



Combining supervised run interval training or moderate-intensity continuous training with the diabetes prevention program on clinical outcomes

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Abstract

Purpose The present study was designed to evaluate the 16 weeks diabetes prevention program (DPP) combined with instructed run sprint interval training (INT) or moderate-intensity continuous training (MICT) on glycemic control, body composition, fitness, exercise adherence, and perceived exercise enjoyment in sedentary, adults with prediabetes.

Methods Participants completed three weekly supervised sessions of INT (4–10 bouts of 30 s maximal sprints followed by a 4 min active recovery) or MICT (30–60 min at 45–55% HRR) exercise coupled with the DPP for 16 weeks. At baseline, 8 and 16 weeks, participants completed fitness and clinical assessments as well as questionnaires to assess group and time differences.

Results Twenty-nine study participants (INT $n = 17$, MICT $n = 12$) were randomized, however, significantly ($p = 0.024$) more participants withdrew from the INT ($n = 11$) than MICT ($n = 4$) treatment. There was no significant difference between groups in perceived exercise enjoyment, but, the MICT group significantly improved their perceived exercise enjoyment (10.8 ± 14.2 ; $p = 0.021$) from baseline to 16 weeks. Both INT and MICT groups decreased their body weight (2.0 ± 0.8 vs. -5.5 ± 1.4 kg; $p < 0.001$), BMI (-0.6 ± 0.3 vs. -2.1 ± 0.5 kg/m²; $p < 0.001$), body fat mass (1.4 ± 0.6 vs. -4.2 ± 1.0 kg; $p < 0.001$), fasting glucose (-0.09 ± 0.01 vs. -0.18 ± 0.02 mmol/L; $p = 0.020$), and HbA1c (-0.21 ± 0.09 vs. $-0.12 \pm 0.12\%$; $p = 0.001$), respectively, however, the MICT had greater reductions (GxT: $p \leq 0.05$) in body weight, BMI, and body fat than the INT group.

Conclusion Sixteen weeks of MICT is adhered to better and elicits greater improvements in body composition than INT. Nevertheless, both interventions similarly reduced fasting glucose and HbA1c in adults with prediabetes, suggesting either treatment could be effective for T2D prevention.

Keywords Prediabetes · Glucose control · Body composition · Exercise enjoyment · Sprint interval training · Diabetes prevention program

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Abbreviations

ACSM	American College of Sports Medicine
ANOVA	Analysis of variance
BMI	Body mass index
BP	Blood pressure
DPP	Diabetes prevention program
GxT	Group by time interaction
HbA1c	Hemoglobin A1c
HR	Heart rate
INT	Interval training
ITT	Intention to treat
MICT	Moderate-intensity continuous exercise
OGTT	Oral glucose tolerance test
PACES	Physical activity enjoyment scale

RPE	Rate of perceived exertion
SE	Standard error
T2D	Type 2 diabetes
WHR	Waist-to-hip ratio

Introduction

Prediabetes is a major public health concern, affecting approximately 86 million adults in the United States (American Diabetes Association 2016). Prediabetes is characterized as an increased blood glucose concentration that is higher than normal but not high enough for a type 2 diabetes (T2D) diagnosis (American Diabetes Association 2016; Centers for Disease Control and Prevention 2016). Without pharmacological or lifestyle intervention, prediabetes generally progresses to T2D within 10 years (Centers for Disease Control and Prevention 2016). The consequences of utilizing pharmacological interventions to treat prediabetes and prevent the progression of the disease includes increased out of pocket expense and risk for adverse events (Gillies et al. 2007). Furthermore, a meta-analysis comparing lifestyle to pharmacological interventions on the prevention of prediabetes progressing to T2D showed that lifestyle interventions are as effective as pharmacological treatment (Gillies et al. 2007). Thus, lifestyle interventions should be the first-line treatment for intervening in adults with prediabetes.

The diabetes prevention program (DPP) was designed to compare the efficacy of an intensive lifestyle intervention, designed to treat or delay the development of T2D in adults with prediabetes, compared to a standard lifestyle recommendations combined with metformin or a placebo drug (The Diabetes Prevention Program Research Group 1999). In short, the intensive lifestyle intervention included 16 individual educational sessions from case managers on diet, exercise, and behavior modification over 24 weeks. Furthermore, case managers provided individualized support to aide in participants reaching the two primary goals of the program, losing > 7% of initial body weight and increasing activity levels to achieve 150 min/week of moderate physical activity (The Diabetes Prevention Program Research Group 1999). To aide in reaching the physical activity goals, participants underwent two supervised exercise sessions per week. With this, 74% of participants in the lifestyle intervention group met the physical activity goal by the end of the 24 weeks (The Diabetes Prevention Program Research Group 1999, 2002). In 2.8 years, the DPP showed that an intensive lifestyle intervention had the greatest proportion of participants who met the physical activity goal, had the greatest weight loss (5.6 vs. 2.1 vs. 0.1 kg), and lowest incidence of diabetes (4.8 vs. 7.8 vs. 11.0

cases per 100 person-years) compared to the standard lifestyle recommendations coupled with metformin or a placebo drug, respectively (The Diabetes Prevention Program Research Group 2002).

Despite the clear benefits of exercise for preventing the progression of the disease, Taylor et al. (2010) found that only 38% of adults with prediabetes are meeting the American College of Sports Medicine's (ACSM) physical activity guidelines. The most commonly reported barriers to physical activity are internal barriers, specifically perceived lack of time and lack of enjoyment (Mullen et al. 2011; Stutts 2002). Therefore, presenting an exercise intervention that addresses these barriers and elicits similar physiological adaptations as moderate-intensity exercise is crucial to the prediabetic population as an effort to slow the progression of the disease.

