbal and written instructions (see Document, Supplemental Digital Content 1, Supplementary Methods detailing these instructions, http://links.lww.com/MSS/B282) outlining evidence-based HIIT options for ongoing unsupervised training (4, 8, 26-29).

All outcome measurements were obtained at 0, 6 and 12 months (unless noted differently) by trained assessors blinded to support and exercise groups. Height, weight (primary outcome), waist circumference, and blood pressure were obtained in duplicate using standard protocols (24). Body composition was measured by dual energy x-ray aborptiometry (DXA) at 0 and 12 months (GE Lunar Prodigy, GE Healthcare, Madison WI, USA). Visceral fat volume was estimated using the Lunar Encore software CoreScan (Version 16, GE Healthcare). A fasted venous blood sample was obtained by a registered nurse; plasma total cholesterol (TC), HDL cholesterol (HDL-C) and triglyceride (TG) levels were measured by enzymatic methods using a Cobas Mira Plus Analyser, and LDL cholesterol (LDL-C) concentrations were derived using the Frielwald formula (30). High-sensitivity CRP was measured using a CRP Unimate kit (Roche Diagnostics) and glycated hemoglobin (HbA1c) by enzymatic methods on a Cobas Mira Plus Analyzer (Roche Diagnostics, Indianapolis, Indiana). Active ghrelin levels were assessed via

immunoassay (Human Gut Hormone Panel LINCOplex Kit, LINCO Research, St Charles, MO). Total activity (counts per minute) and time spent performing moderate to vigorous physical activity (MVPA) were measured with all participants wearing an Actigraph accelerometer (GT3X, ActiGraph, Pensacola, FL) for 7 days. Data were analysed using both 15 second (to capture shorter bouts of intense exercise) and 60 second (to enable comparison with the international literature) epochs. Data were analysed using an automated programme developed in MATLAB (MathWorks, Natick, MA, USA) which "removes" all sleep data, specific to each day and each individual (31). Physical fitness was ascertained using a modified YMCA sub-maximal cycle ergometer (Monark ergometer, model 828E, Sweden) to estimate VO_{2peak} (32). A submaximal test was used for this overweight and largely unfit population, as maximal testing in a trial of this size was not pragmatic, nor likely to result in true peak values (25, 33). Information on demographics (age, sex, ethnicity, education, employment status) and personality (ten-item personality inventory) (34) was obtained at baseline. At each time point, participants completed questionnaires assessing perceived self-efficacy and enjoyment of physical activity (35).

Additional measures of adherence to HIIT were recorded using Polar RC3/RCX GPS heart rate monitors worn during all unsupervised HIIT sessions over one week at 0, 3, 6, 9 and 12 months. Within each HIIT session, heart rate was recorded continuously, providing measures of maximum heart rate, and the duration of time exceeding pre-defined thresholds of 80% and 90% of the predicted maximum heart rate (HR_{max}, calculated from 220-age). Heart rate data were subsequently uploaded and analyzed using Polar online software (*polarpersonaltrainer.com*).

Statistical analysis

Mixed models, with a random effect for participant, adjusting for age, sex, the monitoring group to which the participants were randomized, and the relevant baseline variables were used to analyze the data. No adjustments were made for multiple comparisons. For those outcomes that were not collected at 6 months, linear regression was used, adjusting for age, sex and baseline to estimate differences between the exercise groups. The results are presented as differences (95% confidence intervals) between groups.

A subsequent analysis, limited to those choosing HIIT, used similar methods to compare participants with different levels of adherence to HIIT. Full adherence was defined *a priori* as providing at least two recordings of adequate HIIT sessions at three or more of the three-monthly reviews. Partial adherence was defined as providing only one recording of an adequate HIIT session at three or more of the review periods, and non-adherence was defined as less HIIT data than these amounts. All analyses were performed using Stata 13.1 or a later version (StataCorp, College Station, TX, USA).

Results

Table 1 shows that the 104 participants (41.6%) that chose to try HIIT did not differ at baseline from those choosing standard exercise recommendations in terms of demographics, BMI, body composition, aerobic fitness or physical activity levels. The psychological measures were also similar, with small significant differences observed in just two personality indices; the HIIT cohort showing higher scores for agreeableness (p=0.02) and extraversion (p=0.03) than the current recommendations group.

The initial supervised HIIT training session was completed by 102 participants. Sufficiently intense intervals (heart rates exceeding 80% HR_{max}) were achieved by 88 participants (86.2%) with 41 (40.2%) exceeding 90% HR_{max}. Twelve participants were unable to attain adequate intensity, primarily limited by leg fatigue specific to the cycling modality.

Table 2 illustrates the differences in outcomes according to exercise program for all the participants who remained in the trial, regardless of adherence to either exercise protocol. Retention was 70% in the HIIT cohort and 67% in the current recommendations group at 12 months. No significant group differences were observed in weight, body fat or blood pressure at 6 or 12 months. Despite recommendations for duration and intensity of exercise being markedly different between the groups, estimated VO_{2peak} and physical activity were similar at 12 months. Both groups achieved 32-52 minutes of MVPA/day and self-efficacy for exercise remained unchanged throughout the trial in both groups. However, at both 6 and 12 months, enjoyment of physical activity was approximately 1 SD higher in HIIT compared with the current recommendations group (difference in scores; 95% CI: 2.5; 0.6, 4.3).

