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Effects of high intensity interval training on sustained reduction in cardiometabolic risk associated with overweight/obesity. A randomized trial

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ABSTRACT

Background: Considering the potential greater cardiocirculatory effects of high intensity interval training (HIIT), we hypothesized that a 2-month supervised high volume short interval HIIT would induce greater improvements in CRF and cardiometabolic risk and increase long-term maintenance to physical activity compared to isocaloric moderate intensity continuous training (MICT) in overweight/obesity.
Methods: Sixty (19 females) subjects with overweight/obesity were randomized to three training programs (3 times/week for 2 months): MICT (45 min, 50% peak power output-PPO), HIIT (22 × 1-min cycling at 100% PPO/1-min passive recovery) and HIIT-RM (RM: recovery modulation, i.e. subjects adjusted passive recovery duration between 30s and 2 min). After the intervention, participants no longer benefited from supervised physical activity and were instructed to maintain the same exercise modalities on their own. We assessed anthropometrics, body composition, CRF, fat oxidation, lipid profile, glycemic balance, low-grade inflammation, vascular function, spontaneous physical activity and motivation for eating at three time points: baseline (T0), 4 days after the end of the 2-month supervised training program (T2) and 4 months after the end of the training program (T6).
Results: HIIT/HIIT-RM induced greater improvement in VO_{2peak} (between +14% and +17%), power output at ventilatory thresholds and at maximal fat oxidation rate (+25%) and waist circumference (−1.53 cm) compared to MICT and tended to decrease insulin resistance. During the four-month follow-up period during which exercise in autonomy was prescribed, HIIT induced a greater preservation of CRF, decreases in total and abdominal fat masses and total cholesterol/HDL.
Conclusion: We have shown greater short-term benefits induced by a high volume short interval (1 min) HIIT on cardiorespiratory fitness and cardiometabolic risk over an isocaloric moderate intensity continuous exercise in persons with overweight/obesity. We also showed greater long-term effects (i.e. after 4 months) of this exercise modality on the maintenance of CRF, decreases in total and abdominal fat masses and total cholesterol/HDL.

1. Introduction

Obesity is a major health burden because of associated comorbidities, such as increased risk of insulin resistance, diabetes, cardiovascular diseases, cancers and possibly higher mortality rate.[1]

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Management of obesity relies on nutritional intervention or bariatric surgery and regular physical activity. The latter contributes to improving body composition and global health.[2] Cardiorespiratory endurance training is recommended since it can increase fat oxidation,[3] preserve fat-free mass[4] and decrease insulin-resistance associated with tissue fat infiltration.[3] Increasing cardiorespiratory fitness (CRF) is relevant in populations with cardiometabolic morbidity since every 1-MET increase in CRF decreases the cardiovascular risk by 15%.[5] Peak oxygen consumption (VO_{2peak}) is frequently reduced in individuals with obesity[6] and this has been related, at least in part, to cardiocirculatory alteration[7–10] and particularly cardiac systolic dysfunction.[11,12] Hence, exercise programs specifically targeting cardiocirculatory improvements would be relevant for this population.

Long-duration moderate intensity exercise training (MICT at 40–50% of peak power output, 45-min-1 hour) decreases body fat, optimizes fat oxidation, improves insulin resistance[5,6] and is advocated because it is well tolerated by deconditioned individuals with obesity and cardiometabolic disorders.[13] During the last decade, high intensity interval training (HIIT) has been proposed as an alternative to MICT for rehabilitation purposes.[14,15] HIIT may be more time-efficient than traditional recommended cardiorespiratory endurance training for health (i.e. MICT), particularly on risk factors associated with obesity[16,17] and cardiocirculatory function.[18,19]

The superior efficiency of HIIT compared with MICT is not consistently observed[20,21] and depends upon the characteristics of the HIIT and MICT protocols being compared: i.e. isocaloric or not, frequency, program duration, number of repetitions, interval exercise duration, duration of the recovery phase, modalities of recovery (i.e. passive or active). The greater benefits of high volume HIIT over MICT on vascular adaptations (flow-mediated dilation) are well documented in overweight/obesity since the landmark study of Tjonna et al., 2008.[22] However, except one study[19] showing a greater efficiency over MICT, low volume HIIT (10 × 1 min, 90–95% maximum heart rate, 1-min active recovery) provides at best similar cardiovascular benefits compared to high volume MICT.[16,18] From a weight management point of view, it is admitted that an adequate volume of energy expenditure during exercise is required for clinically meaningful weight management benefits. Several studies have shown significant effects of low-volume HIIT on reductions in fat mass.[23,24] However, these studies failed to show a greater effect of low-volume HIIT when compared with MICT.[24,25] Hence there is a need to find more efficient and well tolerated exercise protocols in the long term for persons with obesity who are generally reluctant to exercise.[26]

Long term adherence to exercise is the major challenge for weight management[2] and cardiometabolic risk prevention.[27] The greater effect of HIIT on CRF compared to an isocaloric MICT is thought to be systematic when interval duration is greater than 2 min.[20] However, the total duration of this interval exercise time can be too demanding for patients. It has been argued that the efficacy of HIIT should be determined not only in terms of the physiological health benefits but also the likelihood that individuals will adhere to HIIT protocols, in particular when they perform them alone or unsupervised.[28,29] Hence, a less demanding but still efficient strategy regarding cardiometabolic risk is required. For this purpose, we proposed to increase the volume of the 1-min work intervals at 100% VO_{2peak} followed by 1-min passive recovery efficient HIIT strategy previously used in diabetes[19,30] in order to optimize cardiometabolic health and test the feasibility and adherence in individuals with overweight/obesity.

The aim of the present single-blind randomized study was to compare the effects of two 8-week isocaloric supervised exercise training programs (22 × 1 min HIIT vs MICT) in subjects with overweight/obesity on CRF (primary outcome) and cardiometabolic risk (secondary outcome: total and visceral fat, lipid profile, glycemic balance, vascular function and stiffness). We also aimed to measure exercise adherence at six months (i.e. four months after the end of the supervised program). We hypothesized that due to its greater cardiocirculatory effect, HIIT would induce i) a greater improvement in cardiorespiratory fitness (VO_{2peak}) and a reduction in cardiometabolic risk (improvements in lipid profile, insulin resistance and vascular function) immediately after a 2-month program and ii) a better maintenance of these changes 4 months after this program due to better long-term adherence to exercise compared to MICT in subjects with overweight/obesity.

