



Effects of various interval training regimes on changes in maximal oxygen uptake, body composition, and muscular strength in sedentary women with obesity

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Abstract

Purpose We determined the effects of two high-intensity interval training (HIIT) regimens [the traditional (TRAD) and periodized (PER)] on changes in maximal oxygen uptake (VO_2max), body composition, and muscular strength in sedentary, obese women.

Methods Seventeen women (age and BMI = 37.5 ± 10.5 year and 39.1 ± 4.3 kg/m²) were randomized into a 6 week regime of TRAD or PER which consisted of three sessions per week, two in the laboratory, and one on their own. Pre- and post-training, VO_2max , body composition, and muscular strength of the knee extensors (KE) and flexors (KF) were assessed via ramp cycling to exhaustion, air displacement plethysmography, and isokinetic dynamometry, respectively.

Results VO_2max was increased by 4–5% in response to training ($p = 0.045$) with no group-by-time interaction ($p = 0.79$). Body mass, fat mass, and waist-to-hip ratio were unaltered ($p > 0.05$) in response to training, yet there was a significant change in percent body fat ($p = 0.03$), percent fat-free mass ($p = 0.03$), and absolute fat-free mass ($p = 0.03$) in TRAD but not PER. No change occurred in KE ($p = 0.36$) or KF torque ($p = 0.75$) in response to training and there was no group-by-time interaction ($p > 0.05$).

Conclusions Low-volume HIIT improved VO_2max and body composition but did not modify muscular strength, which suggests that obese women desiring to increase strength should initiate more intense HIIT or partake in formal resistance training.

Keywords High-intensity interval exercise · Obesity · Air displacement plethysmography · Muscular force

Abbreviations

BMI	Body mass index
FFM	Fat-free mass
HIIT	High-intensity interval training
HR	Heart rate
VO_2max	Maximal oxygen uptake
MVC	Maximal voluntary contraction
MET	Metabolic equivalent
MICT	Moderate-intensity continuous training
PPO	Peak power output
%BF	Percent body fat
VT	Ventilatory threshold

Introduction

In 2014, 36.5% of the U.S. population was considered obese (Ogden et al. 2015). Moreover, obesity rates are increasing, with the incidence of obesity in U.S. adults increasing from approximately 30% in 2000 to 37% in 2014. In addition, more women suffer from obesity or extreme obesity compared to men (Ogden and Carroll 2010). Obesity is a preventable condition commonly combated by diet and exercise interventions (Pi-Sunyer et al. 1998). However, only 20% of U.S. adults meet the 2008 U.S. Department of Health and Human Services Physical Activity Guidelines for Americans (Centers for Disease Control and Prevention 2010). Low levels of cardiorespiratory fitness (VO_2max) and a high percentage of body fat (%BF) are risk factors for many chronic diseases such as diabetes, hypertension, dyslipidemia, and cardiovascular disease (Kannel et al. 1991; Abate 2000; Kodama et al. 2009) which increase risk of morbidity and mortality (Katzmarzyk et al. 2004). Another consequence of low levels of physical activity is poor muscular strength

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(Rantanen et al. 1992) which is an independent risk factor for diabetes and cardiovascular disease (Shiroma et al. 2017) as well as all-cause mortality (Rantanen et al. 2000). Therefore, it is necessary to investigate effective strategies to improve VO_2max , body composition, and muscular strength in obese adults.

Despite the well-documented benefits of exercise training, many obese individuals do not participate in physical activity citing lack of time as the largest barrier (Reichert et al. 2007). In fact, only 1.5–3.0% of obese adults meet the current recommendations of 150 min/week of moderate-intensity continuous training (MICT) (Tudor-Locke et al. 2010), so research is needed to identify practical and effective exercise modalities in this population. High-intensity interval training (HIIT) is characterized by repeated, brief, and intense exercise bouts separated by active recovery. In non-obese adults, significant increases in VO_2max , fat oxidation, glycemic control, and exercise performance occur in response to HIIT (Gibala et al. 2006; Hazell et al. 2010; Astorino et al. 2011) which improve exercise capacity and health status (Daussin et al. 2008). In addition, studies have tested the effects of HIIT in overweight and obese individuals. Kong et al. (2016) reported that 5 weeks of HIIT requiring 20 min bouts consisting of repeated 8 s sprints followed by 12 s recovery increased VO_2max by 9% which was similar to MICT (10%). Similarly, Sawyer et al. (2016) showed significant increases in VO_2max in obese adults (%BF and BMI = 45.6% and 37.4 kg/m²) after 8 weeks of HIIT. In contrast, Baekkerud et al. (2016) reported that only higher volume HIIT consisting of 4 × 4 min bouts resulted in significant improvements (10%) in VO_2max compared to lower volume 10 × 1 HIIT (3%) and MICT at 70%HR_{max} (3%) in adults with BMI equal to 30 kg/m². The disparate changes in VO_2max across studies are likely due to different participant characteristics as well as differences in the specific HIIT regimes employed, and warrant further study investigating the effects of HIIT in individuals with obesity. Moreover, the individuals in these studies typically exhibit mild obesity as participants in the Kong et al. (2016) and Baekkerud et al. (2016) studies had %BF < 35%. Less is known about the efficacy of HIIT to improve VO_2max in individuals with more severe obesity who maintain altered cardiovascular function (de Divitiis et al. 1981) which may lead to low values of VO_2max . Low VO_2max is a significant risk factor for onset of cardiovascular disease, hypertension, and diabetes (Sui et al. 2008), and has been cited as the best predictor of mortality and morbidity (Myers et al. 2002; Katzmarzyk et al. 2004). Thus, HIIT could be used as a strategy to induce rapid gains in fitness level which is essential in obese populations.