In order to gauge adherence to HIIT, the number of unsupervised HIIT sessions recorded by heart rate monitoring at 0, 3, 6, 9 and 12 months is shown in Table 3. The proportion of participants who did not provide data increased from 18 (17.6%) at baseline to 73 (71.6%) at 12 months. Those adhering to HIIT completed 1-3 sessions per week, with up to 9 participants completing 4 or more sessions a week at each time-point.

HIIT participants spent 21-24 minutes a week in total exceeding 80% HR_{max}, of which approximately 9 minutes was above the 90% HR_{max} threshold (see Table, Supplemental Digital Content 2, detailing the number of participants who achieved set exercise intensities at each time point, http://links.lww.com/MSS/B283). Participants recorded a variety of HIIT modalities, including using hills, stairs, running, exercise equipment such as bikes, elliptical trainers, and rowing machines, as well as home-based circuit type exercises such as burpees and star jumps. A few participants recorded taking part in commercial gym, online or app-based HIIT workouts, as well as some high-intensity sport-based training such as futsal or squash, and all of these activities produced exercise of adequate (≥80% HR_{max}) intensity (data not shown).

Given the apparently poor adherence to HIIT long-term, a further analysis was undertaken to ascertain how adherence affected outcomes. Based on the *a priori* adherence categories, 24 participants (23.1%) were considered fully adherent, 17 (16.3%) were partially adherent, with the majority (n=63, 60.6%) not meeting adherence criteria. It was apparent that fully adherent participants were more likely to be male (p=0.03) and leaner (p= 0.03), but they did not differ in terms of age, BMI, physical activity or aerobic fitness at baseline from non-adherent participants (see Table, Supplemental Digital Content 3, comparisons of baseline characteristics between adherent and non-adherent participants, http://links.lww.com/MSS/B284). However, differences in outcomes were apparent (Table 4). At 12 months, weight (-2.7kg; 95% CI: -5.2, -0.2), waist circumference (-2.4cm; -4.7, -0.2), visceral fat volume (-292cm^3; -483, -101) and HbA1c (-0.9mmol/mol; -1.7, 0.0) were significantly lower in fully adherent compared with non-adherent participants. Interestingly, while self-efficacy for physical activity was also higher (2.5; 0.7, 4.3), enjoyment of physical activity was lower in fully adherent participants (-2.2; -4.4, 0.0). By

contrast, adherence was not associated with differences in blood pressure, total body fat, or aerobic fitness, although partially adherent participants were less physically active than non-adherent participants (Table 4).

Discussion

Our study illustrates that HIIT was chosen by a large number of overweight individuals, who were able to initially perform it effectively and independently using a variety of modalities. However, opting for three-weekly HIIT as an alternative to 30 minutes of daily moderate intensity exercise did not result in meaningful differences in any health outcomes at 12 months, most likely due to poor adherence in the real world setting by the majority of participants. Without supervision, adherence to HIIT declined rapidly over 12 months, although participants maintained similar levels of physical activity overall compared with those following standard exercise guidelines. Significant decreases in weight and visceral fat were achieved by a relatively small group of participants who reported adherence to the HIIT protocol.

Although it has been argued that overweight non-athletic individuals would be unlikely to try HIIT (1, 15), 42% of participants opted to do so as an alternative to daily moderate intensity exercise. It has been contended that overweight or obese people would be unable to successfully perform high intensity exercise without support (1). The results of this study suggest this may be partially true. Our findings demonstrate that the majority of participants proved able to perform HIIT at an adequate intensity (greater than 80%HR_{max}) under supervision, but much smaller numbers met our participation targets of at least twice per week, particularly over the longer

term. Thus, it appears that HIIT can be effectively undertaken by most overweight and obese people with minimal training, but that long-term adherence remains a significant challenge.

A number of existing trials have concluded that supervised HIIT can lead to improvements in fitness, body composition and blood indices (8-10, 12). In contrast, this study demonstrates that a single HIIT intervention without ongoing support did not lead to clinically significant changes in these outcomes over 12 months, most likely due to inadequate adherence. Only those who were adherent to the protocol (23%) showed the meaningful improvements in weight and visceral fat that have typically been shown in the laboratory setting (13, 36).