Sprint interval training is a time efficient type of interval training that utilizes supramaximal 30-s 'all out' exercise efforts to elicit the similar physiological adaptations as traditional moderate-intensity continuous aerobic training (MICT) (Burgomaster et al. 2007; Hazell et al. 2014; Macpherson et al. 2010; Rowley et al. 2017; Sandvei et al. 2012), including significant improvements in body mass, fat mass, waist circumference, VO_{2peak} , and fasting glucose (Hazell et al. 2014; Macpherson et al. 2010; Sandvei et al. 2012). Interestingly, it has previously been shown that 8 weeks of MICT and sprint interval training similarly improve fasting glucose in young, healthy adults (Sandvei et al. 2012); however, 12 weeks of sprint interval training or MICT did not improve fasting glucose or HbA1c in overweight/obese women with normal glucose tolerance (Rowley et al. 2017). Nevertheless, it has yet to be determined if instructed sprint interval training (INT) is superior to MICT for improvements in fasting glucose and hemoglobin A1c (HbA1c) as well as other clinical outcomes in adults with impaired fasting glucose and/or glycemic control. Furthermore, to date, the effectiveness of the DPP has only been explored when coupling an intensive lifestyle intervention with moderate-intensity exercise and not INT. Previous work by our group showed that 12 weeks of run sprint interval training resulted in the same exercise adherence and perceived exercise enjoyment as MICT, suggesting that individuals will adhere similarly to either exercise intensity (Rowley et al. 2017).

The purpose of the present study was to evaluate the effects of supervised MICT versus run INT when combined with the DPP's 16-week intensive lifestyle intervention educational classes in adults with prediabetes at improving clinical and fitness measures. The secondary purpose of the study was to determine the perceived exercise enjoyment and exercise adherence to MICT or INT in adults with prediabetes.

Methods

Overview

This study was a 16-week, randomized controlled trial designed to compare the effects of a INT protocol to a MICT exercise protocol in sedentary adults with diagnosed prediabetes, according to the American Diabetes Association criteria (fasting plasma glucose 100–126 mg/dL, blood glucose between 140 and 199 mg/dL 2 h after an oral glucose tolerance test (OGTT), or HbA1c of 5.7–6.4%). Clinical and fitness measures, perceived exercise enjoyment, and exercise adherence were assessed at baseline, 8 weeks, and 16 weeks. All procedures performed in this study were in accordance with the ethical standards of James Madison University's (Harrisonburg, VA) Institutional Review Board and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Participants

For the study, 37 adults, aged 18–71 years, were recruited by flyers, television commercials, newspaper and radio advertisements, and referrals from local physicians in the Harrisonburg, VA area. At baseline, a physician approval form confirming the participant's prediabetes diagnosis was received and informed consent was obtained from all individual participants included in the study. Study participants were physician-diagnosed prediabetic, had no other known diseases or comorbidities limiting physical activity (assessed with the physical activity readiness questionnaire), and were sedentary (defined as not meeting the ACSM physical activity recommendations and assessed using the international physical activity questionnaire). The international physical activity questionnaire required participants to self-report activity levels for the past 7 days to determine low, moderate, or high activity levels (Craig et al. 2003). Participants were excluded if they had a previous diagnosis of type 1 or type 2 diabetes, women who were currently pregnant, and/or those demonstrating signs or symptoms of cardiovascular disease according to the ACSM. Of the 37 adults recruited, 29 participants met inclusion criteria and were randomized.

Clinical measures

Height (cm) was measured with a stadiometer and weight (kg) was measured on a digital platform to assess body mass index (BMI). Dual-energy X-ray absorptiometry (DXA, GE Lunar Prodigy iDXA, Chicago, IL) was used to measure body fat (kg) and lean mass (kg). Waist and hip circumferences were obtained with a plastic tape measure to determine

waist-to-hip ratio (WHR) and central obesity. Resting heart rate (RHR, bpm) as well as systolic and diastolic blood pressure (BP, mm/Hg) were assessed after a 10-min rest period laying supine.

Participants had their blood drawn from an antecubital vein by a certified phlebotomist after an overnight fast at a laboratory associated with the regional hospital. Blood parameters assessed included blood glucose, HbA1c, and insulin. The homeostasis model assessment was used to estimate insulin resistance (HOMA-IR) (Matthews et al. 1985).

Fitness measures

Cardiorespiratory fitness was assessed using a maximal oxygen consumption (VO_{2peak}) treadmill test (Parvo Medics, Sandy, UT). After a 3 min warm-up, VO_{2peak} was measured utilizing a modified ramp protocol. Participants self-selected a speed they could comfortably maintain for the test. Grade began at 0% and increased by 2.5% every 3 min until maximal effort was reached according to the following criteria; a respiratory exchange ratio greater than 1.1, a rating of perceived exertion (RPE) of 19 or 20 on the Borg Scale, and/or a HR max within 10 beats/min of age expected HR max.

Exercise enjoyment

The physical activity enjoyment scale (PACES) assessed physical activity enjoyment utilizing a 16-statement questionnaire. The questionnaire scored participants on a seven point Likert Scale ranging from 1 ("Disagree a lot") to 7 ("Agree a lot"). Each question began with "When I am active" (Kendzierski and DeCarlo 1991). A higher total score on PACES was associated with a higher perceived enjoyment.

