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Feasibility and preliminary efficacy of high intensity interval training in type 2 diabetes☆

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ABSTRACT

Aims: To compare the feasibility of high intensity interval exercise (HI-IE) versus moderate intensity continuous exercise (MI-CE) in patients with type 2 diabetes (T2D), and to investigate the preliminary efficacy of HI-IE and MI-CE for improving glycated hemoglobin A_{1c} (HbA_{1c}) and body composition.

Methods: Individuals with T2D were recruited and randomly assigned to HI-IE and MI-CE. Exercise training was performed 5 days per week for 12 weeks. Recruitment, retention, adherence, feeling states and self-efficacy were analyzed for feasibility. Changes in HbA_{1c} and percent body fat from baseline were investigated at 12 weeks to determine the preliminary efficacy.

Results: Of 126 participants showing interest to join the study, 15 individuals were randomized and completed the program. No participants dropped out from the study after enrollment. Adherence rates were high and did not differ between HI-IE and MI-CE ($p > 0.05$; >97.2% of the eligible exercise sessions for both groups). Feeling states and self-efficacy did not differ between the groups. Percent trunk fat decreased in both HI-IE and MI-CE ($p = 0.007$ and 0.085, respectively). Total percent body fat, percent leg fat, and subcutaneous fat width were significantly reduced in both groups ($p < 0.05$), whereas HbA_{1c} did not change from baseline ($p > 0.05$). The degree of improvement was similar between the interventions ($p > 0.05$).

Conclusion: In individuals with T2D, implementing a 12-week structured HI-IE training can be as feasible as MI-CE training. Both interventions are equally effective in lowering total body fat but have little impact on HbA_{1c} in relatively well controlled participants with T2D.

1. Introduction

Current physical activity or exercise recommendations for patients with type 2 diabetes (T2D) suggest a minimum of 150 min per week of moderate to vigorous aerobic exercise [1]. However, data are conflicting as to whether or not individuals with T2D benefit more from participating in high intensity exercise. Recent meta-analyses have highlighted the variability in the response to various exercise protocols and have suggested that a greater exercise dose predicts greater decreases in glycated hemoglobin A_{1c} (HbA_{1c}) [2]. Conversely,

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greater exercise intensity per se has been shown to lead to greater improvements in HbA_{1c} in some meta-analyses [3] but not others [2,4].

Similarly, while high intensity exercise has been indicated to improve insulin sensitivity [5–7], the mechanisms by which exercise intensity affects insulin sensitivity are not well understood. Acute increases in non-oxidative glucose disposal [8–10] or chronic preferential reduction in intra abdominal adipose tissue (IAAT) [11], just to name a few, may be more prominent following high intensity exercise and contribute to enhanced insulin sensitivity. Recently, more attention has been directed toward the effect of high intensity exercise on IAAT due to its role in the pathogenesis of insulin resistance and T2D. Nonetheless, studies have shown conflicting results with some studies showing preferential reductions in IAAT with higher intensity exercise irrespective of energy expenditure [12–14] while others report no differences [15,16]. Thus, whether exercise intensity can be tailored to favor preferential reductions in IAAT and HbA_{1c} remains inconclusive.

While the benefits of high intensity exercise requires further research, there are several concerns regarding the feasibility of implementing high intensity exercise, particularly in older, sedentary or overweight participants with comorbidities such as T2D. Primary perceived barriers include concerns over the risk of injury [17], poor adherence [18], and low self-efficacy in the ability to implement exercise [19]. One approach to minimizing the barriers to high intensity exercise may be the use of interval exercise training which alternates between high intensity exercise bouts and lower intensity recovery periods. Interestingly, while only a few previous studies [20–22] have prescribed interval training in people with T2D, all demonstrated preferable effects with one study [20] reporting greater reductions in HbA_{1c} and IAAT than other studies identified in a meta-analysis [2]. Unfortunately, this latter study did not have a moderate intensity exercise comparison group and it is unknown whether the greater than expected benefits were due to the intervention itself or to some characteristics of the participants.

As recently suggested by Hawley et al., high intensity interval training may be a potent therapeutic intervention to improve blood glucose concentrations and body composition [23]. Nonetheless, to our knowledge there has not yet been a randomized trial that compares the feasibility and chronic effects of high intensity interval exercise (HI-IE) and moderate intensity continuous exercise (MI-CE) interventions in T2D. The objective of this pilot study was to compare the feasibility (recruitment, adherence and retention) of HI-IE versus MI-CE in patients with T2D. Secondary outcomes of interest included investigation of the preliminary efficacy of HI-IE and MI-CE in improving HbA_{1c} and estimates of IAAT. Compensatory changes in daily steps and energy intake throughout the study were also investigated.

2. Methods

2.1. Design

This was a 12-week, single center, parallel-group randomized trial (ClinicalTrials.gov registration number: NCT01144078) conducted in Edmonton, Alberta, Canada. Ethical approval was obtained from the University of Alberta Health Research Ethics Board.

2.2. Participants

Initial recruitment was conducted through newspaper advertisement and websites. These recruitment strategies briefly outlined the inclusion criteria: (1) men and women between 55 and 75 years (y) of age; (2) diagnosed with T2D; (3) able to exercise 5 days per week; and (4) non-smokers. Other recruitment procedures were conducted through word of mouth and by contacting the individuals with T2D who expressed interest in participating in research studies.