In this study, the adherence of the participants choosing to undertake daily moderate intensity continuous exercise could not be directly compared to the adherence of the HIIT group, as exercise performance was measured using different methods. Adequate execution of HIIT was best established using heart-rate monitoring to ascertain that sufficient intensity was achieved, because accelerometry may not effectively capture non-ambulatory intense activity such as stationary cycling. In contrast, for participants opting for usual forms of exercise, accelerometry provided the best means of evaluating physical activity levels. However, it is well established that adherence to any structured exercise program is poor, especially for those with obesity (1, 37, 38). This study has demonstrated that if HIIT is advised but not supported, the majority of overweight participants will not obtain additional health benefits from this form of exercise by 12 months. While previous studies have suggested that HIIT is considered enjoyable and even preferred in supervised environments (17), our findings support other work indicating that in free-living environments, poor adherence leads to more modest health outcomes (39). It is

important to note that our HIIT participants did not become less physically active than those choosing to follow more traditional exercise regimes.

The strengths of our study include its 'real-world' design, in a large number of participants, and over a longer time frame than has typically occurred in HIIT research. We also used DXA to measure body composition, and collected habitual physical activity data by accelerometry, with objective assessment of HIIT participation by heart rate monitoring. Our study also has some limitations. In order to best represent free-living conditions, participants were allowed to choose their exercise program. While we observed very few differences in our exercise groups at baseline, it is possible that differences existed in variables we did not measure. Attrition was relatively high at 31.6% (23), although this is not unusual for lifestyle interventions. Small changes in aerobic fitness may not have been detected due to the use of submaximal estimation of VO_{2peak}, which was the safest and most pragmatic test for this population, but inherently less accurate than maximal oxygen uptake testing (32, 40). It is possible that adherence to HIIT was overestimated by our use of one week of HIIT recordings every 3 months, as some participants may have undertaken a HIIT session only when provided with a heart rate monitor. However, alternative options such as daily records over the full 12 months in a sample of this size were not feasible. Allowing our participants to undertake a wide variety of HIIT protocols is important for real world utilisation, but does not allow any mechanistic interpretations or delineation of more "successful" protocols.

In conclusion, our study indicates that HIIT may be a tolerable alternative to daily moderate intensity exercise for people who are overweight or obese, although it is unlikely to lead to

differences in important health outcomes for all who attempt it. However, those participants who do adhere to a HIIT regime experience important health benefits, indicating that HIIT can be included as a suitable exercise option. Further work to determine how best to improve long-term adherence in the real world may lead to HIIT being a viable public health strategy to improve health outcomes.

Acknowledgements

The results of this study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation. The results of the present study do not constitute endorsement by the American College of Sports Medicine.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

MR was the PhD student on the SWIFT study and designed and undertook the HIIT intervention. She saw all participants, collected and analysed all heart rate monitoring data, and wrote the first and subsequent drafts of the paper. RCB was a co-investigator, assisted with study design and commented on the manuscript. SMW was a co-investigator, assisted with study design, was responsible for all statistical analyses and commented on the manuscript. KM-J was a co-investigator, assisted with study design, completed the accelerometry analyses, and commented on the manuscript. HO was a co-investigator, assisted with study design, oversaw the medical aspects of the study, and commented on the manuscript. MJ was a co-investigator, assisted with study design and commented on the manuscript. RWT conceived the idea for the study, was the principal investigator of the project, and was responsible for overall study design and monitoring of data collection. All authors read and approved the final manuscript.

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Figure Legend

Figure 1: Participant recruitment and eligibility

Supplemental Digital Content files

Supplemental Digital Content 1.docx—Details on HIIT recommended HIIT protocols

Supplemental Digital Content 2.docx—Duration of exercise above threshold recorded during HIIT sessions by participants providing recordings

Supplemental Digital Content 3.docx—Baseline characteristics of adherent, partially adherent and non-adherent HIIT participants