Although HIIT consistently improves VO_2max (Weston et al. 2014), it does not always significantly reduce fat mass in healthy individuals (Hottenrott et al. 2012; Astorino et al. 2013; Bagley et al. 2016). Similar results have also

been shown in obese populations, as some data state that MICT is more effective for fat mass reduction than HIIT (Keating et al. 2014; Kong et al. 2016). However, other findings in obese populations demonstrate that HIIT significantly reduces body fat (Trapp et al. 2008; Gillen et al. 2013; Sawyer et al. 2016). Therefore, there is no consensus regarding the effects of HIIT on changes in body composition in obese populations (De Feo 2013).

Similar to body composition, HIIT does not consistently increase muscular strength in healthy populations (Astorino et al. 2012; Faude et al. 2013; Costigan et al. 2015). Nevertheless, in older adults, 5 months of HIIT significantly improved strength (Nemoto et al. 2007). HIIT and its more intense form, sprint interval training (SIT), primarily lead to adaptations within the oxidative system (Burgomaster et al. 2005; Zinner et al. 2016), yet strength is dictated more by muscle hypertrophy and responses within the central nervous system such as alterations in motor unit recruitment. Nevertheless, the high force and supramaximal intensity characteristic of SIT require a greater contribution of non-oxidative metabolism and, in turn, may result in improved muscular strength (Slade et al. 2002; Alemdaroğlu 2012).

The purpose of this study was to investigate the effects of two different regimes of high-intensity interval training on changes in VO_2max , body composition, and muscular strength in sedentary, obese women. We required one session of at-home training per week to examine the feasibility of HIIT performed outside of a lab setting. Although obese women have participated in previous HIIT studies (Gillen et al. 2013; Keating et al. 2014; Smith-Ryan et al. 2016), the body mass index (BMI) of these women ranges from 28 to 32 kg/m² classifying them as overweight or Class I obesity. Nevertheless, there is a paucity of data concerning effects of HIIT on VO_2max , body composition, and muscular strength in women with more severe obesity (class II and III), whose risk of chronic disease is higher than that of less obese individuals (Field et al. 2001). One characteristic of previous studies is that only one HIIT regime was implemented, which does not shed light on the efficacy of diverse regimes of HIIT. We hypothesized that modifying the structure of HIIT throughout training (periodized = PER) would promote a greater increase in VO_2max and reduction in %BF compared to the traditional HIIT (TRAD), because the variation associated with PER facilitates a changing training stimulus (Astorino et al. 2017) and greater caloric deficit creating a negative energy balance necessary for weight loss (Manore et al. 2014). We also hypothesized that PER would cause a greater increase in muscular strength compared to TRAD, because the supramaximal intensities incorporated in PER require greater activation of fast twitch muscle fibers and dependence on non-oxidative metabolism.

Materials and methods

Participants

Women ($n = 17$, mean age and percent body fat = 37.5 ± 10.5 years and $48.7 \pm 3.6\%$) were recruited via e-mail announcements and flyers placed on the university campus. Inclusion criteria included women ages 18–55 years old; sedentary (< 2 h of moderate-to-vigorous activity per week in the previous 12 months); a body mass index (BMI) ≥ 35 kg/m²; absence of pre-existing health conditions including hypertension, diabetes, or heart disease; not taking any medications that may affect metabolism; and no injuries. There were no significant differences in baseline characteristics between women completing the two training regimes other than relative VO_2max , which was higher ($p = 0.01$) in TRAD versus PER (21.5 ± 3.2 mL/kg/min vs. 17.3 ± 2.4 mL/kg/min) although still classified as “very poor” for their age and gender. Each participant completed a PAR-Q (Adams 1999) and a physical activity and health history questionnaire before initiating the study. Written informed consent was obtained from all participants prior to commencement of the study. This study protocol was approved by the University Institutional Review Board.