The study coordinator conducted a brief telephone interview to confirm the potential eligibility of participants, answered questions regarding the study, and scheduled a first meeting. In the first meeting participants responded to questionnaires to further screen for the following criteria: (1) post-menopausal for more than 5 y; (2) $<$150 min of structured exercise per week; (3) $<$3 kg body weight change within the last 6 months (mo); (4) absence of diabetes-related complications and limitations to regular exercise; and (5) self-reported absence of alcohol or substance abuse within last 12 mo. Blood pressure (BP) was measured at rest to ensure the participants were safe to perform exercise intervention (cutoff criteria $<$ 140/90). The use of prescription medications that might affect body fat distribution (i.e., insulin and thiazolidinedione) was considered a contraindication to participation. Participants meeting the inclusion criteria provided a baseline fasting blood sample measured at a local accredited diagnostic laboratory ($DynaLIFE_{DX}$, Edmonton, AB). Individuals with $HbA_{1c} > 9\%$, LDL $>$ 3.5 mmol/l or total cholesterol to HDL ratio $>$ 5.0 were excluded. The fasting blood sample was used to determine baseline lipids, lipoproteins, fasting blood glucose and HbA_{1c} concentrations. All participants provided written informed consent.

2.3. Initial assessment

Participants performed a graded exercise stress test on a treadmill (stress test) under the supervision of a trained physician, and reported to the University of Alberta on a separate day to assess baseline anthropometric characteristics, body fat, peak oxygen consumption (VO_{2peak}) and ventilatory threshold (VT). Height was measured with a wall-mounted stadiometer. Waist and hip circumferences and sagittal diameter were measured as previously described [24]. Briefly, waist and hip circumferences were measured with a flexible tape measure (Almedic, Saint-Laurent, QC) in standing with feet together at the end of a normal expiration (end-tidal). Waist circumference was measured midway between the costal arch and the iliac crest and hip circumference was measured as the maximal circumference over the buttocks at the level of the trochanters. For sagittal diameter, while participants were lying supine on the floor, a sliding-beam caliper was used to measure the vertical distance between the floor and the abdomen at the level of umbilicus. All measures were performed in duplicate to the nearest 0.1 cm. Where the difference exceeded 0.5 cm, measurements were repeated and the average of the closest two was calculated.

Body fat, i.e., percent total body fat, trunk fat, arm and leg fat, was analyzed with dual-X-ray absorptiometry (DXA) scan (LUNAR Prodigy High Speed Digital Fan Beam X-Ray-Based Densitometry with encore 9.20 software; General Electric, Madison, WI). The detailed mechanism of DXA has been described elsewhere [25]. Also, accuracy and reliability of DXA to determine abdominal adiposity has previously been demonstrated [26]. A trained radiographer determined subcutaneous fat width from the DXA measures [24]. IAAT was subsequently estimated based on the subcutaneous fat width and anthropometric measures, as described by Bertin et al. [24].

VO_{2peak} and VT were determined using a cycle ergometer (Monark 818; Monark, Varberg, Sweden) and a TrueMax® (ParvoMedics) metabolic measurement system that was calibrated for air volume and gas concentrations as per the manufacturer's instruction. The exercise began pedaling at 60–65 revolution per minute (rpm) with no resistance. Power output was increased by approximately ~30 W for the first 2 min and then by 15 W per min thereafter. The data were acquired every 15 s and the highest VO_2 (ml/kg/min) observed before reaching volitional exhaustion determined VO_{2peak} [27]. VT was determined using a υ-slope method [28]. Participants were instructed to maintain the cadence between 60 and 65 rpm and the test was terminated when participant failed to keep up with the cadence. The highest resistance completed during the last min while maintaining 60–65 rpm was used to determine peak power output (PO).

2.4. Run-in phase

Before randomization to the HI-IE and MI-CE interventions, participants were required to participate in a 2-week run-in period. The purpose of the run-in period was two-fold: to favor the randomization of initially compliant participants; and to gradually habituate participants to the exercise interventions. During the run-in period, participants reported to the University of Alberta for 30-min exercise sessions on Monday, Wednesday and Friday for 2 weeks. The exercise intensity was set at workload corresponding to 40% oxygen consumption reserve (VO_2R), the ratio of the net oxygen costs to net maximal oxygen consumption [29]. All exercise sessions were supervised by a member of the investigative team. The prerequisite for randomization was attendance at 5 out of the 6 run-in visits.

2.5. Randomization

Participants were randomly allocated to HI-IE and MI-CE intervention groups. Randomization was stratified by sex and completed by a computer program. While blinding of the participants was not feasible, blood samples and body fat assessments were completed by individuals who were unaware of group allocation.

2.6. Intervention

Both groups exercised at the time of participants' convenience 5 days per week (Monday–Friday) for 12 consecutive weeks in a fitness center. Exercise duration, frequency, and average relative intensity (VO_2R) of HI-IE and MI-CE groups were matched. The MI-CE group performed continuous exercise at 40% VO_2R, whereas the HI-IE protocol involved alternating between 1-min intervals at 100% VO_2R followed by 3-min recovery intervals at 20% VO_2R (average = 40%) except for one day (Wednesday), when they performed MI-CE protocol. As many complete intervals as possible were completed during HI-IE training session (e.g., 7 intervals in a 30 min period (7×4 min = 28 min)), with the remaining time spent at 40% VO_2R to ensure that the average work output for both groups corresponded to 40% of the VO_2R. To obtain appropriate workload for each individual, peak oxygen consumption was first determined from the baseline progressive maximal walking and stationary cycling exercise tests, followed by the calculation of the workload that yielded the oxygen cost equivalent to the VO_2R of interest (i.e., 20, 40 and 100%) [29].

Participants were progressed from 30 min per session for weeks 1–4 to 45 min per session for weeks 5–8, and then to 60 min per session for weeks 9–12 post randomization. Stationary cycling and treadmill walking were performed alternately for exercise variety. All exercise sessions were supervised and delivered at a University of Alberta exercise facility.