2. Methods

2.1. Subjects

Sixty (19 females), non-active (less than 2 h of low-intensity physical activity per week) subjects with overweight/obesity (age: 54 ± 11 yr, body mass index (BMI): 31.5 ± 2.8 kg m^{-2}) recruited through local advertisements were included in the present study after medical assessment (clinical interview, ECG, respiratory function test). The main inclusion criteria were: age between 18 and 65 yrs, BMI >27 kg m^{-2}, no diabetes treated by insulin, no heart and respiratory diseases (except sleep apnea treated by continuous positive airway pressure).[31] Written informed consent was obtained from all subjects. The study was approved by the local ethics committee and performed according to the Declaration of Helsinki. The presence of metabolic syndrome was assessed as follows: central obesity (defined as waist circumference in men ≥94 cm or women ≥80 cm) plus any two of the following four factors: raised triglycerides (≥150 mg/dL (1·7 mmol/L) or specific treatment for this lipid abnormality); reduced HDL-cholesterol (<40 mg/dL (1·03 mmol/L) in men; < 50 mg/dL (1·29 mmol/L) in women or specific treatment for this lipid abnormality); raised blood pressure (Systolic ≥130 mm Hg or Diastolic ≥85 mm Hg or Treatment of previously diagnosed hypertension); raised fasting plasma glucose (fasting plasma glucose ≥100 mg/dL (5.6 mmol/L) or previously diagnosed type 2 diabetes).[32]

2.2. Experimental design

In this prospective, randomized single-blind study (Consort Flow Diagram, Fig. 1), all subjects were randomized into 3 groups: moderate intensity continuous cycling exercise (MICT; n = 20), high intensity intermittent cycling exercise (HIIT; n = 20), high intensity intermittent cycling exercise with modulation of recovery duration interval (HIIT-RM; n = 20). The latter intervention aimed at improving HIIT tolerance since our HIIT program required twice as many work intervals as proposed previously.[30]

The training groups performed three 45-min sessions per week for 8 weeks in hospital setting. After this supervised program, subjects were asked to continue the same program modality in autonomy for 4 months. Before (T0) and 4 days after the 8-week supervised period (T2), cardiorespiratory and metabolic tests were conducted. Spontaneous physical activity and motivation for eating were also assessed at T0 and T2. All these evaluations were repeated 4 months (T6) after the training period. Participants were asked to maintain their habitual activity and their eating habits during the study. All measured data were obtained and analyzed by an assessor blinded to group allocation.

2.3. Exercise training

All training sessions were supervised and performed in hospital setting on an electrically-braked cycle ergometer (Corival, Lode

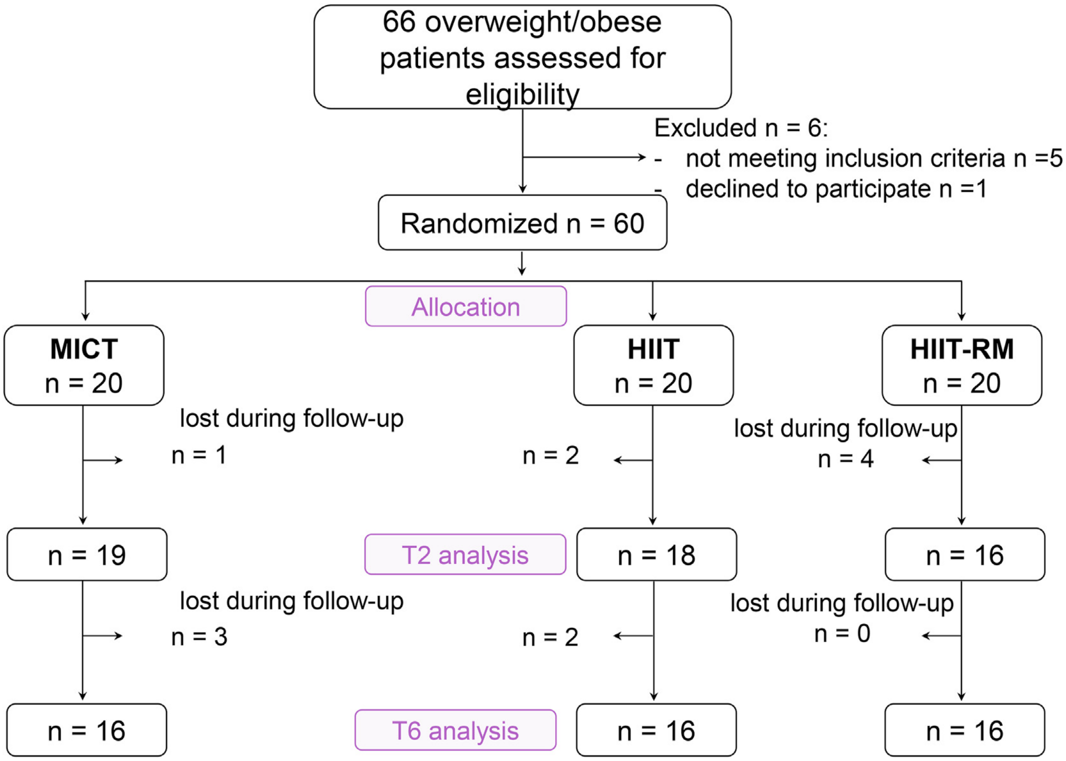

Fig. 1. Flow chart of the study design.

B.V., Groningen, Netherlands) with heart rate continuously recorded (T34, Polar Electro Oy, Kempele, Finland) and the rate of perceived exertion (RPE) assessed every 6 min for MICT and every 3 bouts for HIIT programs using a 15-point scale ranging from 6 ("no exertion at all") to 20 ("maximal exertion").[33] Participants were encouraged when needed.

In MICT, cycling workload was adjusted to 50% of peak power output (PPO) i.e. close to the intensity eliciting maximal fat oxidation rate.[34] HIIT, performed 45 min of intermittent exercise consisting of 22 bouts of 1-min cycling at 100% PPO interspaced by 1-min passive recovery. HIIT-RM performed the same program as HIIT except participants could control the duration of passive recovery (ranging from 30 s to 2 min). Participants in the HIIT-RM group were informed that they could decide the length of the recovery bout. This was aimed at satisfying their feeling of autonomy with regards to the exercise they were performing.

The duration of each exercise training session was progressively increased from 32 min at 50% PPO/16 min at 100% PPO the first week to 44 min at 50% PPO/22 min at 100% PPO the last week for MICT and HIIT respectively.

At the end of the two-month exercise training program, participants were instructed to maintain their physical activity levels were instructed to maintain the same exercise modalities achieved during the supervised program on their own. Participants were able to exercise at similar intensities based on heart rate and rates of perceived exertion achieved during the supervised exercise sessions.