Figure 1

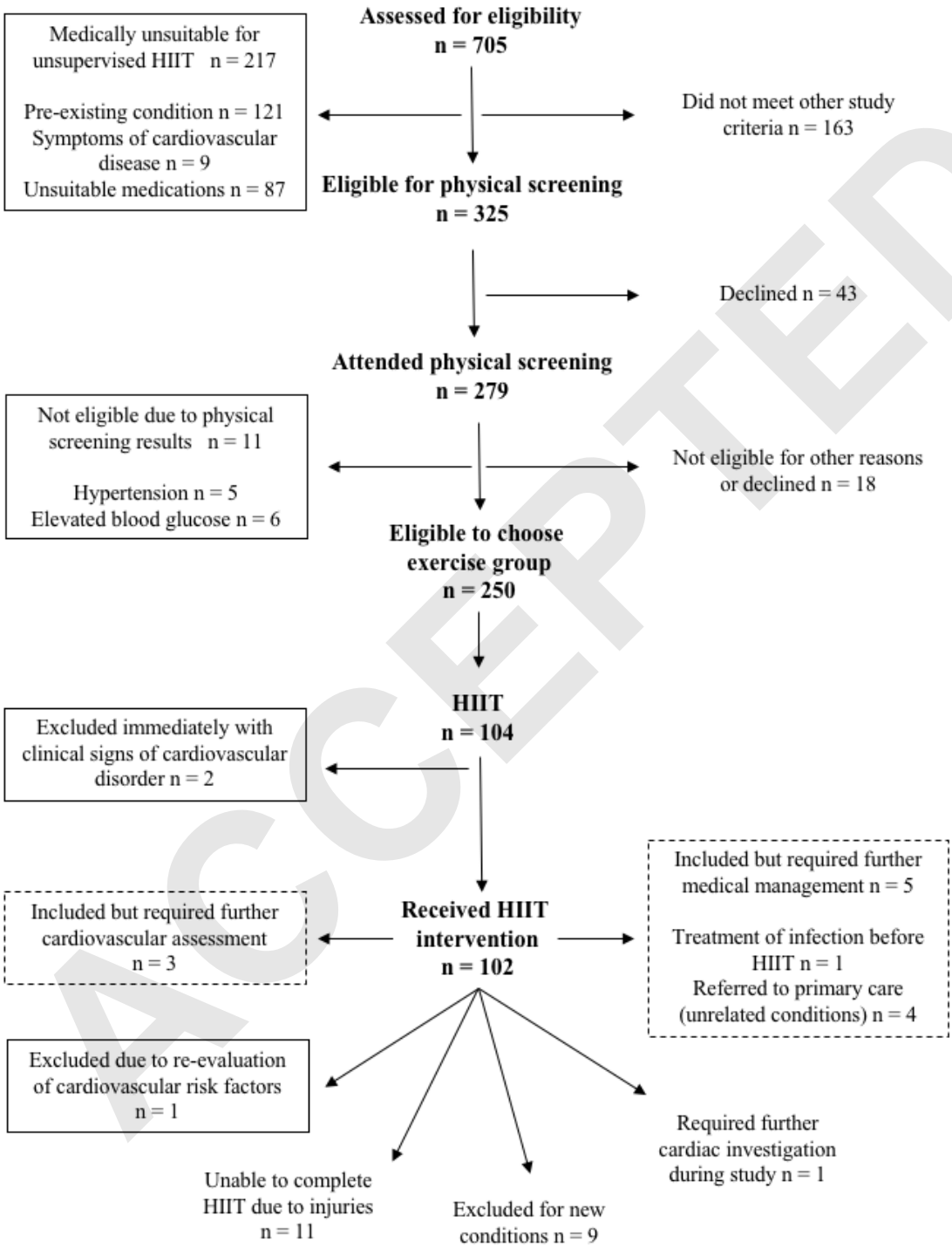

Table 1. Baseline characteristics of participants choosing HIIT or current recommendations

Variable		HIIT	Current recommendations	P[a]
n		104 (41.6%)	146 (58.4%)	
Female n (%)		59 (56.7%)	96 (65.8%)	0.15
Age (years)		43.5 (10.2)	43.9 (11.5)	0.76
Education	School only	19 (18.3%)	30 (20.6%)	0.06
	Post secondary	19 (18.3%)	44 (30.1%)	
	University	66 (63.5%)	72 (49.3%)	
Ethnicity	NZEO[b]	92 (88.5%)	128 (87.7%)	0.63
	Maori	7 (6.7%)	11 (7.5%)	
	Pacific	4 (3.9%)	3 (2.1%)	
	Asian	1 (1.0%)	4 (2.7%)	
Employment	Full-time	76 (73.1%)	101 (69.2%)	0.30
	Part-time	21 (20.2%)	30 (20.6%)	
	Not employed	6 (5.8%)	7 (4.8%)	
	Not stated	1 (1.0%)	8 (5.5%)	
Weight (kg)		96.2 (15.5)	95.7 (16.7)	0.84
Height (cm)		170.9 (9.9)	169.8 (9.2)	0.35
Body mass index (kg/m^2)		32.9 (4.2)	33.1 (4.5)	0.67
Waist (cm)		101.4 (12.7)	101.5 (12.4)	0.96

Percentage body fat (%)		39.2 (7.3)	40.6 (7.5)	0.15
Visceral fat (cm^3)		1495 (1009)	1434 (903)	0.62
Systolic blood pressure (mm Hg)		124.1 (15.6)	123.9 (15.4)	0.90
Diastolic blood pressure (mm Hg)		78.8 (10.1)	78.4 (9.9)	0.72
Estimated VO_2max (ml/kg/min)		28.6 (6.1)	28.5 (6.9)	0.88
Physical activity	Counts per minute	327 (96)	333 (120)	0.70
	Sedentary minutes/day[c]	600 (77)	584 (90)	0.17
	MVPA (mins/day)[d]	51 (32)	50 (33)	0.72
	MVPA (mins/day)[c]	36 (31)	36 (32)	0.94
% meeting MVPA guidelines[c]		77.9	68.4	0.11
Perceived benefits of physical activity[e]		12.3 (2.1)	12.7 (2.1)	0.09
Enjoyment of physical activity[f]		19.8 (6.3)	19.6 (6.1)	0.80
Self-efficacy for physical activity[g]		15.5 (4.7)	15.1 (4.6)	0.51
Encouragement of physical activity[h]		5.2 (2.0)	5.6 (2.2)	0.10
Personality[i]	Extraversion	4.9 (0.9)	4.7 (0.9)	**0.02**

	Agreeableness	5.2 (1.1)	4.9 (1.1)	**0.03**
	Conscientiousness	5.2 (1.2)	5.1 (1.1)	0.54
	Emotional stability	5.0 (1.4)	4.8 (1.3)	0.19
	Open to experiences	5.3 (1.0)	5.1 (1.0)	0.06
Resilience score[j]		3.5 (0.8)	3.5 (0.8)	0.86

Data presented as mean (SD) unless otherwise indicated.