Dietary intake

Dietary intake and patterns were assessed by participants completing a 3 day food intake record prior to clinical and fitness testing at each time point. Food intake records were analyzed using the Nutrition Data System for Research 2.0 (Minneapolis, MN) to determine total caloric intake and macronutrient composition, including carbohydrate, fat, and protein, of daily intake. Participants were counseled on how to appropriately complete the food intake record and quality assurance was conducted by a Registered Dietician Nutritionist.

Exercise and lifestyle interventions

Participants were randomized to two different groups including an INT or MICT protocol. All training sessions were supervised by trained exercise physiologists, 3 days a week,

for 16 weeks. Training volume progressed every 4 weeks. Each exercise session began and ended with stretching and a 5 min walk at a self-selected, low-intensity speed and grade. Weekly physical activity was measured by accounting for time spent in supervised exercise including the warm-up, exercise training protocol, and cool down. At the familiarization session participants were informed that they were required to attend 80% of exercise sessions or risked termination from the study. Exercise adherence was defined as the total number of sessions attended out of 48.

The INT group was instructed to run maximally at a self-selected speed and grade on a motorized treadmill so that HR was within 10 bpm of HR_{max} and RPE reached 19–20 on the Borg Scale. HR and RPE were recorded after each interval. Initially, INT ran four, 30 s perceived maximal sprints. Following the 30 s sprint, participants had a 4 min active rest of walking at a speed of 2.0 mph and 0% grade. Every 4 weeks the number of sprints increased by 2 so by the end of the training, INT participants were completing 10 sprints. The MICT group initially walked on a treadmill for 30 min at 45–55% of heart rate reserve. Every 4 weeks, the length of training increased by 10 min so that at the end of the study, participants in the MICT group participated in 60 min sessions.

All participants were required to attend the 16-week CDC DPP's educational classes (The Diabetes Prevention Program Research Group 1999). The DPP classes were taught by certified lifestyle coaches in a group setting. If participants could not attend their group session they were required to make up the session on an individual basis.

Statistical analysis

All 29 participants' randomized data were assessed using the intention to treat (ITT) analysis in accordance with the DPP's principles. For participants who withdrew or dropped out, the last observation carried forward method (Streiner and Geddes 2001) was utilized to fill missing data points. However, we acknowledge that there are many methodological approaches to handle missing data (Elobeid et al. 2009). A secondary analysis was run for only participants who completed the entire intervention ($n = 12$) and is available in the Supplementary Tables. Data were analyzed using the statistical program SPSS (v. 24, IBM Analytics, Armonk, New York). Baseline variables, assessed using independent t tests, were not different between the two study groups. Clinical and fitness measures were analyzed using a two-way repeated measure analysis of variance (ANOVA) to assess group by time interaction (GxT) and time effects. Bonferroni post hoc analysis was used to determine group and time differences. Within group differences for the PACES questionnaire and non-normally distributed data were determined

using Friedman's related samples analysis with Wilcoxon signed rank post hoc analysis. Between group differences for PACES questionnaire and non-normally distributed data were determined using Mann–Whitney U analysis. Data are presented as mean \pm standard error (SE). Significance was set a priori at $p \leq 0.05$.

Results

Participant characteristics

Over 10 months, 29 study participants were randomly assigned to one of the two interventions (INT $n = 17$, MICT $n = 12$). Participants were obese (BMI 35.85 ± 1.32 kg/m²), sedentary (VO_{2peak} 24.45 ± 1.09 mL/kg/min), and characterized as having prediabetes (HbA1c $5.86 \pm 0.08\%$; fasting glucose 100.86 ± 2.30 mg/dL). Throughout the study, 14 participants withdrew due to injury (INT $n = 6$), abnormal cardiovascular response to exercise (INT $n = 1$), lack of time (INT $n = 3$, MICT $n = 2$), and personal reasons (INT $n = 1$, MICT $n = 1$), and there was a significantly greater number of participants who dropped out of the INT group compared to the MICT group ($p = 0.024$). Therefore, 15 participants (INT $n = 6$, MICT $n = 9$) completed the entire 16-week intervention (Supplementary Data).

Exercise adherence, training, and enjoyment

Exercise adherence was not different at 8 weeks (INT 18 ± 1 , MICT 20 ± 1 , out of a possible 24 sessions) or 16 weeks (INT 43 ± 1 , MICT 44 ± 4 , out of a possible 48 sessions) between the groups. Participants in the INT group completed sprint intervals at an averaged $79.8 \pm 3.3\%$ HR_{max} and 15.6 ± 0.5 RPE for all sessions over the 16 weeks, and MICT participants worked at an average $53.1 \pm 2.3\%$ HRR and 11.0 ± 0.8 RPE for all sessions completed. There were no differences between groups at any time point or in change from baseline to 8 weeks, 8 weeks to 16 weeks, or baseline to 16 weeks for perceived exercise enjoyment; however, the MICT group significantly increased ($p = 0.030$) the PACES scores over the study while the INT group did not (Fig. 1). Post hoc analyses in the MICT group showed that perceived enjoyment significantly increased from baseline to 8 weeks (9.15 ± 3.37 ; $p = 0.041$) as well as from baseline to 16 weeks (10.77 ± 14.19 ; $p = 0.021$) but there was no change from 8 weeks to 16 weeks (1.62 ± 3.33 ; $p = 0.114$). The change in perceived exercise enjoyment was greater from baseline to 8 weeks than 8 weeks to 16 weeks in MICT ($p = 0.056$) and INT ($p = 0.059$) groups.