Study design

A repeated-measures, within-subjects study design was utilized for this study. After baseline testing, we used block randomization to place participants into TRAD or PER, and they subsequently completed a 6 week exercise intervention, with three training sessions per week. Two training sessions per week were completed in the laboratory and the third was done outside of the laboratory without supervision. Energy expenditure was not matched between groups. VO_2max and peak power output (PPO) were assessed pre-, mid-, and post-training via ramp exercise performed on an electronically braked cycle ergometer (Velotron DynaFit Pro, RacerMate, Seattle, WA). These variables were measured midway through training to account for expected initial increases in PPO and VO_2max seen in response to HIIT conducted in an inactive population (Astorino et al. 2013) and to promote training progression. Body composition and muscular strength were measured pre- and post-training. Measurements were taken a minimum of 24 h after individual training sessions, which were at least 24 h apart. Time of day of assessments and training was standardized within subjects. Participants were asked to maintain habitual diet and physical activity during the study.

Assessment of VO_2max and body composition

Participants were required to abstain from physical activity for 24 h prior to this session and complete a 3 h fast. All body composition measures were performed before assessment of VO_2max . Initially, standing height and body mass were assessed using a stadiometer and scale (Health-o-meter Professional, Creative Health Products, Ann Arbor, MI) and were used to calculate body mass index. Following standardized procedures (Heyward and Gibson 2014), waist and hip circumferences were measured with a measuring tape to determine waist-to-hip ratio. Waist circumference was measured at the narrowest part of the trunk, while hip circumference was measured at the widest portion of the buttocks. Fat mass and fat-free mass were measured using air displacement plethysmography (BodPod, COSMED, USA Inc., Chicago, IL). Before each measurement, the BodPod was calibrated according to the manufacturer. Previous data show that this is a valid approach to assess %BF in obese participants with a standard error equal to 3.6% (Ginde et al. 2005). Thoracic volume was measured via a breathing tube and filter. The participant was able to see the computer screen while in the BodPod chamber to follow the breathing instructions for the thoracic volume measurement. Participants wore tight spandex clothing and a swim cap to ensure accurate measures of body volume. Any metal, such as jewelry and eyeglasses, was removed.

Subsequently, participants performed a progressive exercise test to volitional exhaustion on an electrically braked cycle ergometer (Velotron DynaFit Pro, RacerMate, Seattle, WA). Power output started at 40 W for 2 min and was increased by 20 W/min in a ramp like manner until exhaustion. Gas exchange data (VO_2), ventilation (V_E), carbon dioxide production (VCO_2), and respiratory exchange ratio (RER) were acquired every 15 s with a metabolic cart (ParvoMedics TrueOne, Sandy, UT) which was calibrated before exercise according to the manufacturer’s recommendations. During testing, heart rate (HR) was continually measured via telemetry (Polar Electro, Woodbury, NY). Maximal oxygen uptake was determined as the mean of the two highest consecutive values within the last three measurements of the test. Verbal encouragement was given throughout the test. Peak power output (PPO) was identified as the work rate consequent with volitional fatigue, which was identified when pedal cadence was below 50 rev/min. After a 10 min active cooldown, women underwent a verification test on the cycle ergometer at 105%PPO attained during the ramp test to ensure that they achieved a ‘true’ VO_2max . Participants were asked to maintain cadence above 50 rev/min during testing. If a participant achieved a higher VO_2max during the verification test, the verification results were used (Sawyer et al. 2016). Oxygen pulse was calculated as the quotient of VO_2 (mL/min) and HR (b/min) and expressed as mL/beat.

Ventilatory threshold (VT) was determined using gas exchange data acquired during the maximal exercise test. The V-slope method (VCO_2/VO_2), adopted from Beaver et al. (1986), was used to determine VT for all the participants at baseline, 3 weeks, and 6 weeks of training. The VT was identified as the time in the test consequent with a nonlinear increase in VCO_2 with no change in VO_2 and was expressed as a percentage of VO_{2max} and in Watts. Two researchers independently determined VT using the V-slope method for each subject; results were then compared to determine the final values.