2.7. Questionnaires

Participants completed the subjective exercise experiences scale [30], a 12-item, 7-point Likert scale to assess positive and negative feeling states: positive well-being, psychological distress, and fatigue. In addition, three types of self-efficacy: task-efficacy for elemental aspects of the behavior; coping-efficacy for exercising under challenging circumstances; and scheduling-efficacy for arranging one's time commitments to exercise regularly were assessed by a 10-item, 10-point Likert scale questionnaire [31]. Both questionnaires have been demonstrated to be sensitive to exercise interventions [30,32]. Questionnaires were first provided during the run-in phase and were repeated in weeks 6 and 12 of the intervention. Consequently, questionnaires were completed during weeks of different exercise duration (i.e., 30, 45, and 60 min). Participants' satisfactions with the exercise training program were measured with another questionnaire provided at the completion of the 12-week exercise training. Participants were instructed to rate on a 7-point Likert scale anchored with 1 = 'not beneficial at all' and 7 = 'very beneficial'.

2.8. Outcomes and measurement

The primary outcome of this study was the feasibility of conducting the planned study in terms of recruitment, retention and adherence. In regards to recruitment, we identified the number of potential participants who responded to our initial recruitment strategies, the proportion who remained interested after being informed of the requirements of the study, as well as the proportion being randomized. From the retention perspective, we were interested in identifying the attrition rate which was established as discontinuation of the intervention and loss to follow-up measurement for both conditions following randomization and by the end of 12

weeks of training. Finally, adherence was measured through attendance to the exercise sessions and compliance to the prescribed intensities. All exercise sessions were monitored by study personnel who noted attendance in a log and ensured each participant completed each exercise bout at the individually prescribed intensity and duration. For the subjective exercise experiences scale and self-efficacy questionnaires, means of positive well being, psychological distress, fatigue, and self-efficacies were calculated [31].

Important secondary outcomes were the preliminary efficacy of HI-IE at reducing IAAT and improving HbA_{1c}. Within a week of the last exercise session, VO_{2peak}, VT, anthropometric analyses, DXA, and blood profile measurements were repeated. Our original intention was to estimate the amount of IAAT by using a previously validated technique which combines DXA and anthropometric measurements to calculate IAAT [24]. However, it became apparent that this indirect measurement was unsuitable for examining longitudinal changes as the calculation was confounded by changes in other parameters. Accordingly, raw anthropometric and DXA data were analyzed to determine changes in body composition. VT was visually determined using the graphically display generated by the software on the metabolic measurement system by a single researcher who was blinded to the participants and to the order of testing.

To assess compensatory behavior changes, participants used a provided pedometer (Walk4Life Inc., Plainfield, IL). The pedometer was provided a week before the initiation of exercise training and was worn on a daily basis throughout the study period. Participants also completed 3-day dietary record during the run-in phase, the 6th week of the training intervention, and within 1 week of the last day of the training session. Participants were encouraged to continue to consume their regular diet.

2.9. *Data analysis*

Data were tested for normality using histogram and normal probability plots. Where skewness was visually identified, the normality was further tested using Kolmogorov–Smirnov test. Treatment group differences in baseline characteristics were tested using independent *t*-tests. We used descriptive statis-

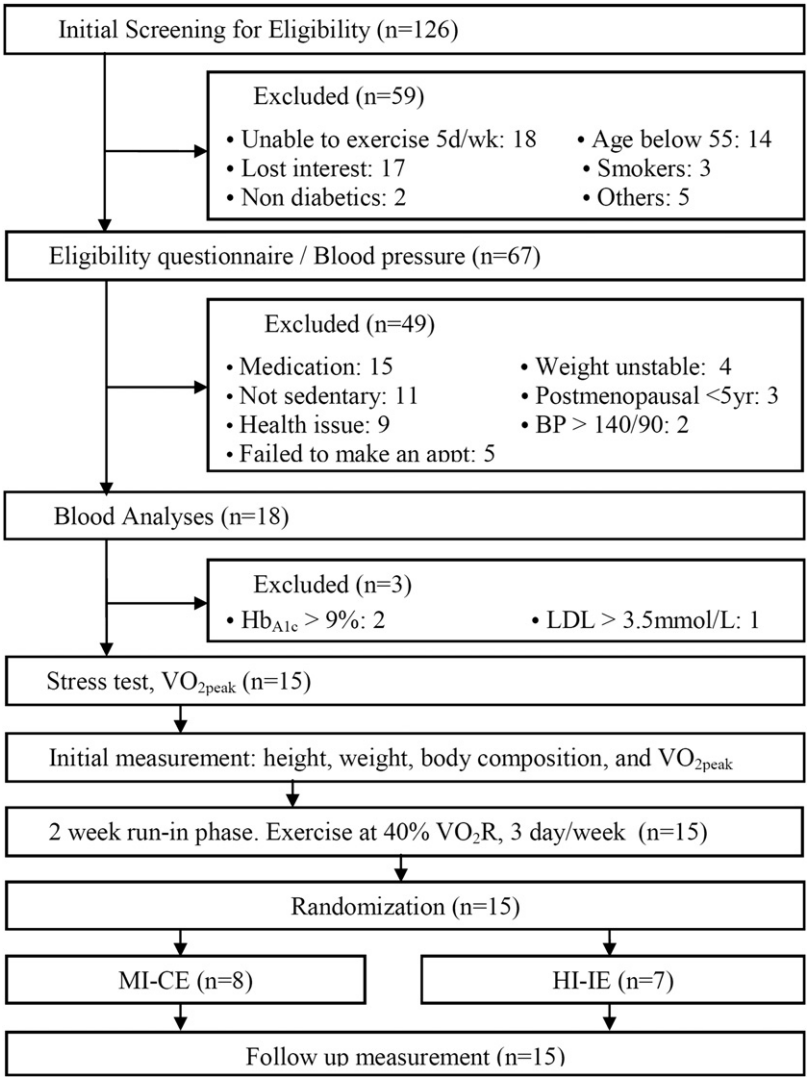

Fig. 1 – Study flow diagram. Questionnaires and 3-day dietary records were completed during the run-in phase, 6th week after randomization, and within one week of the last exercise session.

tics to examine recruitment, retention and adherence rates, as well as quantitative analyses to investigate the differences between HI-IE and MI-CE. Friedman ANOVA by ranks and Mann–Whitney *U* tests with Bonferroni adjusted *p*-value of 0.01 were undertaken for positive well being, psychological distress, fatigue, self-efficacy measures and training program satisfaction.