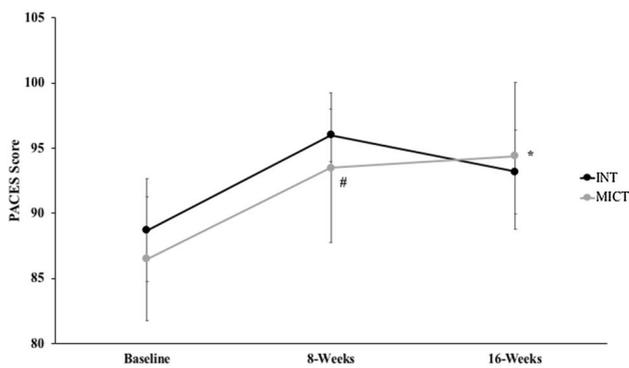


Fig. 1 Physical activity enjoyment scale scores at baseline, 8 weeks, and 16 weeks between INT and MICT groups. Data are presented as mean ± SE and based off of the intention to treat analyses. *Significant time effect ($p < 0.05$) in MICT group. #Significant difference ($p < 0.05$) within the MICT group from baseline to 8 weeks. INT run sprint interval training, MICT moderate-intensity continuous training, PACES physical activity enjoyment scale

Clinical and fitness measures

Clinical and fitness measures at all time points for both interventions are reported in Table 1. Both groups significantly (time: $p < 0.001$) decreased body weight, BMI, and fat mass (Fig. 2). Post hoc analyses showed that from baseline to 16 weeks, the INT group had a trend towards a significant improvement in body weight ($- 2.00 \pm 0.79$ kg; $p = 0.066$) and BMI ($- 0.64 \pm 0.26$ kg/m²; $p = 0.084$), and

from baseline to 8 weeks, the INT group had a significant improvement in body fat mass ($- 1.38 \pm 0.50$ kg; $p = 0.039$). The MICT group had a significant improvement in body weight ($- 3.66 \pm 0.79$ kg; $p = 0.001$), BMI ($- 1.22 \pm 0.31$ kg/m²; $p = 0.007$), and body fat mass ($- 2.12 \pm 0.61$ kg; $p = 0.013$) from baseline to 8 weeks. BMI significantly improved ($- 0.88 \pm 0.26$ kg; $p = 0.017$) and there was a trend towards a significant improvement in body weight ($- 1.80 \pm 0.67$ kg; $p = 0.061$) and fat mass (2.07 ± 0.75 kg; $p = 0.053$) from 8 to 16 weeks in the MICT group. Finally, the MICT group had a significant decrease in body weight ($- 5.46 \pm 1.35$ kg; $p = 0.005$), BMI ($- 2.09 \pm 0.50$; $p = 0.004$ kg/m²), and body fat mass ($- 4.20 \pm 0.98$ kg; $p = 0.003$) from baseline to 16 weeks. MICT elicited greater reductions in body weight (GxT: $p = 0.023$), BMI (GxT: $p = 0.011$), and body fat mass (GxT: $p = 0.014$) (Fig. 2) compared to INT. Post hoc analyses showed no significant between group difference at baseline, 8 weeks, or 16 weeks in these variables.

Over the 16 weeks, the INT group had a non-significant 2.03% decrease in body weight while the MICT group had a significant 5.17% decrease. The INT group had a non-significant 1.76% decrease in BMI while the MICT group had a significant 5.34% decrease over 16 weeks. With this, the MICT group had a clinically meaningful reduction in their BMI categorization from obesity class II to obesity class I and the INT group remained in the obesity class II category throughout the entire study. Over the 16 weeks, the INT group had a non-significant 3.14% decrease in

Table 1 Clinical and fitness measures at baseline, 8 weeks, and 16 weeks for MICT and INT groups

	INT (n = 17)			MICT (n = 12)		
	Baseline	8 weeks	16 weeks	Baseline	8 weeks	16 weeks
Age (years)	45.7 ± 4.4	–	–	50.8 ± 4.4	–	–
Weight (kg)	98.4 ± 5.8	97.4 ± 5.8	96.4 ± 6.2*	96.2 ± 4.3	92.7 ± 4.1	91.3 ± 3.8 ⁺ *
BMI (kg/m ²)	35.8 ± 2.0	35.2 ± 1.9	35.1 ± 1.9*	36.0 ± 1.7	34.8 ± 1.6	34.1 ± 1.6 ⁺ *
Fat mass (kg)	43.3 ± 3.9	42.0 ± 3.9	42.0 ± 4.0*	44.2 ± 3.5	41.8 ± 3.5	40.1 ± 3.5 ⁺ *
Lean mass (kg)	51.8 ± 2.5	52.0 ± 2.5	52.3 ± 2.5	48.4 ± 2.0	48.0 ± 2.2	48.0 ± 2.2
WHR	0.93 ± 0.03	0.93 ± 0.03	0.93 ± 0.03	0.98 ± 0.03	0.98 ± 0.02	0.97 ± 0.03
RHR (bpm)	68.4 ± 2.7	67.2 ± 2.4	65.8 ± 2.4	69.9 ± 3.31	68.1 ± 2.8	66.6 ± 2.9
SBP (mm/Hg)	124.2 ± 3.0	120.9 ± 2.9	115.8 ± 6.2	129.3 ± 4.7	125.0 ± 4.2	126.8 ± 3.8
DBP (mm/Hg)	82.1 ± 2.5	79.8 ± 2.0	82.0 ± 1.8	78.2 ± 2.9	76.5 ± 2.9	76.3 ± 2.8
Fasting glucose (mmol/L)	5.52 ± 0.14	5.42 ± 0.12	5.43 ± 0.13*	5.72 ± 0.24	5.49 ± 0.22	5.54 ± 0.22*
HbA1c (%)	5.76 ± 0.11	5.55 ± 0.13	5.55 ± 0.14*	6.00 ± 0.11	5.70 ± 0.09	5.88 ± 0.08*
Fasting insulin (pmol/L)	86.5 ± 9.2	82.9 ± 11.3	77.1 ± 7.4	79.9 ± 9.0	83.1 ± 10.5	75.8 ± 9.6
HOMA-IR (%)	1.58 ± 0.20	1.51 ± 0.20	1.41 ± 0.13	1.46 ± 0.18	1.55 ± 0.20	1.40 ± 0.18
VO _{2peak} (mL/kg/min)	24.4 ± 1.4	25.2 ± 1.4	25.3 ± 1.4	24.5 ± 1.8	25.8 ± 2.2	26.6 ± 2.0