[a]Comparison between HIIT and current recommendations group analyzed using chi-squared (categorical variables) or independent t-test (continuous variables) analyses as appropriate.

[b]New Zealand European and Others.

[c]Using 60 second epochs

[d]Using 15 second epochs

From total possible scores of [e]16, [f]42, [g]25, and [h]10.

Using a [i]7-point or [j]5-point scale.

Table 2. Body composition, exercise, and fitness outcomes for those choosing HIIT compared with current recommendations

Variable	Month	HIIT[a]		Current Recommendations[b]		Difference (95% CI)[c]	p
		n	Mean (SD)	n	Mean (SD)		
Weight (kg)	0	88	96.2 (15.7)	121	95.5 (16.1)		
	6	85	92.1 (14.5)	119	93.0 (16.5)	-0.56 (-2.2 to 1.1)	0.50
	12	73	92.7 (14.7)	98	92.9 (18.0)	-0.44 (-2.5 to 1.6)	0.68
Body fat (%)	0	68	38.1 (7.0)	96	40.0 (7.7)		
	12	68	36.1 (8.2)	96	38.6 (8.6)	-0.3 (-1.5 to 0.8)	0.57
Visceral fat volume (cm^3)	0	69	1579 (1045)	94	1473 (917)		
	12	69	1308 (910)	94	1311 (904)	-103 (-256 to 49)	0.18
Waist circumference (cm)	0	88	101.3 (13.1)	121	101.6 (12.0)		
	6	85	97.2 (11.5)	119	98.4 (11.1)	-0.3 (-1.9 to 1.2)	0.67
	12	73	98.2 (12.2)	98	98.6 (12.1)	0.3 (-1.4 to	0.71

						2.0)	
Systolic blood pressure (mm Hg)	0	88	123.6 (15.6)	120	125.2 (15.0)		
	6	85	121.9 (13.8)	118	123.4 (14.9)	-0.5 (-3.4 to 2.5)	0.76
	12	73	119.8 (13.8)	98	120.8 (13.9)	-0.3 (-3.0 to 2.4)	0.81
Diastolic blood pressure (mm Hg)	0	88	78.4 (10.1)	120	79.0 (9.9)		
	6	85	76.8 (9.7)	118	77.0 (10.2)	0.2 (-1.8 to 2.2)	0.84
	12	73	75.6 (9.4)	98	76.2 (10.2)	-0.4 (-2.5 to 1.7)	0.71
Estimated VO_{2peak} (ml/kg/min)	0	76	29.1 (6.6)	106	28.9 (7.3)		
	6	70	30.1 (6.4)	97	29.7 (6.5)	0.2 (-1.1 to 1.5)	0.76
	12	63	28.9 (5.4)	90	28.6 (6.5)	0.0 (-1.3 to 1.2)	0.95
Counts per minute	0	71	331 (93)	108	343 (124)		
	6	68	319 (102)	102	327 (124)	-1 (-27 to 24)	0.91
	12	56	360 (136)	78	348 (126)	12 (-26 to 49)	0.54
Sedentary time	0	68	594 (80)	105	587 (90)		

(minutes/day)[d]							
	6	65	589 (69)	99	574 (78)	12 (-7 to 31)	0.21
	12	54	543 (82)	77	556 (78)	-14 (-41 to 12)	0.29
MVPA(minutes/day)[e]	0	71	50 (19)	108	50 (23)		
	6	68	44 (20)	102	46 (23)	-1 (-6 to 3)	0.57
	12	56	52 (27)	78	50 (23)	1 (-6 to 8)	0.86
MVPA (minutes/day)[d]	0	68	35 (18)	105	36 (21)		
	6	65	32 (18)	99	34 (20)	-1 (-6 to 3)	0.58
	12	54	37 (24)	77	38 (22)	0 (-6 to 6)	0.98
Self-efficacy for physical activity[f]	0	87	15.5 (4.3)	121	15.2 (4.6)		
	6	84	14.2 (4.9)	119	14.8 (4.5)	-0.8 (-1.9 to 0.3)	0.16
	12	72	14.8 (5.1)	98	15.3 (4.7)	-0.5 (-1.9 to 0.8)	0.45
Enjoyment of physical activity[g]	0	87	19.3 (5.7)	121	19.5 (6.2)		
	6	84	20.7 (6.3)	118	19.0 (5.9)	2.1 (0.6 to 3.6)	**0.01**
	12	72	20.6 (6.3)	98	18.4 (5.3)	2.5 (0.6 to 4.3)	**0.01**
HbA_{1c} (mmol/mol)	0	66	33.5 (3.1)	96	33.6 (2.6)		
	12	66	33.0 (3.0)	96	33.2 (2.7)	-0.2 (-0.6 to	0.48