For the secondary outcomes measured before and after the intervention period (i.e., anthropometric measures, body fat and HbA_{1c}) one-way ANCOVA (HI-IE vs. MI-CE) was performed on post training outcomes with baseline values serving as covariates to compare the treatment effects. Paired sample *t*-tests were also performed to investigate within group changes from baseline. Intention-to-treat analysis was performed for all variables unless otherwise stated.

For step counts and dietary intake analyses, two-way (intervention by time) repeated-ANOVA was used. Step counts were stratified into before exercise training, 30 min per session, 45 min per session, and 60 min per session. Dietary records were analyzed using Fitday dietary analysis program (http://www.fitday.com) by two investigators and, where discrepancies in caloric intake exceeded 300 kcal per day, the data were reanalyzed. The average of the two caloric intakes was used for the statistical analyses. Quantitative data was analyzed using Minitab 15 statistical software (Minitab Inc., State College, PA, USA). All data are presented as means ± SD. *p*-Values <0.05 were considered significant unless otherwise stated.

3. Results

3.1. Recruitment

Between June 2010 and February 2011, 126 participants were screened. The intervention was delivered between September 2010 and June 2011. Fig. 1 shows the flow of the participants from recruitment to follow-up. Of the 126 individuals screened, 59 did not meet the initial inclusion criteria and were excluded. The most common reasons for exclusion were time constraint to exercise 5 days per week ($n = 18$) and loss of interest ($n = 17$). Subsequently, another 49 were excluded after briefly meeting with the study coordinator. The most common reasons for exclusion were medication ($n = 15$) and being too active ($n = 11$). The remaining 18 participants provided a blood sample. Three did not meet our inclusion criteria and were excluded. Fifteen participants (12%) entered the run-in phase. All completed the minimum of 5 exercise sessions during the run-in phase and were randomly allocated to HI-IE and MI-CE intervention groups.

3.2. Participants

Descriptive characteristics of the 15 participants (8 males and 7 females) are summarized in Table 1. Of the 7 participants allocated to HI-IE: 4 were treated with metformin alone; 1 with metformin and sitagliptin, and 2 with diet intervention alone. Of the 8 participants in MI-CE: 4 were treated with metformin alone, 1 with metformin and sitagliptin, 2 with metformin and sulfonylurea, 1 with sulfonylurea and sitagliptin. One participant in MI-CE group discontinued antihyperglycemic medication 9 weeks into the 12-week intervention period. The discontinuation was not related to our exercise program but due to a delay in renewing a prescription. As a direct result of this, a large increase in blood glucose concentration was observed, and it was decided to repeat the fasting blood glucose and HbA_{1c} analyses while excluding the participant. All the other data obtained from the participants were included in the analyses.

At baseline, sagittal diameter and waist circumference were lower in HI-IE than MI-CE ($p < 0.05$). There were no significant baseline differences in body fat, fitness, or blood profiles between groups.

3.3. Retention

Once enrolled in the study, all 15 participants completed all phases of the study. No one dropped out from the exercise intervention after randomization.

3.4. Adherence

Through the 12 weeks of exercise training intervention, both HI-IE and MI-CE groups had similar exercise adherence, with the mean attendance of 56 sessions for HI-IE and 57 for MI-CE (97.2 ± 2.7 and $97.3 \pm 3.7\%$ of the eligible exercise sessions completed within each exercise condition, respectively). Reasons for not attending sessions included: health issues, automobile troubles, and business trips.

3.5. Secondary outcomes

Contrary to our expectation, although it did not reach statistical significance, IAAT increased from 110.3 ± 20.0 to 116.8 ± 22.80 and from 141.6 ± 40.7 to 154.6 ± 43.1 cm^2 in HI-IE and MI-CE, respectively. Because we suspected the increase was associated with the formula used to compute IAAT, raw-DXA data were analyzed and presented. Table 1 summarizes changes from baseline. The decreases in percent trunk fat were significant in HI-IE ($p = 0.007$) and showed tendency to decrease in MI-CE ($p = 0.075$). Total percent body fat, percent leg fat, and subcutaneous fat width were significantly reduced in both groups ($p < 0.05$). Conversely, in both exercise intervention groups fasting blood glucose, HbA_{1c}, cholesterol, HDL, LDL, ratio of cholesterol to HDL, triglycerides concentration, body weight, sagittal diameter, waist circumference and percent arm fat did not change from baseline to post intervention. One-way ANCOVA showed no significant differences between the interventions, indicating the similar effectiveness of both types of exercise after accounting for the baseline differences. For fasting blood glucose and HbA_{1c}, neither intention-to-treat nor per-protocol analysis resulted in any significant differences. VO_{2peak} did not change in either group but oxygen consumption at VT increased significantly ($p = 0.025$ for both groups). Maximal PO attained during VO_{2peak} test increased significantly only in HI-IE ($p = 0.029$).

Step counts tended to be higher when mean steps during the 60 min exercise bout were compared to the pre-training mean ($p = 0.053$), probably due to a longer time spent on the treadmill. The step counts differed significantly between HI-IE

Table 1 – Baseline blood profiles, anthropometric measures, body fat, and exercise performance changes over 12-week exercise training.