Data are presented as mean ± SE and based off of the intention to treat analyses

INT run sprint interval training, MICT moderate-intensity continuous training, BMI body mass index, WHR waist-to-hip ratio, RHR resting heart rate, SBP systolic blood pressure, DBP diastolic blood pressure, HbA1c hemoglobin A1c, HOMA-IR homeostatic model assessment of insulin resistance

⁺Significant group by time interaction ($p \leq 0.05$), *Significant time effect ($p \leq 0.05$)

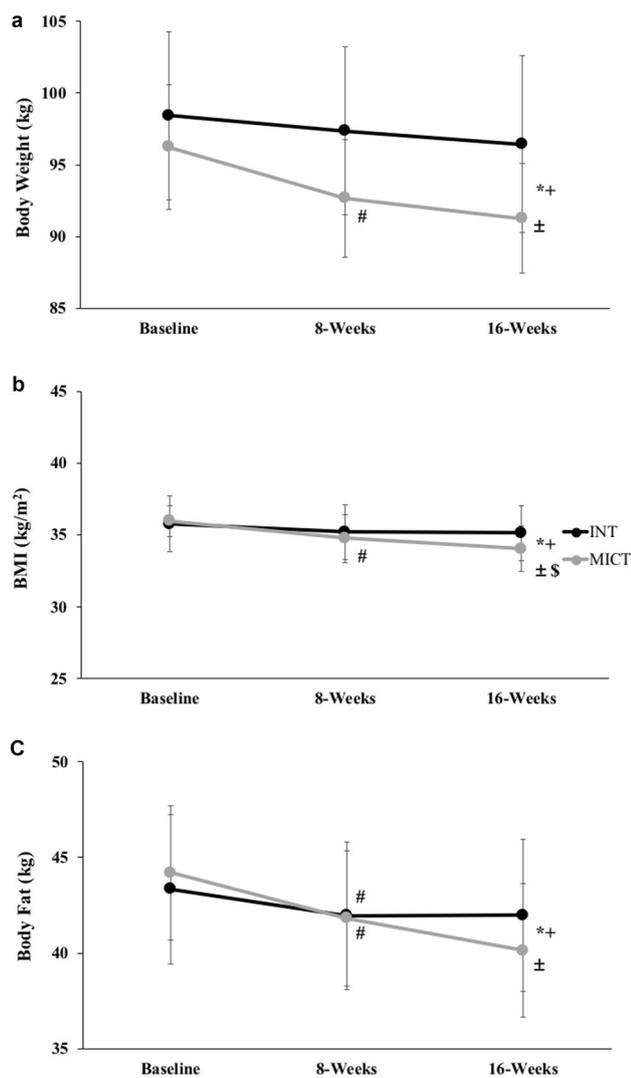


Fig. 2 Changes in body weight (a), BMI (b), and body fat mass (c) at baseline, 8 weeks, and 16 weeks between INT and MICT groups. Data are presented as mean \pm SE and based off of the intention to treat analyses. +Significant group by time interaction ($p < 0.05$). *Significant time effect ($p < 0.05$). #Significant difference ($p < 0.05$) in the INT or MICT group from baseline to 8 weeks. \pm Significant difference ($p < 0.05$) in the MICT group from baseline to 16 weeks. \S Significant difference ($p < 0.05$) in the MICT group from 8 weeks to 16 weeks. INT run sprint interval training, MICT moderate-intensity continuous training, BMI body mass index

body fat mass while the MICT group had a significant 9.19% decrease in body fat mass.

There was no significant group by time interaction for fasting glucose, HbA1c, or insulin, however, both groups similarly improved their fasting glucose (time: $p = 0.020$) and HbA1c (time: $p = 0.001$). Changes in fasting glucose, HbA1c, and insulin over the 16 weeks are shown in Fig. 3 for both INT and MCIT groups. Post hoc analyses showed the INT group had a trend towards a significant improvement in HbA1c from baseline to 8 weeks ($-0.22 \pm 0.08\%$; $p = 0.055$)