2.4. Measurements

2.4.1. Maximal exercise test

Maximal progressive exercise test to exhaustion was achieved on an electrically-braked cycle ergometer (Corival, Lode B.V.). After 2 min of rest, followed by 2-min warm-up at 50 W for male and 30 W for female, power output was increased by 20 W for male and 15 W for female every 2 min until exhaustion (pedaling frequency: 70–80 rpm). Heart rate (12-channel ECG, Custo cardio 110 BT, Custo med GmbH, Ottobrunn, Allemagne) and gas exchange (MetaMax 3B, Cortex Biophysik GmbH, Leipzig, Germany) were monitored continuously. VO_{2peak} was defined as the highest oxygen intake sustained for at least 30 s during the test. Leg fatigue and dyspnea (assessed with a standard 100-mm visual analog scale) were recorded every 2 min until the end of exercise. Capillary blood sample was taken after 2 min of recovery from the fingertip to determine blood lactate concentration (Lactate Plus®, Nova Biomedical Corporation, Waltham, MA, USA). Ventilatory thresholds (VT1 and VT2) were determined according to the criteria of Wasserman et al.[35]

2.4.2. Submaximal metabolic exercise test

A submaximal ergocycle exercise test (Corival, Lode B.V.) performed in the morning after an overnight fast, allowed specific metabolic variables determination.[36] This test consisted in a 3-min warm-up at 20% followed by four 6-min steady-state workloads at 30, 40, 50 and 60% of the PPO previously determined.[37] Gas exchange was monitored continuously throughout the test. The maximal fat oxidation rate (MFO in $mg \cdot min^{-1}$) and the power output at this point (Lipoxmax) were assessed.[37]

2.4.3. Body composition

After measurement of height, weight, waist circumference (midway between the lowest rib margin and the iliac crest), hip circumference (widest level over the greater trochanters) whole body magnetic resonance imagery (MRI) allowing for total fat and lean mass determinations was performed on a Sigma Advantage 1.5-T scanner (General Electric Medical Systems, Milwaukee, WI, USA) using a validated protocol previously used in our laboratory.[38] In addition, we assessed the surface (in cm^{-2}) of total abdominal, visceral, and subcutaneous fat at the level of L4-L5 intervertebral space. The images were analyzed manually with a homemade software (Matlab R2006, The Math Works, Inc., Natick, MA, USA) allowing adipose tissue identification (25). We assessed liver fat with the two-point Dixon method based on phase-shift imaging in which hepatic fat fraction was calculated from the signal difference between the vectors resulting from in-phase (IP) and out-of-phase (OP) signals.[39] During this multi-breath-hold T1-weighted dual gradient echo sequence corrected for T2*, pixel signal intensities from IP and OP images were obtained from selected regions of interest of 4 cm^2 in the left lobe liver and the spleen (control).

2.5. Vascular markers and biological analyses

Arterial stiffness was assessed by carotid-femoral pulse-wave velocity (Complior, Artech Medical; Pantin, France).[40] Endothelial function was assessed by reactive hyperemia using finger plethysmography (Endo-PAT, Itamar Medical Ltd, Caesarea, Israel).[41]

After an overnight fast, blood samples were drawn for immediate plasma analysis of glucose, triglycerides, total and high-density lipoprotein cholesterol (HDL-C), high-sensitive C-reactive protein (hsCRP) (automated Boehringer Mannheim/Hitachi 917 analyser, Roche diagnostic kit, Meylan, France). The low-density lipoprotein cholesterol (LDL-C) was calculated according to the Friedewald's formula. Fasting plasma–insulin concentration was determined with a human insulin-specific double antibody radioimmunoassay (RIA; Linco Research, St Charles, Missouri, USA). The insulin resistance was calculated according to the homeostasis model assessment of insulin resistance (HOMA2-IR), based on fasting blood glucose and insulin concentrations (http://www.dtu.ox.ac.uk/).

2.5.1. Spontaneous physical activity

As already reported,[42] mean daily time spent in sedentary time, physical activity, steps per day and daily energy expenditure were analyzed by a triaxial accelerometer worn on the upper arm for 7 days, which also estimated energy expenditure through galvanic skin response and heat flux (SenseWear, BodyMedia Inc., PA, USA) at baseline (T0) and one week after the end of the 2-month supervised training program (T2) and 4 months after the intervention period during which participants exercised on their own (T6). Accelerometers were worn for 24 h/day except during water-based activities such as showering. Accelerometer data were averaged over 24 h. Due to technical issues, accelerometry data were available in only 15 subjects for MICT, 9 for HIIT and 5 for HIIT-RM.

2.5.2. Motivation for eating

Motivation was assessed using the Dutch Eating Behavior Questionnaire.[43] Participants completed this questionnaire satiated and before an exercise session. The Dutch Eating Behavior Questionnaire (DEBQ) is an internationally recognized gold standard instrument for simultaneously assessing the three cognitive, emotional and behavioral dimensions of eating behavior. It is a 33-item self-administered questionnaire and ratings are made on a 5-point Likert scale.

2.6. Statistical analysis

A power analysis with G Power Version 3.1 allowed calculation of the sample size needed for this study. With a power of 0.8 at $\alpha = 0.05$ and a greater effect for HIIT (+20%) compared to MICT (+10%) on the primary outcome VO_{2peak},[22] the sample size for each group was estimated to be 20. Normality of distribution and homogeneity of variances of all the variables were assessed using a Shapiro-Wilk normality test and the Levene's test. Between-group comparisons at T0 and of changes between T0-T2, T0-T6 and T2-T6 were performed for all variables using Kruskal–Wallis test (normality and homogeneity of variances not confirmed). In case of significance, post-hoc Mann and Whitney was applied with a Bonferroni correction for alpha slippage to locate the difference between groups. Within each group, the comparison of variables between each time point (T0, T2, T6) was assessed with a Friedman test. In case of significance, post-hoc Wilcoxon test was applied with a Bonferroni correction for alpha slippage to locate the difference between time points. Hence, for all statistical analyses, a two-tailed alpha level of 0.016 was used as the cut-off for significance. Effect sizes (Cohen's d) were calculated using the online software available at: http://www.danielsoper.com/statcalc3/. All data are presented as mean ± SD. All statistical procedures were performed on Statistica version 10 (Statsoft, Tulsa, OK).

3. Results

3.1. Baseline characteristics and program achievement

At baseline, medications, metabolic syndrome[44] frequency, body composition, cardiorespiratory fitness, biological variables, vascular function, spontaneous physical activity and sleep variables were not significantly different between groups (Tables 1–5). Motivation for eating did not differ between the 3 groups at baseline (MICT, T0: 2.81 ± 1.00; HIIT, T0: 2.50 ± 0.77; HIIT-RM, T0: 2.65 ± 0.92).

Seven patients did not complete the training program for personal reasons: 1, 2 and 4 in MICT, HIIT and HIIT-RM groups, respectively. Five participants refused the follow-up at T6: 3 in the MICT group, 2 in the HIIT group (Fig. 1). The patients who completed the training period performed 98 ± 2% of the scheduled training sessions.

Average energy expenditure for a single training session was similar between groups (HIIT: 220.3 ± 58.8 kcal, HIIT-RM: 209.4 ± 28.8 kcal, MICT: 228.7 ± 28.1 kcal; $p > 0.05$).

Exercise sessions during MICT induced lower ($p < 0.001$) average heart rate (75 ± 2% of individual maximal heart rate) and mean RPE (11 ± 1) compared to HIIT and HIIT-RM (85 ± 2% and 85 ± 3% of individual maximal heart rate, mean RPE of 13 ± 2 and 12 ± 2, respectively).

Four months after the end of the training program, the data from 16 participants per group (MICT, HIIT and HIIT-RM) could be analyzed (Fig. 1).