Variable	Intervention	Baseline	12 weeks	Changes from baseline	p-Value[a]
n (M/F)	HI-IE	4/4	4/4		
	MI-CE	4/3	4/3		
Age (y)	HI-IE	62 (3)			
	MI-CE	63 (5)			
T2DM duration (y)	HI-IE	6 (4)			
	MI-CE	8 (4)			
Body weight (kg)	HI-IE	80.5 (9.9)	79.7 (10.2)	−0.8 (2.4)	NS
	MI-CE	93.9 (18.3)	92.6 (18.8)	−1.3 (0.9)	NS
BMI (kg/m^2)	HI-IE	28.4 (4.1)	28.1 (4.0)	−0.3 (0.9)	NS
	MI-CE	33.1 (4.5)	32.6 (4.3)	−0.5 (0.9)	NS
Total body fat (%)	HI-IE	36.1 (10.9)	34.2 (10.4)	−1.9 (1.4)	0.009
	MI-CE	41.6 (6.3)	40.1 (5.6)	−1.5 (1.5)	0.028
Trunk fat (%)	HI-IE	41.7 (8.9)	39.2 (8.8)	−2.5 (1.6)	0.007
	MI-CE	46.1 (6.3)	44.3 (5.5)	−1.8 (2.4)	0.075
Arm fat (%)	HI-IE	33.3 (15.8)	33.2 (15.5)	−0.1 (1.3)	NS
	MI-CE	40.0 (8.1)	39.6 (7.1)	−0.4 (2.1)	NS
Leg fat (%)	HI-IE	30.0 (13.8)	28.4 (12.9)	−1.6 (1.6)	0.032
	MI-CE	36.7 (7.5)	35.4 (7.1)	−1.3 (1.5)	0.049
Sagittal diameter (cm)	HI-IE	24.2 (1.8)*	24.3 (2.1)	0.2 (0.9)	NS
	MI-CE	27.7 (3.7)	28.2 (3.3)	0.5 (1.3)	NS
Waist circumference (cm)	HI-IE	102.6 (7.2)*	102.2 (6.9)	−0.5 (2.6)	NS
	MI-CE	116.3 (11.0)	115.1 (11.5)	−1.2 (3.5)	NS
Hip circumference (cm)	HI-IE	107.1 (10.3)	105.4 (9.4)	−1.7 (2.4)	NS
	MI-CE	116.0 (6.7)	114.3 (8.9)	1.7 (4.9)	NS
Subcutaneous fat width (cm)	HI-IE	4.4 (1.6)	4.1 (1.6)	−0.3 (0.2)	0.029
	MI-CE	5.8 (1.9)	5.3 (1.9)	−0.5 (0.6)	0.042
Fasting glucose (mmol/l)	HI-IE	6.8 (0.8)	6.7 (0.8)	−0.1 (0.8)	NS
	MI-CE	7.3 (1.7)	7.6 (3.0)	0.3 (2.9)	NS
	MI-CE[b]	7.3 (1.8)	6.7 (1.3)	−0.6 (0.9)	NS
HbA1c (%)	HI-IE	6.6 (0.6)	6.5 (0.5)	−0.1 (0.3)	NS
	MI-CE	6.7 (0.9)	7.0 (1.1)	0.3 (0.5)	NS
	MI-CE[b]	6.6 (0.9)	6.7 (0.8)	0.1 (0.3)	NS
HDL (mmol/l)	HI-IE	1.2 (0.2)	1.2 (0.2)	0.0 (0.1)	NS
	MI-CE	1.3 (0.4)	1.3 (0.4)	0.0 (0.1)	NS
LDL (mmol/l)	HI-IE	2.0 (0.2)	2.2 (0.6)	0.2 (0.6)	NS
	MI-CE	1.8 (0.7)	1.8 (0.7)	0.0 (0.4)	NS
Cholesterol (mmol/l)	HI-IE	3.9 (0.4)	4.0 (1.0)	0.2 (0.9)	NS
	MI-CE	3.9 (0.5)	3.8 (0.8)	−0.1 (0.3)	NS
Cholesterol to HDL ratio	HI-IE	3.2 (0.3)	3.5 (0.7)	0.2 (0.7)	NS
	MI-CE	3.3 (1.1)	3.2 (1.3)	−0.1 (0.4)	NS
Triglyceride (mmol/l)	HI-IE	1.5 (0.4)	1.6 (0.9)	0.1 (0.7)	NS
	MI-CE	2.1 (0.8)	1.6 (0.9)	−0.5 (1.2)	NS
VO_{2peak} (ml/kg/min)	HI-IE	22.8 (5.4)	24.3 (7.4)	1.5 (3.2)	NS
	MI-CE	18.1 (2.7)	18.9 (4.1)	0.8 (2.5)	NS
VO_2 at VT (ml/kg/min)	HI-IE	10.5 (4.8)	12.2 (5.9)	1.7 (1.5)	0.025
	MI-CE	10.5 (1.3)	12.2 (1.5)	1.7 (1.7)	0.025
Peak power output (W)	HI-IE	145 (46)	162 (57)	17 (16)	0.029
	MI-CE	118 (34)	128 (35)	11 (18)	NS

HI-IE, high intensity interval exercise; MI-CE, moderate intensity continuous exercise; HbA_{1c}, glycosylated hemoglobin A_{1c}; VO_{2peak}, peak oxygen consumption; VT, ventilator threshold; NS, not significant. Values are presented as mean (SD).

[a] Changes from the baseline values determined by paired sample t-tests.

[b] $n = 7$, per-protocol analysis (one participant was excluded due to discontinuation of oral antihyperglycemic medication).

* Significantly lower than MI-CE ($p < 0.05$).

ANCOVA on changes from baseline showed no differences between HI-IE and MI-CE among all parameters listed between HI-IE and MI-CE ($p > 0.05$).

and MI-CE, with HI-IE consistently showing higher number of steps throughout the study ($p < 0.001$). After discarding the days on the treadmill, time did not affect step counts ($p = 0.469$), but between-group difference remained significant ($p < 0.001$). Dietary intake of participants did not change over time ($p = 0.96$) and was consistently higher in HI-IE group ($p < 0.01$). The result did not change when the same analysis was performed on caloric intake relative to body mass (kcal/kg). There were no group by time interaction effects.

3.6. *Questionnaires*

Overall results are summarized in Table 2. Changes in positive well being, psychological distress, fatigue, task-efficacy, scheduling-efficacy and coping-efficacy over time were not significant. There were no differences between HI-IE and MI-CE. Equal satisfaction with the interventions was confirmed by the end-of-training questionnaire.