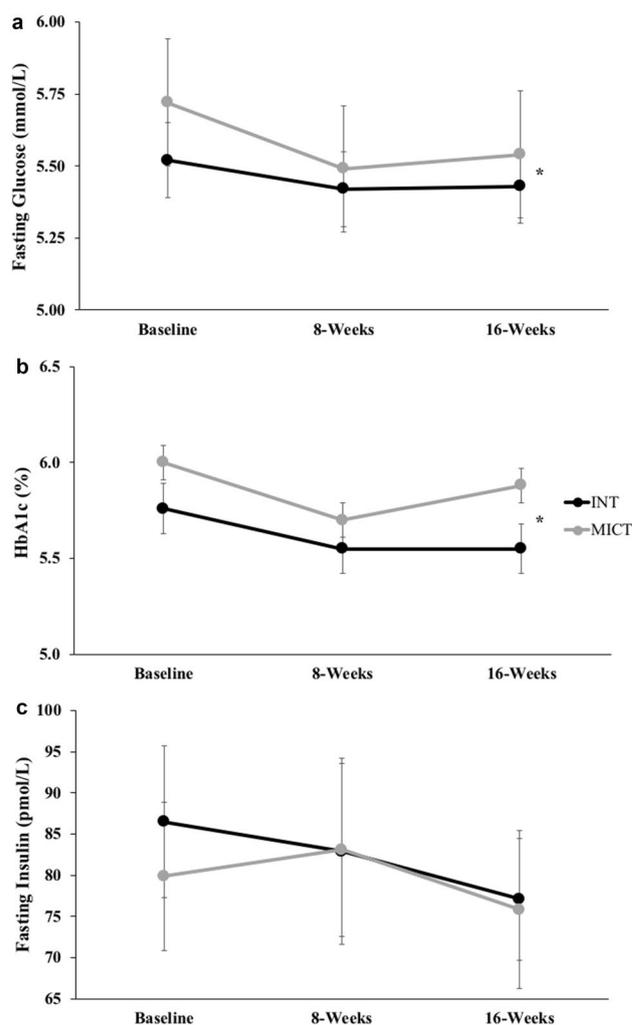


Fig. 3 Changes in fasting glucose (a), HbA1c (b), and fasting insulin (c) over the 16 weeks between INT and MICT groups. Data are presented as mean \pm SE and based off of the intention to treat analyses. *Significant time effect ($p < 0.05$). #Significant difference ($p < 0.05$) in the INT or MICT group from baseline to 8 weeks. INT run sprint interval training, MICT moderate-intensity continuous training, HbA1c hemoglobin A1c

and baseline to 16 weeks ($-0.21 \pm 0.09\%$; $p = 0.073$). The MICT group had a significant improvement in HbA1c from baseline to 8 weeks ($-0.29 \pm 0.10\%$; $p = 0.047$) but no change from baseline to 16 weeks. The percent change for HbA1c was a 3.7% and 2.0% decrease in the INT and MICT group, respectively, over 16 weeks. Fasting glucose was reduced 1.60% in the INT group and 3.16% in the MICT group over 16 weeks.

There was no other significant group by time interaction or a significant time effect for any other variables. However, there was a trend towards both groups increasing their VO_{2peak} (time: $p = 0.059$) (Fig. 4). The INT group had a 3.73% improvement in VO_{2peak} from baseline to 16 weeks while the MICT group had an 8.82% increase.

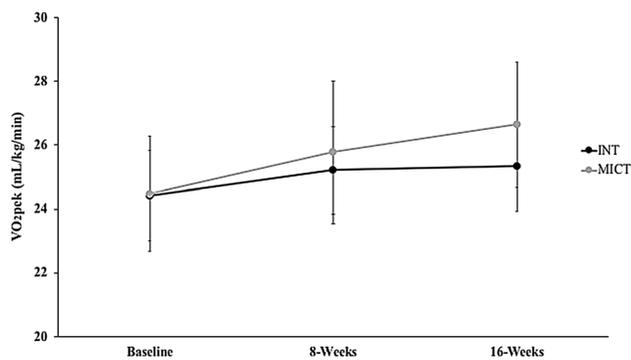


Fig. 4 The change in VO_{2peak} at baseline, 8 weeks, and 16 weeks between INT and MICT groups. Data are presented as mean \pm SE and based off of the intention to treat analyses. *Significant time effect ($p < 0.05$). †Significant difference ($p < 0.05$) within the INT group from baseline to 16 weeks. INT run sprint interval training, MICT moderate-intensity continuous training

Dietary intake

Valid food intake records were returned by 22 study participants (INT $n = 11$, MICT $n = 11$) at baseline and all subsequent time points until participants withdrew from or completed the study. There was no group by time interaction for total caloric intake, carbohydrate, fat, or protein (Table 2), however, both INT and MICT groups significantly decreased their total caloric intake (time: $p = 0.027$) by 20.91% and 11.33%, respectively. Furthermore, the INT group had a 28.65% decrease in total fat intake over the 16-week intervention while the MICT group had a 26.89% decrease (time: $p = 0.002$).

Discussion

In previously sedentary adults with physician-diagnosed prediabetes, 16 weeks of supervised INT and MICT coupled with the DPP-improved fasting blood glucose and HbA1c to the same extent. Previous work showed that MICT combined

with the DPP's intensive lifestyle intervention was effective at improving glucose control in prediabetic adults (The Diabetes Prevention Program Research Group 2002), and we build on this prior work by showing that both exercise training protocols combined with the DPP-improved fasting glucose and HbA1c. Interestingly, the INT group was instructed to run supramaximal 30-s 'all out' sprints, however, these participants actually performed sprints at high intensity and a 'hard' RPE. These findings suggest that INT exercise was sufficient to elicit improvements in glucose control; however, this exercise stimulus was not robust enough to elicit an increase in VO_{2peak} as expected. This highlights that self-selected speed and grade efforts on a motorized treadmill may not be an appropriate modality for supramaximal efforts in obese adults with prediabetes. With this, significantly more participants dropped out of the INT than the MICT treatment, and, while there were not differences between groups, the MICT group increased their perceived exercise enjoyment over the course of the intervention while there was no change in the INT group. Furthermore, the MICT group had superior improvements in body composition measures including body weight, BMI, and total fat mass than the INT group. Taken together, MICT may be a more feasible option for improving clinical outcomes in adults with prediabetes.