Table 1
Patient characteristics of the three groups.

	MICT	HIIT	HIIT-RM
	n = 20	n = 20	n = 20
Gender, M/F	17/3	16/4	14/6
Age, years	51 ± 11	52 ± 8	54 ± 9
Body mass Index, $kg \cdot m^{-2}$	31.8 ± 3.2	31.3 ± 3.1	31.2 ± 2.9
Metabolic syndrome, %	68.2	77.8	66.7
Medications, n			
Angiotensin II blockers	3	5	3
Conversion enzyme blocker	2	–	–
β-blockers	2	1	1
Calcium antagonists	1	1	–
Diuretic	2	2	1
Statins	2	2	2
Lipid lowering	1	–	–
Platelet anti-aggregating agent	5	1	1
Metformin	2	3	1
Anti-depressant	4	–	–
CPAP	15	14	10

Data are presented as mean ± SD or number of patients (n) when appropriate. CPAP: Continuous positive airway pressure.

Table 2
Anthropometrics' data, body composition and liver fat throughout the protocol in the four groups of subjects.

—	Weight	WC	HC	Fat mass	LM	Leg muscular mass	Abdominal FM	Visceral Fat surface	Liver fat mass
	kg	cm	cm	kg	kg	kg	kg	cm^2	%
MICT									
T0	104.2 ± 25.2	114.5 ± 14.2	113.7 ± 18.2	39.3 ± 17.3	64.9 ± 15.0	15.9 ± 3.8	12.2 ± 4.4	178.4 ± 67.7	15.6 ± 11.0
T2	104.1 ± 25.0	113.8 ± 14.4	112.2 ± 18.0*	39.3 ± 17.1	64.8 ± 14.9	16.2 ± 3.8	10.8 ± 4.3	182.4 ± 71.2	14.8 ± 10.2
T6	103.4 ± 24.9	112.8 ± 14.7	112.1 ± 17.7	37.6 ± 13.5	65.8 ± 15.5	15.9 ± 9.4	11.4 ± 5.6	184.9 ± 73.8	15.0 ± 10.3
HIIT									
T0	99.4 ± 16.1	113.7 ± 10.5	108.5 ± 9.7	34.9 ± 11.9	64.5 ± 8.7	15.7 ± 2.4	13.4 ± 4.8	196.8 ± 69.3	18.6 ± 9.1
T2	98.7 ± 15.0	112.1 ± 9.1*	107.8 ± 8.5	33.4 ± 11.5	65.3 ± 8.8	15.9 ± 2.4	13.3 ± 4.4	177.4 ± 49.6	17.0 ± 8.3
T6	98.4 ± 15.5	112.1 ± 9.3	107.2 ± 8.3	33.0 ± 11.1#	65.4 ± 8.9	16.1 ± 2.8	12.5 ± 4.2#	184.1 ± 62.3	17.8 ± 8.2
HIIT − RM									
T0	94.7 ± 17.3	108.5 ± 10.2	108.5 ± 10.8	34.9 ± 9.9	59.8 ± 11.2	14.6 ± 3.3	12.4 ± 5.3	158.0 ± 76.5	12.4 ± 9.7
T2	95.0 ± 17.0	107.3 ± 10.0	107.4 ± 10.4*	34.7 ± 10.1	60.3 ± 11.0	14.9 ± 3.4	12.8 ± 5.6	154.3 ± 57.7	11.9 ± 8.2
T6	94.6 ± 17.5	106.7 ± 9.3	107.4 ± 11.5	34.4 ± 11.4	60.2 ± 11.3	14.5 ± 3.0	12.4 ± 5.4	151.9 ± 59.2	12.0 ± 8.9

Data are presented as mean ± SD. Abbreviations: FM, fat mass; HIIT, high intensity intermittent exercise; HIIT-RM, high intensity intermittent exercise with possibility to modulation the duration of recovery; HC, hip circumference; LM, lean mass; MD, missing data; MICT, moderate intensity continuous exercise; WC, waist circumference. *: $p < 0.016$ between T2 and T0, #: $p < 0.016$ between T6 and T0.

Table 3
Cardiorespiratory fitness throughout the study in the four groups of subjects.

—	PPO	VO_{2peak}	VO_{2peak}	VO_{2peak}	Heart Rate	RER_{peak}	La	PO VT1	PO VT2	P Lipox max	MFO
	watts	$L.min^{-1}$	$mL.kg^{-1}.min^{-1}$	% predicted	bpm		$mmol.L^{-1}$	watts	watts	watts	$mg.min^{-1}$
MICT											
T0	179 ± 79	2.48 ± 0.88	23.2 ± 6.1	118.0 ± 26.6	159 ± 14	1.05 ± 0.06	8.3 ± 1.8	115 ± 48	146 ± 71	77 ± 51	233.7 ± 135.9
T2	191 ± 79*	2.61 ± 0.88	24.4 ± 5.8*	125.6 ± 27.1*	154 ± 19	1.05 ± 0.05	7.7 ± 1.8	123 ± 46	159 ± 70*	87 ± 43	264.3 ± 149.2
T6	186 ± 75	2.50 ± 0.85	24.0 ± 6.0	122.8 ± 16.1	154 ± 21	1.05 ± 0.05	8.2 ± 1.9	121 ± 48	154 ± 72	87 ± 57	228.6 ± 128.5
HIIT											
T0	176 ± 39	2.56 ± 0.58	23.8 ± 5.6	117.9 ± 25.3	165 ± 11	1.04 ± 0.07	8.9 ± 2.2	109 ± 28	139 ± 27	73 ± 19	219.4 ± 88.6
T2	199 ± 42*	2.78 ± 0.56*	26.5 ± 5.5*	131.5 ± 24.6*	162 ± 13	1.05 ± 0.05	9.0 ± 1.2	128 ± 31*	161 ± 34*	91 ± 27	241.9 ± 81.3
T6	185 ± 33	2.61 ± 0.49$	24.9 ± 5.1	124.0 ± 23.4#	160 ± 13	1.05 ± 0.05	8.8 ± 2.4	126 ± 26#	156 ± 29#	80 ± 23	206.3 ± 63.1
HIIT-RM											
T0	163 ± 25	2.47 ± 0.46	23.3 ± 3.1	120.0 ± 15.8	163 ± 13	1.06 ± 0.07	8.8 ± 1.8	114 ± 20	133 ± 23	73 ± 24	217.7 ± 71.5
T2	191 ± 39*	2.71 ± 0.51*	26.4 ± 4.0*	137.3 ± 19.5*	166 ± 14	1.05 ± 0.06	8.8 ± 1.8	124 ± 25	150 ± 36*	76 ± 24	211.3 ± 66.8
T6	175 ± 38	2.59 ± 0.50	24.9 ± 5.4	129.3 ± 24.0#	160 ± 15	1.05 ± 0.07	8.4 ± 1.5	117 ± 24	145 ± 34#	73 ± 18	205.6 ± 87.8

Data are presented as mean ± SD. Abbreviations: HIIT, high intensity intermittent exercise; HIIT-RM, high intensity intermittent exercise with possibility to modulation the duration of recovery; La, blood lactate concentration; MD, missing data; MICT, moderate intensity continuous exercise; MFO, maximal fat oxidation; P Lipoxmax, power at Lipoxmax; PPO, peak power output; PO VT1, power output at ventilatory threshold 1; PO VT, power output at ventilatory threshold 2; RER, respiratory exchange ratio; $VO_{2\ peak}$, peak oxygen consumption. *: $p < 0.016$ between T2 and T0, $: $p < 0.016$ between T6 and T2, #: $p < 0.016$ between T6 and T0.