4. Discussion

To our knowledge, this is the first randomized trial to compare the feasibility of high intensity interval and moderate intensity continuous exercise training in individuals with T2D. The results suggest that both interventions are feasible and provide high satisfaction to participants. While the recruitment rate for this study (12%) is similar to a larger study investigating the effects of different exercise interventions on glycemic control [33,34], the key finding is that, for the subset of participants who were randomized into the exercise training program in the present study, HI-IE training did not negatively impact exercise adherence and retention compared to more traditionally used MI-CE. Adherence and attrition rates observed in HI-IE are superior to most of the studies reporting the rates of individuals with T2D enrolled in structured exercise [2]. These findings are important in light of recent studies showing that interval training can possibly lead to substantial improvements in glucoregulation [21] or metabolic health [22] within a shorter timeframe than other forms of training [23].

A number of contributing factors, including positive feeling states, low psychological distress and fatigue, and high self-efficacy, explain the high adherence and retention rates. A relationship between positive feeling states and exercise participation in aging individuals has previously been reported [35]. In our study psychological responses to exercise stimulus measured via subjective exercise experiences scale were positive throughout the exercise training regardless of exercise intensity and duration, and were highly comparable to those of younger and more fit individuals [36,37]. Moderate intensity exercise has generally believed to be an optimum stimulus to induce positive psychological outcomes, while positive sense of achievement in the completion of a difficult task may also have resulted in the positive feeling states in HI-IE [38]. To date, a few studies have reported an association between high intensity continuous exercise and high psychological distress/fatigue [32,36,39]. However, by performing high intensity exercise in interval fashion, HI-IE showed similar levels of psychological distress and fatigue to MI-CE.

Self-efficacy is another important determinant of adherence. Task-efficacy, coping-efficacy, and scheduling-efficacy observed in this study were high in both groups and were comparable to avid exercisers [31]. The reason for the positive feeling states and high self-efficacy is not clear but may be attributable to high motivation due to voluntary participation, easy accessibility of the training facility, and supervision of each exercise session [19]. In any case, it was speculated that

Table 2 – Means and standard deviations for psychological health, fatigue, and efficacy in response to exercise.

	Exercise duration (min)	HI-IE Mean (SD)	MI-CE Mean (SD)
Psychological well-being	30	5.5 (1.0)	5.4 (1.2)
	45	5.6 (1.0)	6.2 (0.6)
	60	5.6 (1.0)	6.5 (0.5)
Psychological distress	30	1.9 (0.9)	2.1 (1.3)
	45	1.9 (1.2)	1.3 (0.7)
	60	1.2 (0.2)	1.1 (0.2)
Fatigue	30	2.5 (0.9)	3.2 (1.7)
	45	2.5 (0.9)	2.3 (1.1)
	60	2.6 (1.6)	1.9 (1.0)
Task self-efficacy	30	8.4 (1.3)	8.8 (0.6)
	45	8.6 (0.7)	9.2 (0.8)
	60	9.2 (0.8)	9.6 (0.8)
Scheduling self-efficacy	30	7.5 (1.5)	8.0 (0.6)
	45	7.8 (0.9)	8.7 (1.4)
	60	8.3 (1.2)	9.0 (1.2)
Coping self-efficacy	30	8.0 (0.7)	8.7 (1.0)
	45	8.3 (0.9)	9.0 (0.8)
	60	8.1 (0.8)	9.1 (1.0)
Satisfaction (End of study)		6.8 (0.5)	6.8 (0.4)

There were no significant differences in the magnitude of changes among all parameters listed between HI-IE and MI-CE ($p > 0.05$).

the same average relative intensity and the same exercise duration and frequency explained the absence of differences in feeling states and self-efficacy between HI-IE and MI-CE, and hence the similar adherence rates.

With regard to the secondary outcomes, compensatory increases in energy intake and/or decreases in non-exercise energy expenditure have been regarded as factors that, at least partially, negate exercise-induced weight loss [40]. Consequently, we measured energy intake and step counts to exclude the possibility that the secondary outcomes were confounded by compensatory behavioral changes. When two-way ANOVA was performed on food intake and step counts, our results showed that there were no time effects or group by time interaction effects, indicating that caloric intake and physical activity outside the study remained relatively constant for both HI-IE and MI-CE intervention groups. This allowed us to attribute the changes in body composition to the effects of the interventions.

While the secondary objective of the present study was to investigate the effects of different exercise modalities on IAAT and HbA_{1c}, it became apparent that the experimental method chosen for estimating IAAT was inappropriate for detecting longitudinal changes. For example, in some cases where a large reduction in subcutaneous fat width was estimated, we observed an increase in IAAT despite meaningful losses of body mass or the amount of total body fat. This is contrary to what would be expected in studies that have utilized computed tomography or magnetic resonance imaging estimates of IAAT, which have shown that reductions in total body fat or subcutaneous fat width are strongly associated with reductions in IAAT [12,13,41–43]. Accordingly, we analyzed raw anthropometric and DXA data and demonstrated favorable body composition changes in the abdominal area and in lower exercising limbs in both HI-IE and MI-CE. This is an important benefit as excess body fat has long been recognized as an important modifiable risk factor for T2D.

Conversely, while HI-IE resulted in a significant increase in PO, it showed no additional benefits on body composition over MI-CE after accounting for the baseline differences, suggesting the possibility that, when adjusted for relative intensity and volume, HI-IE and MI-CE have equal effectiveness on body composition. This finding is in line with the study by Cho et al., who reported similar impact on body composition changes when continuous high and moderate intensity exercise with duration adjusted for energy expenditure were compared [16]. Since there were no significant changes in food intake and physical activity patterns outside the intervention throughout the study period, similar energy expenditure associated with HI-IE and MI-CE may explain similar changes in body composition.