A primary goal of the DPP's lifestyle intervention was to elicit a greater than 7% decrease in body weight (The Diabetes Prevention Program Research Group 1999, 2002). In the present study, neither INT or MICT groups met this weight loss goal, as the INT group experienced ~2% reduction in body weight while the MICT group experienced ~5% reduction. In this study, ~17% of participants (INT $n = 1$, MICT $n = 4$) elicited a > 7% total weight loss, compared to results from the original DPP's intensive lifestyle group in which nearly 50% of participants elicited a > 7% total weight loss (The Diabetes Prevention Program Research Group 2002). A second goal of the DPP's lifestyle intervention was to reduce dietary fat intake to less than 25% of total calories (The Diabetes Prevention Program Research Group 1999, 2002), and by the end of 16 weeks, INT and MICT reduced their intake

Table 2 Dietary analysis at baseline, 8 weeks, and 16 weeks for MICT and INT groups

	INT ($n = 11$)			MICT ($n = 11$)		
	Baseline	8 weeks	16 weeks	Baseline	8 weeks	16 weeks
Caloric intake (kcal)	2305.0 \pm 235.1	1830.0 \pm 187.3	1823.2 \pm 209.0*	1882.2 \pm 215.2	1690.5 \pm 158.2	1668.9 \pm 175.7*
CHO (g)	247.9 \pm 29.6	215.0 \pm 16.9	217.6 \pm 23.1	208.3 \pm 29.7	198.9 \pm 24.8	197.1 \pm 32.3
Fat (g)	96.3 \pm 8.2	68.2 \pm 11.3	68.7 \pm 11.7*	84.0 \pm 9.5	68.0 \pm 10.1	61.4 \pm 9.4*
Protein (g)	92.4 \pm 8.4	81.2 \pm 8.4	79.1 \pm 9.3	69.4 \pm 8.3	66.9 \pm 6.3	97.2 \pm 24.4

Data are presented as mean \pm SE

INT run sprint interval training; MICT moderate-intensity continuous training; CHO carbohydrate

* Significant time effect ($p < 0.05$)

so that 31.4% and 35.7% of their total calories were coming from dietary fat, respectively. Both treatments fell short of the DPP's goal, however, INT and MICT had a similar reduction in caloric and fat intake. Interestingly, both treatments had the greatest drop in caloric intake from baseline to 8 weeks, which coincided with the greatest decrease in body mass over the intervention. Thus, a reduction in energy intake likely contributed to the weight loss in both groups. However, individuals in the MICT group had greater reductions in body weight and fat mass compared to those completing INT, but INT participants had a greater reduction in caloric intake (-482 ± 203) compared to MICT participants (-213 ± 238) over 16 weeks. A major limitation to the present study is that a true control group was not employed; therefore, we cannot be certain of the independent effects of the exercise training protocols or DPP's lifestyle nutritional intervention on body composition and other clinical outcomes in prediabetic adults. Nevertheless, our data suggest that the MICT group was in a greater energy deficit, despite a smaller caloric deficit, compared to the INT group. Therefore, the MICT group likely lost more weight compared to the INT group due to greater non-exercise physical activity, exercise energy expenditure, and/or post-exercise oxygen consumption. In support of this, our findings are similar to prior work in which 12 weeks of moderate-/high-intensity continuous exercise elicited greater reductions in body weight and fat mass than shorter duration INT in previously sedentary men (Nybo et al. 2010) and obese adults (Schjerve et al. 2008) without a dietary intervention. A limitation to the present study is we did not use accelerometers to measure non-exercise physical activity, and furthermore, we did not directly measure caloric expenditure during or post-exercise with indirect calorimetry to determine if energy expenditure was greater in MICT versus INT. However, prior work following the exact protocol employed in the present study but on a cycle ergometer in healthy males showed that 30 min of moderate-intensity continuous exercise resulted in greater total oxygen consumption during and for 8 h post-exercise compared to 4 bouts of 30-s sprint interval exercise interspersed with 4 min of active recovery (Hazell et al. 2012). Hazell et al. (2012), however, showed that despite greater oxygen consumption during and acutely post-exercise, oxygen consumption was the same with both exercise protocols over a 24 h period in healthy males. In the present study, the INT and MICT groups worked at $\sim 79.9\%$ and $\sim 73.1\%$ of their HR_{max} , respectively, over all exercise sessions. While the INT group was working at a higher exercise intensity compared to MICT, both treatments were reaching the DPP's weekly physical activity goal (The Diabetes Prevention Program Research Group 1999, 2002), measured by accounting for time spent in supervised exercise including the warm-up, exercise training protocol, and cool down for both treatments, by the end of the 16-week intervention.