Table 4
Biological variables and vascular function.

—	TC	Triglycerides	HDL	LDL	TC/HDL	hs-CRP	Glycemia	Insulin	HOMA2-IR	HOMA2-%S	HOMA2-%B	PAT	PWV
	$g.L^{-1}$	$g.L^{-1}$	$g.L^{-1}$	$g.L^{-1}$	$g.L^{-1}$	$mg.L^{-1}$	$mmol.L^{-1}$	$\mu UI.\ mL^{-1}$		%	%		$m.s^{-1}$
MICT													
T0	1.89 ± 0.38	1.58 ± 1.06	0.46 ± 0.12	1.17 ± 0.37	4.46 ± 1.75	5.05 ± 7.44	5.67 ± 1.03	12.5 ± 5.6	1.7 ± 0.8	73.3 ± 35.8	104.7 ± 29.5	2.1 ± 0.5	7.7 ± 1.1
T2	1.81 ± 0.33	1.48 ± 0.98	0.46 ± 0.13	1.12 ± 0.40	4.24 ± 1.42	3.57 ± 4.76	5.72 ± 0.85	12.8 ± 7.7	1.7 ± 1.0	75.5 ± 46.3	110.0 ± 45.2	2.0 ± 0.5	7.4 ± 0.9
T6	1.86 ± 0.37	1.52 ± 0.88	0.46 ± 0.11	1.15 ± 0.36	4.29 ± 1.31	2.70 ± 2.68	5.56 ± 0.95	10.7 ± 5.2#	1.4 ± 0.7#	91.5 ± 51.8#	95.1 ± 25.8	1.9 ± 0.4	7.3 ± 0.9
HIIT													
T0	2.04 ± 0.40	1.46 ± 0.61	0.49 ± 0.10	1.23 ± 0.37	4.22 ± 1.03	2.12 ± 1.99	5.92 ± 0.92	11.5 ± 5.3	1.5 ± 0.7	79.7 ± 37.7	91.1 ± 33.8	2.1 ± 0.6	8.8 ± 1.7
T2	2.02 ± 0.33	1.50 ± 0.61	0.47 ± 0.10	1.22 ± 0.28	4.40 ± 0.99	1.94 ± 1.83	6.46 ± 1.56	10.7 ± 4.1	1.5 ± 0.6	79.9 ± 36.7	78.2 ± 32.8	2.0 ± 0.3	8.0 ± 1.3
T6	2.00 ± 0.28	1.24 ± 0.56	0.51 ± 0.12	1.23 ± 0.23	4.09 ± 0.95	1.85 ± 1.82	5.93 ± 0.82	14.1 ± 9.9	1.9 ± 1.3	80.0 ± 46.0	98.8 ± 44.3	1.9 ± 0.5	8.4 ± 0.9
HIIT-RM													
T0	1.94 ± 0.46	1.36 ± 0.57	0.53 ± 0.12	1.17 ± 0.42	3.83 ± 0.84	2.62 ± 2.99	5.44 ± 0.57	11.2 ± 6.2	1.6 ± 0.7	82.6 ± 45.1	106.4 ± 41.1	2.1 ± 0.6	7.8 ± 1.0
T2	1.96 ± 0.47	1.52 ± 1.06	0.53 ± 0.12	1.18 ± 0.42	3.86 ± 1.02	2.27 ± 1.50	5.43 ± 0.70	9.1 ± 4.3	1.3 ± 0.5	100.1 ± 58.2	94.5 ± 42.0	2.2 ± 0.6	7.7 ± 1.0
T6	2.02 ± 0.55	1.25 ± 0.52	0.52 ± 0.11	1.27 ± 0.47	3.97 ± 0.98	1.90 ± 1.37	5.56 ± 0.60	10.2 ± 6.0	1.4 ± 0.8	112.6 ± 114.6	92.9 ± 40.6	2.2 ± 0.6	8.0 ± 1.6

Data are presented as mean ± SD. Abbreviations: HDL, high density lipoprotein; HIIT, high intensity intermittent exercise; HIIT-RM, high intensity intermittent exercise with possibility to modulation the duration of recovery; HOMA, homeostasis model assessment of insulin resistance; hs-CRP, high-sensitive C-reactive protein; LDL, low density lipoprotein; MD, missing data; MICT, moderate intensity continuous exercise; PAT, peripheral arterial tone; PWV, pulse wave velocity; TC, total cholesterol; TC/HDL, ratio between total cholesterol and high density lipoprotein; #: $p < 0.016$ between T6 and T0.

3.2. Metabolic syndrome

Compared to T0, the metabolic syndrome prevalence rate did not change at T2 (MICT: 77.2%, HIIT: 94.4%, HIIT-RM: 75.0%) and T6 (MICT: 68.4%, HIIT: 60.1%, HIIT-RM: 63.1%).

3.3. Body composition (Table 2)

From T0 to T2, waist circumference significantly decreased in HIIT group ($p = 0.007$, ES: 0.16) and tended to decrease in HIIT-RM ($p = 0.025$, ES: 0.12). Hip circumference significantly decreased in

Table 5
Spontaneous physical Activity and sleep variables.

	Steps/d	EE	EE	ST	LPA	M-VVPA	Sleep duration	Time lying down	Sleep efficiency
	n	kcal	MET	min	min	min	min	min	%
MICT									
T0	7473 ± 3607	3042 ± 685	1.24 ± 0.19	1045 ± 125	202 ± 70	92 ± 62	391 ± 87	444 ± 161	84 ± 4
T2	7822 ± 3603	3066 ± 717	1.23 ± 0.18	1094 ± 83	199 ± 61	93 ± 53	398 ± 72	477 ± 75	83 ± 7
T6	6270 ± 2583	2849 ± 673	1.23 ± 0.19	1033 ± 200	159 ± 86	82 ± 53	410 ± 74	484 ± 78	84 ± 4
HIIT									
T0	8796 ± 1690	2926 ± 622	1.31 ± 0.25	1048 ± 144	253 ± 109	93 ± 65	364 ± 129	457 ± 195	81 ± 7
T2	7759 ± 3516	2732 ± 340	1.38 ± 0.54	1067 ± 138	208 ± 135	94 ± 83	393 ± 104	486 ± 144	82 ± 8
T6	7920 ± 3579	2871 ± 561	1.41 ± 0.32	1045 ± 136	195 ± 112	105 ± 90	396 ± 129	501 ± 187	80 ± 10
HIIT-RM									
T0	9642 ± 1906	2695 ± 589	1.32 ± 0.17	1055 ± 85	269 ± 46	91 ± 51	384 ± 24	459 ± 38	84 ± 6
T2	9813 ± 3552	2639 ± 687	1.42 ± 0.37	1029 ± 84	268 ± 32	83 ± 70	372 ± 65	444 ± 88	84 ± 5
T6	9869 ± 2863	2757 ± 587	1.42 ± 0.27	1068 ± 76	225 ± 67	127 ± 66	387 ± 71	473 ± 91	82 ± 8