						0.3)		
hs-CRP (mg/L)	0	66	2.4 (3.3)	96	2.6 (2.9)			
	12	66	2.5 (4.1)	96	2.4 (2.7)	0.6	(-0.1 to	0.11
						1.2)		
Total cholesterol (mmol/L)	0	66	5.5 (1.0)	96	5.4 (0.9)			
	12	66	5.2 (1.0)	96	5.3 (1.0)	-0.2	(-0.4 to	**0.03**
						0.0)		
LDL cholesterol (mmol/L)	0	66	3.6 (1.0)	96	3.4 (0.8)			
	12	66	3.4 (0.9)	96	3.4 (0.9)	-0.1	(-0.3 to	0.19
						0.1)		
Triglycerides (mmol/L)	0	66	1.4 (0.5)	96	1.3 (0.6)			
	12	66	1.2 (0.5)	96	1.3 (0.6)	-0.1	(-0.3 to	0.13
						0.0)		
HDL cholesterol (mmol/L)	0	66	1.3 (0.3)	96	1.3 (0.4)			
	12	66	1.3 (0.3)	96	1.4 (0.4)	0.0	(-0.1 to	0.11
						0.0)		
Ghrelin (pg/mL)	0	66	49.1 (20.4)	95	45.8 (13.8)			
	12	66	49.0 (19.3)	95	49.7 (16.7)	-0.5	(-6.3 to	0.87
						5.3)		

[a]HIIT participants advised to complete 3 sessions each week of high intensity intervals, resulting in RPE of 8 or greater, with overall exercise durations of 5-25 minutes per session.

[b]Participants choosing current recommendations advised to undertake at least 30 minutes per day of moderate intensity exercise on 5 or more days of the week.

[c]Difference (95% CI) between HIIT relative to current recommendations analysed by mixed effects regression analysis and adjusted for age, sex, intervention group and relevant baseline variable.

[d]Using 60 second epochs

[e]Using 15 second epochs

[f]From a possible score of 25

[g]From a possible score of 42

Table 3. Unsupervised HIIT heart rate recordings returned over 12 months[a]

Time point	Did not provide HIIT data n (%)	Did not achieve HIIT n (%)	Number of adequate[b] HIIT sessions achieved/week n (%)				
			1	2	3	4	5+
Baseline unsupervised	18 (17.6)	1 (1)	21 (20.6)	21 (20.6)	32 (30.8)	4 (3.9)	5 (4.9)
3 months	45 (44.1)	1 (1)	15 (14.7)	14 (13.7)	22 (21.6)	5 (4.9)	0
6 months	61 (59.8)	1 (1)	10 (9.8)	13 (12.7)	10 (9.8)	5 (4.9)	2 (2.0)
9 months	65 (63.7)	2 (2.0)	12 (11.8)	10 (9.8)	10 (9.8)	2 (2.0)	1 (1)
12 months	73 (71.6)	0	9 (8.8)	9 (8.8)	10 (9.8)	1 (1)	0

[a]Assessed out of 102 participants who received the initial HIIT intervention

[b]Adequate defined as attaining heart rates at or above 80% of estimated HR_{max} during HIIT session

Table 4. Effect of HIIT adherence over 12 months

Variable	Adherence[a]	Month 0		Month 12		Difference (95% CI)[b]	P
		n	Mean (SD)	n	Mean (SD)		
Weight (kg)	Non	47	95.2 (16.3)	33	93.1 (16.0)		
	Partial	17	95.0 (14.5)	16	90.6 (12.7)	-1.2 (-3.8 to 1.5)	0.38
	Full	24	99.1 (15.4)	24	93.6 (14.4)	**-2.7** (-5.2 to -0.2)	**0.04**
Waist circumference (cm)	Non	47	100.0 (13.4)	33	98.0 (13.0)		
	Partial	17	102.8 (11.7)	16	98.5 (8.2)	-1.0 (-3.9 to 1.9)	0.51
	Full	24	102.9 (13.7)	24	98.3 (13.5)	-2.4 (-4.7 to -0.2)	**0.04**
Body fat (%)	Non	28	36.7 (6.6)	28	34.9 (8.0)		
	Partial	16	41.8 (6.2)	16	40.7 (7.4)	0.5 (-1.8 to 2.7)	0.67
	Full	24	37.3 (7.5)	24	34.3 (8.2)	-1.3 (-3.2 to 0.6)	0.16
Visceral fat (cm^3)	Non	29	1506 (976)	29	1352 (998)		
	Partial	16	1393 (778)	16	1235 (590)	-22 (-244 to 200)	0.85
	Full	24	1790 (1263)	24	1305 (1001)	-292 (-483 to -101)	**0.01**
Systolic blood pressure	Non	47	124.3 (16.8)	33	121.8 (14.4)		