Assessment of muscular strength

A familiarization trial of the muscular strength protocol was held 10 min after baseline assessment of VO_{2max} to reduce the effects of learning. Testing began with participants completing a 5 min warmup on a cycle ergometer (Monark 808e, Vansbro, Sweden). Subsequently, muscular strength was assessed on the first and last day of training using an isokinetic dynamometer (Biodex System 3, Shirley, NY). This measure was taken before the training sessions to reduce the effects of fatigue. A series of straps were placed across the trunk, abdomen, and exercising limb, and range of motion of the knee joint was set. Participants performed one set of five repetitions at 60°/s with their dominant leg to determine peak knee extension (KE) and peak knee flexion (KF) torque. The coefficient of variation in torque at this velocity is 1% (Drouin et al. 2004). Verbal encouragement was given throughout the test.

Interval training regime

All sessions were performed on an electronically braked cycle ergometer (Velotron DynaFit Pro, RacerMate, Seattle, WA). Each session was preceded by a 5-min warm up at 20%PPO. During each session, HR was continuously assessed using telemetry (Polar, Lake Success, NY). Exercise intensities were adjusted halfway through training based on a mid-training VO_{2max} assessment, which was performed after the ninth session of HIIT. A description of each training regime is included in Table 1.

To accompany supervised lab-based training 2 day/week, participants were instructed to perform 1 day of interval training on their own either at home or in a gym. This was done to test the feasibility of HIIT in individuals with obesity. The protocol matched the regimen done in the laboratory for that week. The participants were given downloadable HR monitors (Polar, Lake Success, NY) to verify the intensity of training. They were instructed to perform training at 80–95% HRmax obtained during the VO_{2max} test. Participants returned the HR monitors on a weekly basis for the Investigators to download the data.

Monitoring of physical activity and diet

Throughout the study, participants were asked to maintain their sedentary lifestyle and habitual dietary patterns. Verification of participant compliance was assessed via completion of dietary logs and use of accelerometers, which were administered at the pre-, mid-, and post-assessments. The dietary logs were completed over a consecutive 3 day period including 1 weekend day, with macronutrient intake analyzed via the United States Department of Agriculture software Choose My Plate. Participants were provided a wrist

Table 1 Description of the high-intensity interval training performed in the study

	Number of bouts	Bout duration (s)	Rest duration (s)	Intensity (% PPO)	Warm up (min)	Total time (min)
Traditional						
Week 1	10	60	60	70	5	25
Week 2	10	60	60	75	5	25
Week 3	10	60	60	80	5	25
Week 4	10	60	60	75	5	25
Week 5	10	60	60	80	5	25
Week 6	10	60	60	85	5	25
Periodized						
Week 1	10	60	60	70	5	25
Week 2	6	20	120	105	5	19
Week 3	7	120	60	60	5	26
Week 4	10	60	60	75	5	25
Week 5	6	20	120	110	5	19
Week 6	7	120	60	65	5	26

accelerometer (ActiGraph, Pensacola, FL) and given specific instructions on how to wear the device over a 4 day period. Steps/day was used to quantify habitual physical activity.

Data analysis

Data are expressed as mean \pm SD and were analyzed using SPSS 22.0 (Chicago, IL). To assess the effects of HIIT on changes in VO_2max , PPO, and related gas exchange variables, two-way ANCOVA with repeated measures was used, with baseline VO_2max used as a covariate. Body composition and muscle strength changes were analyzed using a two-way ANOVA with repeated measures. Tukey's post hoc test was used to determine differences between means when a significant F ratio was found. Cohen's d was used to estimate effect size, with 0.2 equal to a "small" effect size, 0.5 representing a "medium" effect size, and >0.8 representing a "large" effect size. Independent t test was used to identify differences in baseline traits between regimes. The Greenhouse–Geisser correction was used to account for the sphericity assumption of unequal variances across groups. Significance was set at $p < 0.05$.

Results

Of the 17 women, 9 completed the TRAD protocol and 8 completed the PER protocol. The average peak HR during training was equal to $90.0 \pm 4.5\%$ HRmax in TRAD and $87.5 \pm 5.2\%$ HRmax in PER, which verifies the intensity of training. The compliance rate for in-lab training across participants was 100%, whereas the compliance rate for at-home training sessions was equal to $74.2 \pm 25.1\%$ in TRAD and $66.7 \pm 33.3\%$ in PER ($p = 0.60$ between groups). Compared to lab-based HIIT, peak HR was significantly higher during at-home training in weeks 1–4 ($p = 0.01$; $p = 0.007$; $p = 0.01$;

$p = 0.03$). There was no difference in peak HR between lab-based and at-home training for weeks 5 ($p = 0.99$) and 6 ($p = 0.31$).