Data are presented as mean ± SD. Abbreviations: EE, daily energy expenditure; HIIT, high intensity intermittent exercise; HIIT-RM, high intensity intermittent exercise with possibility to modulation the duration of recovery; LPA, daily light physical activity; MD, missing data; MICT, moderate intensity continuous exercise; M-VVPA, daily moderate to very vigorous physical activity; ST, sedentary time.

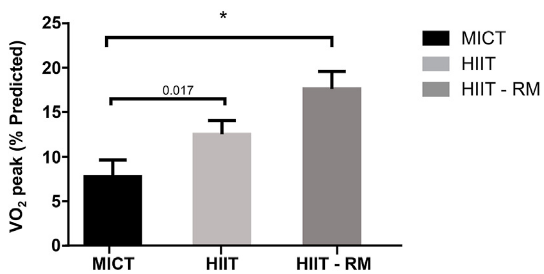

Fig. 2. Changes in VO_{2peak} (% predicted) from T0 to T2 in the three groups (MICT: moderate intensity continuous exercise; HIIT: high intensity intermittent exercise; HIIT-RM: high intensity intermittent exercise with possibility to modulate the duration of recovery); T0: baseline; T2: after 2 months of training. Significant differences between groups: *p < 0.016.

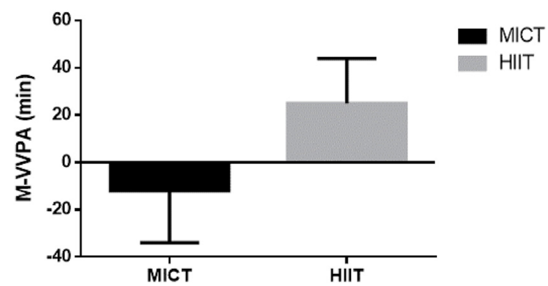

Fig. 4. Comparison of variations in moderate to very vigorous physical activity between T6 and T2 in the 2 exercise groups (MICT: moderate intensity continuous exercise; HIIT: high intensity intermittent exercise). T2: after 2 months of training, T6: Four months after supervised program.

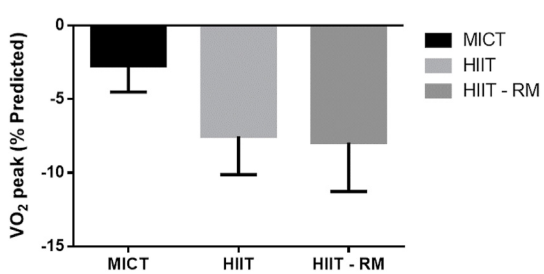

Fig. 3. Changes in VO_{2peak} (% predicted) from T2 to T6 in the three groups (MICT: moderate intensity continuous exercise; HIIT: high intensity intermittent exercise; HIIT-RM: high intensity intermittent exercise with possibility for the subject to modulate the duration of recovery). T2: after 2 months of training, T6: Four months after supervised program.

MICT ($p = 0.007$, ES: 0.08) as well as in HIIT-RM ($p < 0.001$, ES: 0.11).

From T2 to T6, leg muscular mass tended to decrease ($p = 0.027$, ES: 0.10) only in HIIT-RM.

From T0 to T6, in HIIT, fat mass ($p = 0.011$, ES: 0.17) as well as abdominal fat mass ($p = 0.014$, ES: 0.20) decreased. In HIIT-RM, waist circumference decreased but did not reach statistical significance ($p = 0.06$, ES: 0.19). In MICT, hip circumference tended to decrease ($p = 0.017$, ES: 0.09).

3.4. Maximal exercise response (Table 3, Figs. 2 and 3)

From T0 to T2, PPO significantly increased in all groups (MICT, $p = 0.0034$; HIIT, $p < 0.001$; HIIT-RM, $p < 0.001$). This improvement was greater for HIIT-RM (ES: 0.85) than MICT (ES: 0.15; $p = 0.007$).

VO_{2peak} increased or tended to increase in all trained groups in % predicted, in $L.min^{-1}$ and in $mL.kg^{-1}.min^{-1}$. The improvement in VO_{2peak} was greater in HIIT (in $L.min^{-1}$, ES: 0.39; in $mL.kg^{-1}.min^{-1}$, ES: 0.49; in %predicted, ES: 0.54) and HIIT-RM (in $L.min^{-1}$, ES: 0.49; in $mL.kg^{-1}.min^{-1}$, ES: 0.89; in %predicted, ES: 0.95) compared to MICT (in $L.min^{-1}$, ES: 0.15; $p < 0.01$; in $mL.kg^{-1}.min^{-1}$, ES: 0.22; $p < 0.001$; in %predicted (Fig. 2), ES: 0.28; $p = 0.017$ and $p = 0.013$ respectively).

Power output at VT1 was significantly increased with HIIT ($p = 0.003$, ES: 0.64) and tended to increase with HIIT-RM ($p = 0.023$, ES: 0.41). Power output at VT2 was significantly increased in all trained groups (MICT, $p = 0.001$; HIIT, $p < 0.0001$; HIIT-RM, $p = 0.001$). This improvement at VT2 tended to be greater for HIIT (ES: 0.72) compared to MICT (ES: 0.19) ($p = 0.035$).

From T2 to T6, no change was observed for MICT. PPO tended to decrease in HIIT ($p = 0.020$, ES: 0.39) and HIIT-RM ($p = 0.029$, ES: 0.39). VO_{2peak} expressed in $L.min^{-1}$ was decreased at T6 compared to T2 for HIIT ($p = 0.016$, ES: 0.32). VO_{2peak} expressed in $mL.kg^{-1}.min^{-1}$ tended to decrease in HIIT-RM ($p = 0.022$, effect size: 0.33) from T2 to T6 (Table 3). VO_{2peak} expressed in %predicted (Fig. 3) tended to decrease from T2 to T6 for HIIT ($p = 0.022$, ES: 0.31) and HIIT-RM ($p = 0.023$, ES: 0.36).