Our findings, however, need to be interpreted with caution given the small sample size, the presence of significant baseline differences in some characteristics despite random assignment, and large individual variability in certain changes. An investigation with more participants is warranted to elucidate the impact of different exercise interventions. Another potential factor that could have affected the outcome was the presence of a run-in phase. The run-in phase required the attendance of 5 out of 6 sessions to be eligible for the study and this could have resulted in a selection bias by favoring participants who were more likely to be compliant to the intervention. This selection of more compliant individuals strengthens internal validity but may weaken external validity. However, because all participants were able to complete the run-in phase and were randomized, the impact of the run-in phase on selection bias was minimized.

It is also important to note that there are many different forms of high-intensity interval training. A unique strength of our study is that both exercise groups were matched in regards to prescribed exercise duration, frequency, mean relative intensity and volume. While this allows us to control for confounding variables in a research context, it may not represent some practical forms of interval training that may have less recovery and/or shorter total exercise durations. With regard to HbA_{1c}, fasting glucose, cholesterols, lipoproteins, and triglycerides, there was minimal to no improvement observed in the present study. As indicated by a recent systematic review, relatively low HbA_{1c} at baseline [2], as well as lack of statistical power to detect meaningful differences may be responsible for the lack of change. Lastly, while changes in VO_{2peak} did not achieve significant improvement, VT increased significantly, suggesting that both interventions were effective in improving aerobic fitness. While VO_{2peak} is a valid surrogate of VO_{2max} [27], it was expected to be influenced by many factors especially in those who are not accustomed to exercising at a high intensity. Therefore, we regarded VT as more robust assessment of the intervention effects in this population.

In conclusion, high adherence and retention rates indicated that, in individuals with T2D, implementing a 12-week structured high intensity interval exercise training can be as feasible as moderate intensity continuous exercise training. This information is essential for planning more definitive trials, which would require a relatively large sample size and more sensitive measures of glycemic control and intra-abdominal fat. Our results also demonstrated that 12-week HI-IE and MI-CE interventions are equally effective in lowering total body fat but have little impact on HbA_{1c} in relatively well controlled participants with type 2 diabetes.

Conflict of interest

The authors declare that they have no conflict of interest.

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REFERENCES

[1] Colberg SR, Sigal RJ, Fernhall B, Regensteiner JG, Blissmer BG, Rubin RR, et al. Exercise and type 2 diabetes: the American College of Sports Medicine and the American Diabetes Association: joint position statement executive summary. Diabetes Care 2010;33:2692–6.

[2] Umpierre D, Ribeiro PA, Kramer CK, Leitao CB, Zucatti AT, Azevedo MJ, et al. Physical activity advice only or structured exercise training and association with HbA1c levels in type 2 diabetes: a systematic review and meta-analysis. JAMA 2011;305:1790–9.

[3] Boule NG, Kenny GP, Haddad E, Wells GA, Sigal RJ. Meta-analysis of the effect of structured exercise training on cardiorespiratory fitness in type 2 diabetes mellitus. Diabetologia 2003;46:1071–81.

[4] Snowling NJ, Hopkins WG. Effects of different modes of exercise training on glucose control and risk factors for complications in type 2 diabetic patients – a meta-analysis. Diabetes Care 2006;29:2518–27.

[5] Dubé JJ, Fleishman K, Rousson V, Goodpaster GH, Amati F. Exercise dose and insulin sensitivity: relevance for diabetes prevention. Med Sci Sports Exerc 2012;44:793–9.

[6] Coker RH, Hays NP, Williams RH, Brown AD, Freeling SA, Kortebein PM, et al. Exercise-induced changes in insulin action and glycogen metabolism in elderly adults. Med Sci Sports Exerc 2007;38:433–8.

[7] DiPietro L, Dziura J, Yeckel CW, Neufer PD. Exercise and improved insulin sensitivity in older women: evidence of the enduring benefits of higher intensity training. J Appl Physiol 2006;100:142–9.

[8] Devlin JT, Horton ES. Effects of prior high-intensity exercise on glucose metabolism in normal and insulin-resistant men. Diabetes 1985;34:973–9.

[9] Kang J, Robertson RJ, Hagberg JM, Kelly DE, Goss FL, DeSilva SG, et al. Effect of exercise intensity on glucose and insulin metabolism in obese individuals and obese NIDDM patients. Diabetes Care 1996;19:341–9.

[10] Rogers MA. Acute effects of exercise on glucose tolerance in non-insulin-dependent diabetes. Med Sci Sports Exerc 1989;21:362–8.

[11] Tremblay A, Despres JP, Leblanc C, Craig CL, Ferris B, Stephens T, et al. Effect of intensity of physical-activity on body fatness and fat distribution. Am J Clin Nutr 1990;51:153–7.

[12] Irving BA, Davis CK, Brock DW, Weltman JY, Swift D, Barrett EJ, et al. Effect of exercise training intensity on abdominal visceral fat and body composition. Med Sci Sports Exerc 2008;40:1863–72.

[13] Sasai H, Katayama Y, Nakata Y, Ohkubo H, Tanaka K. Obesity phenotype and intra-abdominal fat responses to regular aerobic exercise. Diabetes Res Clin Pract 2009;84:230–8.

[14] Coker RH, Williams RH, Kortebein PM, Sullivan DH, Evans WJ. Influence of exercise intensity on abdominal fat and adiponectin in elderly adults. Metab Syndr Relat Disord 2009;7:363–8.

[15] Nicklas BJ, Wang X, You T, Lyles MF, Demons J, Easter L, et al. Effect of exercise intensity on abdominal fat loss during calorie restriction in overweight and obese postmenopausal women: a randomized, controlled trial. Am J Clin Nutr 2009;89:1043–52.

[16] Cho JK, Lee SH, Lee JY, Kang HS. Randomized controlled trial of training intensity in adiposity. Int J Sports Med 2011;32:468–75.