Change in VO_2max and gas exchange data

Changes in gas exchange data, PPO, and HRmax are shown in Table 2. Results showed a main effect of time for absolute ($p = 0.045$) and relative VO_2max ($p = 0.047$); there was no time-by-group interaction ($p = 0.55$ and $p = 0.48$). Post hoc analysis showed increases in absolute (3 and 6 weeks vs. baseline) and relative VO_2max (6 weeks vs. baseline) occurred in TRAD as well as PER. There were no significant differences in absolute VO_2max between groups at baseline ($p = 0.27$). Absolute and relative VO_2max was increased by 4.8% and 4.7% in TRAD ($d = 0.44$) and 5.2% and 4.1% in PER ($d = 0.33$), with no differences between regimes. There was no change in PPO ($p = 0.49$) or HRmax ($p = 0.16$) and no time-by-group interaction ($p = 0.50$ and $p = 0.29$). Similarly, oxygen pulse was not increased over time ($p = 0.30$) and there was no time-by-group interaction ($p = 0.90$). There was no main effect of time, with no time-by-group interaction, for RER ($p = 0.14$; $p = 0.33$), V_E ($p = 0.16$; $p = 0.62$), or VCO_2 ($p = 0.49$; $p = 0.95$).

Results showed a significant increase in VT expressed as $\% \text{VO}_2\text{max}$ from pre- to post-training ($p = 0.03$), yet there was no time-by-group interaction ($p = 0.18$). Post hoc results showed that, in TRAD, the post-training value was higher than baseline ($d = 1.5$). VT expressed in Watts was not significantly increased with training ($p = 0.53$) and there was no time-by-group interaction ($p = 0.07$).

Change in body composition

There was no significant difference in body mass ($p = 0.07$) or fat mass ($p = 0.19$) from pre- to post-training for either

Table 2 Change in maximal gas exchange data and peak power output in obese women performing high intensity interval training (mean \pm SD)

Variable	Traditional			Periodized		
	Pre	Mid	Post	Pre	Mid	Post
VO_2max (mL/kg/min)	21.5 \pm 3.2	21.9 \pm 3.3	22.5 \pm 3.2*	17.3 \pm 2.4	17.7 \pm 2.7	18.0 \pm 2.2*
VO_2max (L/min)	2.1 \pm 0.3	2.2 \pm 0.3*	2.2 \pm 0.3*	1.9 \pm 0.4	2.0 \pm 0.4*	2.0 \pm 0.3*
V_E (L/min)	91.6 \pm 18.4	84.9 \pm 18.1	92.8 \pm 14.0	75.2 \pm 14.9	68.6 \pm 16.8	74.7 \pm 12.4
VCO_2 (L/min)	2.8 \pm 0.5	2.6 \pm 0.6	2.8 \pm 0.5	2.4 \pm 0.4	2.2 \pm 0.5	2.4 \pm 0.4
RER	1.35 \pm 0.05	1.31 \pm 0.05	1.30 \pm 0.06	1.30 \pm 0.14	1.28 \pm 0.09	1.26 \pm 0.07
HRmax (b/min)	178.3 \pm 18.0	172.0 \pm 17.3	171.1 \pm 16.4	170.5 \pm 8.3	174.1 \pm 8.7	172.0 \pm 10.8
PPO (W)	178 \pm 21	183 \pm 32	194 \pm 31	169 \pm 21	170 \pm 22	175 \pm 24
O_2 pulse (mL/beat)	11.4 \pm 1.1	12.1 \pm 1.3	12.2 \pm 1.1	11.0 \pm 2.0	11.7 \pm 3.3	11.7 \pm 2.7
VT ($\% \text{VO}_2\text{max}$)	46.0 \pm 4.7	47.6 \pm 5.38	50.6 \pm 5.6*	50.0 \pm 4.3	51.8 \pm 6.9	50.6 \pm 5.6
VT (W)	74.0 \pm 11.9	77.0 \pm 13.5	87.7 \pm 16.0	75.1 \pm 16.3	79.4 \pm 17.2	81.2 \pm 15.5

RER respiratory exchange ratio, PPO peak power output, VT ventilatory threshold

* $p < 0.05$ within group versus baseline

group, and no time-by-group interaction for body mass ($p=0.09$) or fat mass ($p=0.24$) (Table 3). In contrast, there was a significant change in %BF from pre- to post-training ($p=0.03$). Post hoc analysis showed that post-training %BF was lower in TRAD ($d=1.12$) but not PER ($d=0.63$). There was a significant change from pre- to post-training in percent fat-free mass ($p=0.03$) and fat-free mass ($p=0.03$). Post hoc analysis showed that percent fat-free mass ($d=1.23$) and fat-free mass ($d=1.24$) were higher post-training in TRAD but not PER ($d=0.49$; $d=0.47$). However, there was no time-by-group interaction for %BF ($p=0.50$), percent fat-free mass ($p=0.33$), or fat-free mass ($p=0.31$).