(mm Hg)	Partial	17	119.1 (12.0)	16	115.0 (13.9)	1.0 (-3.8 to 5.8)	0.68
	Full	24	125.3 (15.5)	24	120.1 (12.8)	-1.7 (-5.8 to 2.3)	0.40
Diastolic blood pressure	Non	47	78.7 (11.4)	33	77.1 (9.1)		
(mm Hg)	Partial	17	75.6 (8.4)	16	73.8 (7.2)	-1.2 (-5.1 to 2.8)	0.57
	Full	24	79.7 (8.3)	24	74.8 (11.1)	-2.0 (-5.5 to 1.5)	0.27
Estimated VO_{2peak}	Non	35	29.5 (6.7)	25	28.8 (5.0)		
(ml/kg/min)	Partial	17	28.0 (4.7)	15	26.5 (3.2)	-1.6 (-3.5 to 0.3)	0.10
	Full	24	29.2 (7.6)	23	30.5 (6.5)	1.3 (-0.3 to 2.9)	0.11
Counts per minute	Non	33	328 (82)	20	368 (138)		
	Partial	15	302 (64)	14	330 (101)	-40 (-75 to -5)	**0.03**
	Full	23	355 (119)	22	373 (156)	-26 (-63 to 10)	0.16
MVPA (minutes/day)[c]	Non	30	34 (18)	18	39 (24)		
	Partial	15	30 (11)	14	31 (17)	-9 (-15 to -3)	**0.01**
	Full	23	39 (21)	22	40 (28)	-5 (-11 to 1)	0.09
MVPA (minutes/day)[d]	Non	33	50 (18)	20	54 (28)		
	Partial	15	42 (13)	14	46 (21)	-7 (-14 to -0.1)	**0.05**

	Full	23	54 (22)	22	54 (29)	-6 (-13 to 1)	0.10
Sedentary time (minutes/day)[c]	Non	30	599 (71)	18	555 (83)		
	Partial	15	586 (99)	14	540 (78)	1 (-32 to 34)	0.97
	Full	23	594 (80)	22	536 (87)	-5 (-35 to 25)	0.74
Self-efficacy for physical activity[e]	Non	46	15.3 (4.3)	32	14.4 (5.1)		
	Partial	17	14.5 (4.7)	16	12.9 (4.5)	-0.3 (-2.5 to 1.9)	0.82
	Full	24	16.7 (3.7)	24	16.5 (5.2)	2.5 (0.7 to 4.3)	**0.01**
Enjoyment of physical activity[f]	Non	46	19.6 (6.3)	32	20.8 (6.8)		
	Partial	17	20.1 (4.2)	16	22.3 (6.4)	2.1 (-0.2 to 4.4)	0.07
	Full	24	18.3 (5.4)	24	19.3 (5.6)	-2.2 (-4.4 to 0.0)	**0.05**
HbA_{1c} (mmol/mol)	Non	27	32.3 (2.1)	27	32.4 (2.6)		
	Partial	16	33.7 (4.0)	16	32.9 (3.5)	-0.8 (-1.7 to 0.1)	0.08
	Full	23	34.8 (2.9)	23	33.9 (3.0)	-0.9 (-1.7 to 0.0)	**0.04**
hs-CRP (mg/L)	Non	27	1.7 (1.8)	27	1.7 (1.6)		

	Partial	16	4.3 (5.7)	16	4.6 (7.7)	0.1 (-1.2 to 1.3)	0.91
	Full	23	1.7 (1.5)	23	2.1 (1.7)	0.3 (-0.7 to 1.4)	0.51
Total cholesterol (mmol/L)	Non	27	5.7 (1.1)	27	5.2 (1.0)		
	Partial	16	5.4 (0.8)	16	5.2 (0.7)	0.2 (-0.2 to 0.6)	0.29
	Full	23	5.4 (1.0)	23	5.3 (1.1)	0.3 (0.0 to 0.7)	0.08
LDL cholesterol (mmol/L)	Non	27	3.7 (1.0)	27	3.4 (1.0)		
	Partial	16	3.5 (0.8)	16	3.4 (0.7)	0.2 (-0.1 to 0.5)	0.24
	Full	23	3.5 (1.0)	23	3.4 (1.0)	0.2 (-0.1 to 0.5)	0.27
Triglycerides (mmol/L)	Non	27	1.5 (0.6)	27	1.3 (0.5)		
	Partial	16	1.4 (0.5)	16	1.2 (0.4)	-0.1 (-0.3 to 0.2)	0.70
	Full	23	1.3 (0.5)	23	1.2 (0.5)	0.0 (0.2 to 0.3)	0.94
HDL cholesterol (mmol/L)	Non	27	1.3 (0.3)	27	1.3 (0.4)		
	Partial	16	1.2 (0.4)	16	1.2 (0.4)	0.0 (-0.1 to 0.2)	0.38
	Full	23	1.3 (0.3)	23	1.3 (0.3)	0.1 (0.0 to 0.2)	**0.05**
Acylated ghrelin (pg/mL)	Non	27	49.5 (18.7)	27	51.4 (19.7)		
	Partial	16	47.0 (25.2)	16	43.4 (11.0)	-9.2 (-21.9 to 3.4)	0.15