When comparing T0 to T6, PPO was not significantly different in all three groups (MICT, $p = 0.26$; HIIT, $p = 0.13$; HIIT-RM, $p = 0.06$). However, VO_{2peak} expressed in %predicted was greater only in HIIT ($p = 0.01$, ES: 0.25) and HIIT-RM ($p = 0.005$, ES: 0.46) at T6 compared to T0. Power output at VT1 remained greater at T6 compared to T0 in HIIT ($p = 0.011$, ES: 0.62) only. Power output at

VT2 in HIIT ($p = 0.007$, ES: 0.61) and HIIT-RM ($p = 0.005$, ES: 0.40) only remained greater at T6 compared to T0.

3.5. Submaximal exercise response (Table 3)

From T0 to T2, power output at Lipoxmax tended to increase with HIIT ($p = 0.019$, ES: 0.79) only.

3.6. Biological and vascular variables (Table 4)

From T0 to T2, in HIIT-RM only, HOMA2-IR ($p = 0.017$, ES: 0.47) and HOMA2-%B ($p = 0.022$, ES: 0.29) tended to decrease whereas HOMA2-%S ($p = 0.017$, ES: 0.34) tended to increase.

From T2 to T6, in HIIT, HDL tended to increase ($p = 0.046$, ES: 0.36). Also, the ratio of the total cholesterol on the amount of high-density lipoprotein tended to decrease ($p = 0.019$, ES: 0.32). In MICT, HOMA2-%S tended to increase ($p = 0.023$, ES: 0.33).

From T0 to T6, insulin ($p = 0.004$, ES: 0.33) and HOMA2-IR were significantly decreased ($p = 0.005$, ES: 0.33) whereas HOMA2-%S was increased ($p = 0.009$, ES: 0.41) in MICT.

3.7. Spontaneous physical activity and sleep (Table 5 and Fig. 4)

From T0 to T2, only sedentary time tended to increase ($p = 0.018$, ES: 0.46) in MICT.

From T2 to T6, given the number of missing data, we merged the two HIIT groups for moderate to very vigorous physical activity: M-VVPA did not change significantly (T2: 90 ± 80 min; T6: 110 ± 79 min, $p = 0.106$). Changes in M-VVPA did not differ significantly between HIIT and MICT ($p = 0.15$).

3.8. Motivation for eating

No differences were found whatever the group considered in restrained (MICT, T0: 2.97 ± 0.59, T2: 2.66 ± 0.51, T6: 2.91 ± 0.58; HIIT, T0: 2.77 ± 0.66, T2: 2.87 ± 0.42, T6: 2.72 ± 0.63; HIIT-RM, T0: 2.83 ± 0.49, T2: 2.61 ± 0.45, T6: 2.80 ± 0.68), emotional (MICT, T0: 2.86 ± 1.50, T2: 1.96 ± 0.91, T6: 2.39 ± 0.85; HIIT, T0: 2.07 ± 0.87, T2: 2.25 ± 1.09, T6: 1.88 ± 0.98; HIIT-RM, T0: 2.23 ± 1.42, T2: 3.09 ± 1.45, T6: 2.44 ± 1.20) and external (MICT, T0: 2.64 ± 0.63, T2: 2.38 ± 0.58, T6: 2.43 ± 0.47; HIIT, T0: 2.76 ± 0.64, T2: 2.92 ± 0.69, T6: 2.40 ± 0.71; HIIT-RM, T0: 2.89 ± 0.48, T2: 2.87 ± 0.66, T6: 2.73 ± 0.45) eating behavior.

4. Discussion

Our study aimed at comparing the short- and long-term effects between HIIT and MICT in individuals with overweight/obesity on cardiorespiratory fitness, metabolic risk and long-term adherence to physical activity after a supervised program in an outpatient setting. Immediately after the 8-week intervention, HIIT was more efficient in improving cardiorespiratory fitness and waist circumference despite a lack of effect on cardiometabolic risk factors. Four months after the supervised programs, HIIT induced a better maintenance of cardiorespiratory fitness, and a decrease in total and abdominal fat masses and total cholesterol/HDL.

4.1. Effects of different exercise training modalities on cardiorespiratory fitness and cardiometabolic risk

Benefits in cardiorespiratory fitness were greater for both HIIT programs despite participants presenting normal VO_{2peak} values at baseline. This confirms previous recent meta-analyses.[16,17] The excellent adherence to our high-volume short interval HIIT programs (22 × 1 min-cycling intervals at 100% of PPO) suggests that our protocol was well tolerated by individuals with overweight/obesity. Whereas it seems the superiority of HIIT over an isocaloric MICT on VO_{2peak} ($mL.kg^{-1}.min^{-1}$) is more obvious for intervals duration >2 min (SMD: 0.44 for interval >2 min and 0.13 for interval <2 min[20]), the 1-min exercise intervals of HIITs in our study showed marked greater efficiency (HIIT: $0.49 < ES < 0.89$, MICT: 0.22) on VO_{2peak} in only 2 months versus 3 months in the studies reviewed in Su et al.'s meta-analysis.[20] This could be explained by the larger amount of bouts used in our HIIT programs compared to the <2 min interval negative studies reported in Su et al.'s study.[20] This suggests that the total number of bouts can compensate for the use of bouts that are shorter in duration. This VO_{2peak} improvement (+0.78 METS in HIIT and +0.91 METS in HIIT-RM) is clinically significant since it has been associated with greater survival and a decrease of the mortality risk.[45,46]

The increased power output at VT1 and its tendency to be greater at VT2 in HIIT compared to MICT highlights the efficiency of our HIIT programs on aerobic endurance. This result is in agreement with Arad et al.[47] but contrasts with Schaun et al.'s study.[48] However, the MICT intensity used in the latter study was high, close to VT2 (vs 50% PPO in our study).[48] Importantly, the greater impact of HIIT on VT can be associated with greater functionality during physical activities of daily living. Particularly, the increase in VT1 intensity allows for a higher work rate to be sustained during "fat-reliant" exercise[37] which is relevant for persons with overweight/obesity. Accordingly, Lipoxmax, the intensity for which fat oxidation rate is maximum, tended to increase after HIIT only, suggesting a greater ability to oxidize fat. These well-known exercise effects (regardless the modality of training) on the ability to oxidize lipids[36,49] contribute to reduce the fat accumulation in adipose tissue, liver and muscle, responsible for insulin resistance and the cardiometabolic risk.[50]

The tendency of a greater effectiveness of HIIT over MICT on substrate oxidation confirms previous observations.[51] However, we failed to show an increase in lipid oxidation which has been previously reported following MICT.[13] This result could be explained by the intensity of training used in our study (i.e. 50% PPO). Indeed, an increase in Lipoxmax has been reported with a MICT program and in a population similar to that of our study but the exercise training intensity was individualized to the intensity at the maximum fat oxidation rate (30% of PPO) previously assessed by indirect calorimetry.[13]