Change in muscular strength

Data showed no change in KE ($p=0.36$) or KF torque ($p=0.75$) in response to training. For example, KE and KF torque in TRAD were equal to 152.5 ± 43.4 N-m and 93.5 ± 23.0 N-m, respectively, at baseline, and were not different post-training (141.0 ± 38.0 N-m and 89.5 ± 21.7 N-m). Similarly, in response to PER, there was no change in these measures from pre- (KE = 133.1 ± 23.0 N-m; KF = 88.1 ± 16.3 N-m) to post-training (KE = 135.6 ± 24.4 N-m; KF = 90.9 ± 19.0 N-m).

Table 3 Change in body composition measures in obese women performing high-intensity interval training (mean \pm SD)

Variable	Traditional		Periodized	
	Pre	Post	Pre	Post
Body mass (kg)	99.7 \pm 12.6	99.8 \pm 12.2	110.8 \pm 15.3	111.6 \pm 14.9
Body fat (%)	47.5 \pm 4.5	46.7 \pm 4.6*	50.0 \pm 2.6	49.6 \pm 2.5
Fat mass (kg)	47.7 \pm 10.0	46.8 \pm 9.5	55.4 \pm 9.3	55.4 \pm 8.9
Fat-free mass (%)	52.5 \pm 4.5	53.3 \pm 4.6*	50.1 \pm 2.3	50.5 \pm 2.5
Fat-free mass (kg)	52.1 \pm 5.1	53.9 \pm 4.7*	55.4 \pm 6.6	56.1 \pm 6.6
Waist-to-hip ratio	0.82 \pm 0.1	0.82 \pm 0.1	0.81 \pm 0.1	0.81 \pm 0.1

* $p < 0.05$ within group from pre- to post-training

Table 4 Change in macronutrient intake and physical activity in obese women performing high-intensity interval training (mean \pm SD)

Variable	Traditional		Periodized	
	Pre	Post	Pre	Post
Energy intake (kcal/day)	2143.6 \pm 645.3	1966.7 \pm 732.1	1973.4 \pm 578.9	1734.5 \pm 531.7
Carbohydrate (%)	45.7 \pm 7.6	44.8 \pm 4.7	45.3 \pm 7.3	45.6 \pm 9.5
Fat (%)	37.9 \pm 6.6	39.0 \pm 4.8	37.0 \pm 4.8	37.0 \pm 8.6
Protein (%)	16.2 \pm 3.5	16.2 \pm 2.7	15.8 \pm 3.4	17.0 \pm 2.6
Sugar (g)	98.4 \pm 51.5	83.3 \pm 36.2	76.8 \pm 41.3	62.1 \pm 30.7
Habitual physical activity (steps/day)	8218 \pm 2319	9546 \pm 2446	8561 \pm 2444	7575 \pm 3495

Change in physical activity and dietary intake

Results showed no change in habitual activity ($p=0.63$) or dietary intake ($p=0.12$) during the study, as well as no time-by-group interaction ($p=0.20$ and $p=0.82$, respectively). Table 4 describes changes in macronutrient intake and physical activity during the study.

Discussion

This study compared changes in VO_2 max, body composition, and muscular strength in response to 6 weeks of HIIT in obese, sedentary women. Overall, our results show that different regimes of high-intensity interval training regimes similarly increase cardiorespiratory fitness and body composition in women with obesity, yet have no effect on muscle force production or body weight. Data apply to clinicians who implement exercise regimes in individuals with obesity.

It is apparent that low VO_2 max and obesity are associated with increased risk of chronic disease (Abate 2000; Field et al. 2001). Nevertheless, studies show that HIIT increases cardiorespiratory fitness in persons with class I and II obesity (Kong et al. 2016; Vella et al. 2017) which may lead to decreased risk of chronic disease (Kodama et al. 2009). A 20% increase in VO_2 max was shown in response to 8 weeks of HIIT at 90–95%HRmax in adults with BMI = 36 kg/m² (Sawyer et al. 2016). Lanzi et al. (2015) reported an 11% increase in VO_2 max after 8 HIIT sessions at 90%HRmax in men with class II and III obesity. In a randomized-controlled trial in overweight patients with metabolic syndrome, a 35% increase in VO_2 max was observed in response to 16 weeks of high-volume HIIT consisting of four 4 min intervals at 90%HRmax (Tjonna et al. 2008). Our overall change in VO_2 max equal to 4–5% is lower than the previously reported values, which may be due to differences in duration and intensity of HIIT as well as participants' severity of obesity and existing fitness level across studies. For example, our overall intensity of training (TRAD = 90%HRmax and PER = 87%HRmax) is similar to that employed in several studies (Martins et al. 2016; Vella et al. 2017); however, the