	Full	23	50.2 (19.6)	23	49.9 (23.0)	-1.2 (-12.3 to 9.9)	0.83

[a]Adherence categories defined as full adherence (at least 2 adequate HIIT sessions were recorded at 3+/5 of the 3-monthly reviews), partial adherence (at least 1 adequate HIIT session recorded at 3/5 of the 3-monthly reviews), or non-adherence (less than these amounts)

[b]Difference (95% CI) between adherence groups (partial or full relative to non-adherent) analysed by mixed effects regression analysis and adjusted for age, sex, and intervention group using both 6 and 12 month data

[c]Using 60 second epochs

[d]Using 15 second epochs

[e]From a possible score of 25

[f]From a possible score of 42

Supplementary Methods: Details on HIIT recommended HIIT protocols

Modalities of exercise recommended including home-based exercises, sprinting, hill-walking, cycling, and exercise machines. Subjects were instructed that HIIT activities should be "exercise that uses most of your body and is very hard to do within seconds" and could choose from a variety of evidence-based protocols (4, 8, 26-29). For unfit and inexperienced participants, we recommended 10-20 second HIIT intervals performed at an RPE of 8-9, with 3-5 repetitions. Once adapted, subjects were encouraged to progress to more difficult options such as a standard 'Wingate' type HIIT protocol of 3 repetitions of 30 second maximal intervals, 5-10 one-minute intervals at a RPE of 8, or a single 4-minute interval at the highest intensity that could be maintained. The duration of rest periods were not mandated but it was recommended that between intervals of 1-3 minutes of light activity was appropriate and that participants should feel sufficiently recovered to attempt the next interval at the required intensity. Participants were instructed to perform 3 HIIT sessions per week and in order to be consistent with the 'real-world' nature of the trial, subjects could attend commercial HIIT classes or engage in sprint-based sports. Essentially, any exercise activity that was interval-based and led participants to experience a RPE of 8 or greater could be included. In order to capture a realistic measure of exercise habits, HIIT participants were not explicitly restricted from other forms of exercise, however it was emphasised that HIIT training alone was considered sufficient. Participants were advised to increase the number or intensity of intervals performed over the 12 month period.

Supplemental Digital Content 2. Duration of exercise above threshold recorded during HIIT sessions by participants providing recordings[a]

Timepoint	n	Time spent above threshold during HIIT			
		Time above 80% HR_{max}/session (min)	Time above 90% HR_{max}/session (min)	Total time above 80% HR_{max} /week (min)	Total time above 90% HR_{max} /week (min)
Baseline unsupervised	83	8.5 (9.9)	3.4 (6.4)	22.7 (31.3)	9.2 (19.0)
3 months	56	10.9 (11.1)	4.3 (6.3)	24.7 (27.9)	9.6 (14.3)
6 months	40	10.8 (11.6)	4.0 (6.9)	24.7 (25.0)	9.2 (15.9)
9 months	35	13.3 (25.5)	5.7 (19.7)	23.8 (33.0)	8.8 (23.8)
12 months	29	10.6 (10.9)	4.6 (7.5)	21.3 (25.4)	9.5 (18.4)

[a]Average times (standard deviations), calculated excluding exercise sessions that did not attain required intensity for HIIT

Supplemental Digital Content 3. Baseline characteristics of adherent, partially adherent and non-adherent HIIT participants

Variable	[a]Adherent	[b]Partially adherent	[c]Non-adherent	P[g]
n	24 (23%)	17 (16%)	63 (61%)	
Female Sex n (%)	8 (33%)	11 (65%)	40 (64%)	**0.03**
Age (years)	46.4 (10.9)	42.1 (7.6)	42.8 (10.5)	0.27
BMI (kg/m^2)	32.9 (4.5)	34.0 (4.9)	32.5 (3.9)	0.44
Estimated VO_2peak (ml/kg/min)	29.3 (7.6)	28.0 (4.7)	28.6 (5.9)	0.10
Body fat DXA (%)[d]	37.3 (7.5)	42.3 (6.4)	39.1 (7.2)	**0.03**
Visceral fat (cm^3)[d]	1790 (1263)	1419 (761)	1403 (953)	0.94
MVPA (minutes/day)[e]	39.3 (21.4)	30.0 (11.1)	34.0 (19.3)	0.30

Data expressed as n (%) or mean (SD) as appropriate.

Adherence categories defined as [a]at least 2 adequate HIIT sessions were recorded at 3+/5 of the 3-monthly reviews, [b]at least 1 adequate HIIT session recorded at 3/5 of the 3-monthly reviews, [c]less than these amounts, includes 2 participants who did not receive intervention at baseline

[d]Adjusted for age and sex

[e]Using 60 second epochs, data missing for 1, 2, and 6 participants respectively