Body composition and particularly the accumulation of abdominal fat mass increases cardiometabolic risk.[52] We assessed body composition using indirect and direct "gold-standard" (MRI) measurements.[53] Contrary to the recent meta-analysis of Su et al.[20] we failed to show a decrease in fat mass and an improvement in its distribution. This can be due to the shorter duration of our intervention, i.e. 8 weeks versus at least 12 weeks for the majority (14 among 22) of the studies reviewed in Su et al.[20] We found small decreases in waist circumference in HIIT (-1.5 cm) as well as a decreasing tendency in HIIT-RM (-1.2 cm) without changes in body weight after 2 months training. A recent meta-analysis reported that short-term exercise training (10 weeks on average) of at least moderate intensity can lead to a modest decrease in waist circumference.[25] The very modest decrease in waist circumference observed in our HIIT groups may support a decrease in cardiometabolic risk.[54] Moreover, we found modest decreases in hip circumference (effect sizes MICT: 0.08, HIIT: 0.16, HIIT-RM: 0.11) both in MICT (-1.4 cm) and HIIT-RM (-1.1 cm) as already reported.[55,56] Despite these positive effects of training on indirect measurement of body composition, these results must be taken with caution since they are within the error of measurement.[25] Finally, the relative discordance in the effect of the interventions on body composition between indirect and MRI gold standard measurements is surprising. Since we have already evidenced effects of an exercise program with our method[38] this discordance sustains the very weak effect of the 2-month HIIT programs on waist circumference.

While caloric restriction is more efficient than exercise for weight loss, exercise is more efficient for decreasing visceral fat stores.[57] We did not control the food intake of the participants in our study. We failed to observe any change in either fat mass or visceral fat mass in all 3 groups. This slightly contrasts with a recent meta-analysis[25] showing modest and equal effects of MICT and HIIT programs on body composition, particularly when training was performed on ergocycle. The total lack of effects of our programs on fat mass could have been due to the shorter duration of our program (8 versus at least 10 weeks) and to the fact that we did not control diet.

Unlike previous reports,[14,16,17] we did not observe marked modifications of the cardiometabolic variables (e.g., vascular reactivity, lipid profile, insulin sensitivity) despite the very encouraging tendency of HIIT-RM to improve insulin sensitivity. There are several explanations for these discrepancies. Most studies used longer program (at least 12 weeks[22,58] and longer interval, i.e. 3-4 min[59,60]) durations than the present protocol. In addition, participants from the present study showed at baseline variables associated with cardiovascular and metabolic risk within the normal range, possibly suggesting a ceiling effect. Finally, a large number of participants had treatments for cardiovascular and metabolic pathologies (e.g., hypertension, type 2 diabetes, hyperlipidaemia). Thus, if these treatments were optimal, a ceiling effect could have prevented further improvement.

4.2. Long term adherence and maintenance of cardiorespiratory fitness and cardio-metabolic status

Four months after the supervised exercise programs in an outpatient hospital setting, only 59% of participants declared that they continued to exercise regularly. Accordingly, cardiorespiratory fitness decreased in all three groups. However, VO_{2peak}, power output at VTs were still greater than those obtained at baseline in HIIT groups (Table 3) except for MICT although the majority of HIIT participants failed to maintain the intensity recommended immediately after the supervised hospital outpatient program (Table 5). However, based on the greater (although not significant, see limits below) spontaneous moderate to very vigorous physical activity at T6 compared to T2 (Table 5, Fig. 4), it seems our HIIT groups were able to maintain the intensity of physical activity on their own. We assume this because otherwise the benefits gained during the intervention period would have been lost during the 4 months of detraining.[61] Interestingly, VO_{2peak} decreased from T2 to T6 for HIIT and HIIT-RM but not for MICT. This may be due to the greater improvement induced by HIIT after the 8-week intervention.

The decrease tendency of leg muscular mass ($p = 0.027$) in HIIT-RM 4 months after the supervised program suggests a lack of commitment in sufficiently intense exercise after the supervised program. However, total and abdominal fat masses in HIIT decreased after 6 months compared to baseline. Since the motivation for eating was not altered, those decreases could be due to physical activity in accordance with a recent study[62] showing that despite marked decrease in long term adherence (12 months) to HIIT, the small sample of participants (20%) who maintained HIIT displayed the greater decrease in visceral fat.

It is possible that the challenge of exercising regularly or at an insufficient intensity could explain the lack of effects in the HIIT groups,[62] even though we observed a tendency toward a reduction in cholesterol/HDLc. Of note, in the long term, MICT improved insulin-resistance, as previously reported, despite a lack of increase in MPVA and an increase in sedentary time.[13] This increase could have been mediated however by the relatively good long-term adherence of MICT participants (68%) at T6.

Fifty-nine percent of the participants reported pursuing a physical activity after program discharge whereas it is generally admitted less than 3% of overweight men and 1.5% women reach physical activity recommendations.[63] This poor adherence might be due to the vicious circle initiated by negative affects[26,64] during exercise. More specifically, these affects alter intrinsic motivation. Since the affective responses are perceived more negatively by subjects with overweight/obesity they are less inclined to engage in a physical activity.[26] Nevertheless, in our study 68% in MICT, 59% in HIIT and 47% in HIIT-RM (non-significant) declared pursuing physical activity. However, HIIT did not increase long term physical activity adherence compared to MICT as previously suspected.[65] Finally, HIIT-RM, a variance of HIIT proposed to improve tolerance of HIIT in our participants, did not improve long term commitment to physical activity. Hence other strategies must be proposed to improve the adherence of persons with obesity.

4.3. Limitations and perspectives

Although we showed an excellent tolerance by our participants with overweight/obesity to our strenuous HIIT programs, this needs to be confirmed in more deconditioned patients for whom the proposed HIIT consists in 10×1 min-intervals at 100% of PPO.[30] The long-term adherence to physical activity was important to assess in order to verify if HIIT program (and its variance HIIT-RM) might have favoured greater commitment to this exercise mode. Unfortunately, we lost a lot of data related to spontaneous physical activity due to sensors obsolescence and some participants lost to follow-up. Hence, on one hand, we could not assert with certainty the accuracy of the statements of participants regarding physical activity and on the other hand, check the intensity of this physical activity. Combining our 2 HIIT groups and physical activity intensities from moderate to very vigorous physical activity did not allow reaching statistical significance despite a greater level of MVPA on average. This could be due to a type II error. Hence, this point needs confirmation. Finally, dietary intake regularly assessed by dietary surveys may have contributed to a better understanding of some slight body composition alterations, particularly 4 months after the supervised training. Lastly, the absence of a control group is also a limitation to the present study.

5. Conclusion

We have shown greater short-term benefits induced by a high-volume short interval (1 min) HIIT on cardiorespiratory fitness and cardiometabolic risk over an isocaloric moderate intensity continuous exercise in persons with overweight/obesity. We also showed greater long term (4 months) effects on the maintenance of CRF, decreases in total and abdominal fat masses and total cholesterol/HDL. However, HIIT did not translate into greater commitment to physical activity. Hence, other strategies favoring adherence of persons with overweight/obesity in HIIT in the long term are necessary.

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Disclosure of interest

The authors report no conflicts of interest.

Author statements

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Declaration of competing interest

The authors report no competing financial interest.

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