Nevertheless, the MICT group was exercising for a longer duration (210 min/week) weekly compared to INT (153 min/week). The large difference in time spent exercising likely explains the greater body weight and fat loss in the MICT group compared to INT. Previous work in overweight/obese women who completed a year long dietary regimen combined with moderate/vigorous intensity/duration exercise showed that duration of exercise was more important than exercise intensity for weight loss. In fact, women reporting < 150 , $150\text{--}199$, or ≥ 200 min/week of exercise had a 4.7, 9.5, and 13.6% weight reduction, respectively, in 1 year (Jakicic et al. 2003). Taken together, decreased energy intake and exercise energy expenditure likely contributed to weight loss in both treatments; however, the greater reduction in body weight and fat mass in the MICT group compared to INT is likely due to greater oxygen consumption during and after a longer exercise protocol.

Despite greater body weight and fat loss in the MICT group, both interventions similarly improved fasting glucose and HbA1c. INT and MICT decreased their HbA1c 0.26% and 0.12%, respectively, over 16 weeks. These findings are clinically relevant as previous work showed that every 0.1% reduction in HbA1c resulted in a 5% reduction in mortality in men with a HbA1c $\geq 5\%$ (Khaw et al. 2001). The findings of the present study differ from that of Terada et al. who found that 12 weeks of high-intensity interval training (1-min at $100\% \text{VO}_2\text{R}$ and 3-min recovery at $40\% \text{VO}_2\text{R}$), 5 times/week, did not have any effect on HbA1c in well-controlled T2D patients (Terada et al. 2013). However, patients with T2D tend to have both impaired fasting glucose and impaired glucose tolerance, which may require a greater stimulus of exercise to elicit favorable changes in ones' glucose profile. Metcalfe et al. (2012) showed that three weekly exercise sessions of high-intensity interval training ($3 \times 10\text{--}20$ s all out bouts) done over 6 weeks can improve glucose tolerance in overweight men. A limitation to the current study was that glucose tolerance, per se, was not assessed. Glucose tolerance, assessed by measuring the 2 h glucose value from an OGTT, improves with exercise training due to improvements in delivery, uptake, and storage of glucose in the skeletal muscle. These improvements are elicited, in part, by decreased skeletal muscle insulin resistance as well as improved insulin signaling and metabolic flexibility (Boyd et al. 2013; Gilbertson et al. 2018; Hughes et al. 1993; Little et al. 2011; Mayer-Davis et al. 1998; Perseghin et al. 1996). Prior work has shown that just 2 weeks of work-matched continuous or interval exercise improves post-prandial glucose tolerance, as assessed by an OGTT, in prediabetic adults (Gilbertson et al. 2018). Together with the improvement in HbA1c in the present study, it is likely that both the INT and MICT groups would have had an improvement in post-prandial glucose control if an OGTT was administered.

Nearly 52% of study participants dropped out of the study over the 16 weeks, which aligns with past research showing that between 30 and 70% of participants drop out of exercise programs (Linke et al. 2011; Mullen et al. 2013; Pollock et al. 1977). Fourteen participants dropped out of the present study and only 3 participants were from the MICT group. The primary reason for participants dropping out of the present study was injury ($n = 6$), and all these participants were in the INT group. Similar to our work, prior research has reported a greater number of injuries obtained from participation in interval exercise compared to MICT (Lunt et al. 2014; Nybo et al. 2010). Furthermore, high-intensity, time-saving, conditioning programs (i.e., CrossFit, Insanity) suggest the prevalence of injury is 19.4–73.5% in participants, and the prevalence of injury in these high-intensity conditioning programs is highest in overweight/obese participants with low cardiorespiratory fitness (Tibana and de Sousa 2018). Research also suggests that incomplete recovery (i.e., phosphagen, oxymyoglobin, H^+) between sprint intervals will decrease power output (Tomlin and Wenger 2001), and our participants maintained or increased sprint speed/incline and thereby power output over the exercise session. Collectively, this could have led to over-exertion and injury. We also did not employ a run-in or familiarization period for exercise, and commencing exercise at a high volume is a primary cause of treadmill running-related injuries (Jin 2014). To minimize injury and maximize participant retention, future research studies, particularly with INT in clinical population, should incorporate a run-in period or use cycle ergometers, as cycle ergometers provide a non-weight bearing activity that has less impact on joints while still eliciting physiological improvements (Bouaziz et al. 2015; Burgomaster et al. 2007; Gilbertson et al. 2018).

Despite drop out from the present study, there was no significant difference in perceived exercise enjoyment between the INT and MICT groups for participants. It has been previously shown that in individuals at high risk for developing T2D, encouragement, social support from others, and exercising with individuals of a similar physical level were important factors reported for enjoying and remaining motivated to exercise (Korkiakangas et al. 2011). Exercise sessions were completed in small groups of two to four participants for both exercise treatments, and so participants exercised with individuals of similar physical level. Also, researchers noted that the small groups provided social support and accountability to attend exercise sessions. Together, these reasons, among others, are likely why there were no group differences in perceived exercise enjoyment.

In conclusion, supervised INT or MICT combined with the DPP's 16-week intensive lifestyle educational sessions significantly improves glycemic control in previously sedentary, overweight and obese adults with prediabetes. However, MICT may be superior to INT for eliciting improvements in

body composition and maintaining participation in an exercise program. While MICT may be a more feasible exercise intensity for previously sedentary adults with prediabetes, recommendations for exercise prescriptions should be individualized based on ones' perceived exercise enjoyment and their risk for injury.

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Author contributions NMG and ESE were primarily responsible for analyzing data and writing this manuscript. JDA, TAH, DLW and ESE were responsible for the study design and obtaining funding. NMG, JAM, and KH recruited participants, collected data, trained participants, and maintained data. JDA reviewed and analyzed food logs. All the authors edited this manuscript and approved submission.

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Compliance with ethical standards

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

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