only study with similar participant body fat was by Lanzi et al. (2015); however, their subjects had a 20% higher VO_2max at baseline than our women. Kodama et al. (2009) showed that a 1-MET increase in VO_2max is associated with a 13 and 15% reduction in risk of all-cause mortality and coronary heart disease/cardiovascular disease (CHD/CVD) in healthy populations. Improving cardiovascular fitness is crucial, as low fitness is known to be the strongest predictor for adverse cardiometabolic health outcomes and all-cause mortality (Katsmarzyk et al. 2004). Our participants exhibited an increase in VO_2max of 0.4 METs, which represent a 5–6% decrease in all-cause mortality and CHD/CVD.

The precise mechanisms underpinning the changes in VO_2max in this study are unknown, but a possible explanation is enhanced mitochondrial content or function, which is frequently shown in response to HIIT in non-obese adults (Little et al. 2010; Bishop et al. 2014). However, no study to our knowledge has described changes in mitochondrial content in response to HIIT in individuals with severe obesity. Cardiovascular adaptations associated with chronic obesity include increased blood volume, stroke volume, and cardiac output which can cause left-ventricular hypertrophy (Gaasch et al. 1975; de Divitiis et al. 1981). In addition, systolic and diastolic function decrease which may elicit myocardial dysfunction associated with obesity (Peterson et al. 2004). Persons with obesity also experience a blunted HR response during exercise and recovery which influences exercise capacity (Gondoni et al. 2009). The lack of data in individuals with severe obesity makes it difficult to explain our observed changes in VO_2max , which ranged from a “small” to “medium” effect, and it is plausible that greater training intensity or volume is needed to augment magnitude of response. In contrast to our data, Baekkerud et al. (2016) showed that O_2 pulse was significantly higher in response to HIIT, which suggests an increase in stroke volume from training (Bhambhani et al. 1994). Additional studies are warranted to clarify the precise mechanisms responsible for improvements in VO_2max in persons with class II and III obesity performing high-intensity interval training.

Limited data are available examining changes in ventilatory threshold in response to exercise training in persons with obesity. However, data show a lower ventilatory threshold in persons with obesity compared to normal weight adults (Ofir et al. 2007). Data from Gaskill et al. (2001) reported the occurrence of VT at 54% VO_2max in sedentary non-obese adults, which is higher than our values equal to 46–51% VO_2max . Poole and Gaesser (1985) reported significantly greater increases in VT after 8 weeks of HIIT consisting of ten 2 min bouts at 105% VO_2max versus MICT (35–55 min per session at 50–70% VO_2max) in sedentary adults. Although not assessed in our study, an increase in VT is likely due to improvements in mitochondrial content in response to HIIT (Little et al. 2010).

It is apparent that severe obesity dramatically increases chronic disease risk (Kannel et al. 1991; Abate 2000; Field et al. 2001), yet only 3% of obese males and 1.5% of obese females complete the recommended 30 min of MICT per day (Tudor-Locke et al. 2010). Contrary to our hypothesis, our results exhibit a small albeit significant decrease in %BF in response to TRAD, along with a significant increase in %FFM and absolute FFM. In contrast, no change in %BF, %FFM, or absolute FFM was shown in response to PER. Previous data (Slentz et al. 2004) showed that middle-aged adults are apt to gain weight and abdominal fat when they do not partake in regular physical activity over an 8 mo period, so a maintenance of these variables in an obese population performing our 6 weeks training regime may be seen as a positive response. Additional work is needed to validate these responses in women with obesity undergoing a longer period of exercise training, to determine if they continue to gain weight with abstention from physical activity.