[17] Donahue KE, Mielenz TJ, Sloane PD, Collahan LF, Devellis RF. Identifying supports and barriers to physical activity in patients at risk for diabetes. Prev Chronic Dis 2006;3:A119.

[18] Skarfors E, Wengenert T, Lithell H, Selinus I. Physical-training as treatment for type-2 (non-insulin-dependent) diabetes in elderly men – a feasibility study over 2 years. Diabetologia 1987;30:930–3.

[19] Korkiakangas EE, Alahuhta MA, Laitinen JH. Barriers to regular exercise among adults at high risk or diagnosed with type 2 diabetes: a systematic review. Health Promot Int 2009;24:416–27.

[20] Mourier A, Gautier J, DeKerviler E, Bigard AX, Villette JM, Garnier JP, et al. Mobilization of visceral adipose tissue related to the improvement in insulin sensitivity in response to physical training in NIDDM – effects of branched-chain amino acid supplements. Diabetes Care 1997;20:385–91.

[21] Gillen JB, Little JP, Punthakee Z, Tarnopolsky MA, Riddell MC, Gibala MJ. Acute high-intensity interval exercise reduces the postprandial glucose response and prevalence of hyperglycemia in patients with type 2 diabetes. Diabetes Obes Metab 2012;14:575–7.

[22] Little JP, Gillen JB, Percival ME, Safdar A, Tarnopolsky MA, Punthakee Z, et al. Low-volume high-intensity interval training reduces hyperglycemia and increases muscle mitochondrial capacity in patients with type 2 diabetes. J Appl Physiol 2011;111:1554–60.

[23] Hawley JA, Gibala MJ. What's new since hippocrates? Preventing type 2 diabetes by physical exercise and diet. Diabetologia 2012;55:535–9.

[24] Bertin E, Marcus C, Ruiz JC, Eschard JP, Leutenegger M. Measurement of visceral adipose tissue by DXA combined with anthropometry in obese humans. Int J Obes 2000;24:263–70.

[25] Heymsfield SB, Wang Z, Baumgartner RN, Ross R. Human body composition: advances in models and methods. Annu Rev Nutr 1997;17:527–58.

[26] Glickman SG, Marn CS, Supiano MA, Dengel DR. Validity and reliability of dual-energy X-ray absorptiometry for the assessment of abdominal adiposity. J Appl Physiol 2004;97:509–14.

[27] Day JR, Rossiter HB, Coats EM, Skasick A, Whipp BJ. The maximally attainable Vo(2) during exercise in humans: the peak vs. maximum issue. J Appl Physiol 2003;95:1901–7.

[28] Beaver WL, Wasserman K, Whipp BJ. A new method for detecting anaerobic threshold by gas exchange. J Appl Physiol 1986;60:2020–7.

[29] American College of Sports Medicine. ACSM's guidelines for graded exercise testing and prescription, 8th ed., Philadelphia: Wolters Kluwer Health/Lippincott Williams & Wilkins; 2010.

[30] McAuley E, Courneya KS. The subjective exercise experiences scale (SEES): development and preliminary validation. J Sport Exerc Psychol 1994;16:163–77.

[31] Rodgers W, Sullivan M. Task, coping, and scheduling self-efficacy in relation to frequency of physical activity. J Appl Soc Psychol 2001;31:741–53.

[32] Rodgers WM, Blanchard CM, Sullivan MJ, Bell GJ, Wilson PM, Gesell JG. The motivational implications of characteristics of exercise bouts. J Health Psychol 2002;7:73–83.

[33] Sigal RJ, Kenny GP, Boule NG, Wells GA, Prud'homme D, Fortier M, et al. Effects of aerobic training, resistance training, or both on glycemic control in type 2 diabetes: a randomized trial. Ann Intern Med 2007;147:357–69.

[34] Otterman NM, van Schie CHM, van der Schaaf M, van Bon AC, Busch-Westbroek TE, Nollet F. An exercise programme for patients with diabetic complications: a study on feasibility and preliminary effectiveness. Diabet Med 2011;28:212–7.

[35] McAuley E, Rudolph D. Physical-activity, aging, and psychological well-being. J Aging Phys Act 1995;3:67–96.

[36] Blanchard CM, Rodgers WM, Wilson PM, Bell GJ. Does equating total volume of work between two different exercise conditions matter when examining exercise-induced feeling states? Res Q Exerc Sport 2004;75:209–15.
[37] McAuley E, Elavsky S, Jerome GJ, Konopack JF, Marquez DX. Physical activity-related well-being in older adults: social cognitive influences. Psychol Aging 2005;20:295–302.
[38] Daley AJ, Welch A. Subjective exercise experiences during and after high and low intensity exercise in active and inactive adult females – some preliminary findings. J Sports Med Phys Fitness 2003;43:220–2.
[39] Blanchard CM, Rodgers WM, Spence JC, Courneya KS. Feeling state responses to acute exercise of high and low intensity. J Sci Med Sport 2001;4:30–8.
[40] King NA, Caudwell P, Hopkins M, Byrne NM, Colley R, Hills AP, et al. Metabolic and behavioral compensatory responses to exercise interventions: barriers to weight loss. Obesity 2007;15:1373–83.
[41] Ross R, Janssen I, Dawson J, Kungl AM, Kuk JL, Wong SL, et al. Exercise-induced reduction in obesity and insulin resistance in women: a randomized controlled trial. Obes Res 2004;12:789–98.
[42] Sasai H, Katayama Y, Numao S, Nakata Y, Tanaka K. Effects of exercise on visceral fat in obese middle-aged men: comparison to dietary modification. Jpn J Phys Fit Sport 2008;57:89–99.
[43] O'Leary VB, Marchetti CM, Krishnan RK, Stetzer BP, Gonzalez F, Kirwan JP. Exercise-induced reversal of insulin resistance in obese elderly is associated with reduced visceral fat. J Appl Physiol 2006;100: 1584–9.