Although the training completed in PER varied in intensity and duration, TRAD had greater average energy expenditure per session, which may explain the changes in body composition seen in response to TRAD and not PER. Not only did TRAD have greater average energy expenditure (168 kcal/session vs. 139 kcal/session), it also required 14 min greater overall training volume compared to PER over the 6 weeks. This result suggests that the magnitude of changes in body composition in this population may be greater if higher volume HIIT is performed rather than higher intensity. Our data showing small reductions in %BF are supported by Sawyer et al. (2016) in which 8 weeks of low-volume HIIT in obese women (%BF = 45%) led to a 0.8% reduction in body fat, yet there was no change in body mass or FFM. Their data also showed that 8 weeks of MICT led to no change in %BF despite a 33% higher energy expenditure in MICT versus HIIT (240 vs. 180 kcal/session). Similarly, Gillen et al. (2013) showed that 6 weeks of HIIT consisting of repeated 1 min intervals at 90%HR_{max} reduced %BF by 0.8% and enhanced FFM in overweight and Class I obese women ($\text{BMI} = 29.0 \pm 3.0 \text{ kg/m}^2$). Martins et al. (2016) demonstrated that MICT, HIIT, and $\frac{1}{2}$ HIIT (half the energy deficit of HIIT) led to similar reductions in body mass in sedentary obese women ($\text{BMI} = 33.3 \pm 3.0 \text{ kg/m}^2$). In contrast, Kong et al. (2016) showed no change in body composition in obese women (%BF = 35%) completing 5 weeks of HIIT, although significant changes were shown in response to MICT, which had twice the energy expenditure compared to HIIT. In our study, completion of PER did not decrease %BF or body mass, yet they were maintained. In a study by Slentz et al. (2004), the control group actually gained weight from pre- to post-training. It is possible that maintaining weight or experiencing small reductions in body fat through physical activity is beneficial in individuals with class II and III obesity. There are several mechanisms

potentiated by HIIT which may contribute to body composition alterations, one being excess post-exercise oxygen consumption. Skelly et al. (2014) showed that HIIT (ten 1 min bouts at 90%HRmax) and MICT (50 min at 70%HRmax) elicit similar 24 h energy expenditure in normal weight men, even though energy expenditure during exercise was lower in HIIT than MICT. Another mechanism is enhanced fat oxidation, as Astorino et al. (2013) demonstrated that 12 weeks of HIIT consisting of repeated 1 min efforts at 60–90%PPO improved maximal fat oxidation in sedentary women.

Our results show no change in muscular strength in response to HIIT which oppose our hypothesis. We proposed that the high force required during HIIT, a novel stimulus in this population, would stimulate neural adaptations that would enhance muscle strength. In a previous study, Martinez-Valdes et al. (2017) reported increased muscle torque in young men who completed six sessions of HIIT consisting of repeated intervals at 100%PPO, which was explained by an increase in EMG amplitude and motor unit discharge rate at the highest force levels (> 50% MVC). Interestingly, these changes did not occur in men who performed MICT, which may be due to the greater neuromuscular activation of near-maximal efforts compared to submaximal exercise (Buchheit and Laursen 2013). It is plausible that if PER included additional SIT sessions, increases in strength may have been observed. Similar to our results, Vera-Ibanez et al. (2017) demonstrated no change in MVC after 4 weeks of Wingate-based training in healthy, young men. Even though women performing TRAD showed a slight decrease in strength, fat-free mass significantly increased. Results from a previous study in overweight and obese men and women (%BF = $32.7 \pm 6.5\%$) showed that nine sessions of HIIT increase muscle cross-sectional area by 14% (Blue et al. 2018). In the present study, fat-free mass may have increased in TRAD, yet the neuromuscular stimulus may have been inadequate to increase muscular strength. Considering the relationship between muscular strength and mortality (Rantanen et al. 2000), a maintenance of this outcome through any intervention including HIIT could be viewed as a favorable response especially in an inactive population, and we encourage other authors to identify exercise-based approaches to enhance muscle strength which are practical and effective in this population.

Our study faces several limitations. First, our results cannot be applied to obese populations with existing chronic disease. Another limitation is our small sample size. In addition, without a non-exercising control group, we cannot exclude the possibility that improvements in VO_2max and body composition were not entirely due to HIIT. Air displacement plethysmography is a two-compartment model which may not be sensitive enough to detect small changes in body composition. Similar studies in overweight and obese men and women used a three-compartment model

(Smith-Ryan et al. 2015) and four-compartment model (Smith-Ryan et al. 2016). Moreover, the BodPod can only measure total and not segmental body composition, so body composition changes in specific regions of the body were not detected. We used relatively low-volume HIIT regimens which may be inadequate to promote substantial changes in VO_2max or body composition, and higher volume regimes such as the 4×4 model (Tjonna et al. 2008) may be better suited to modify these outcomes in obese individuals. In addition, the at-home peak HR was higher than that in-lab, suggesting that these women may have been able to tolerate higher training intensities. Nevertheless, our study is strengthened by precise implementation of lab-based training sessions as well as inclusion of “at-home” training, which better translates HIIT outside of a lab setting. In fact, our compliance rate of at-home training equal to 71% is substantially higher than that recently reported (23%, Roy et al. 2018) in overweight adults completing 1 year of HIIT. In addition, we monitored dietary intake and habitual activity via accelerometry, which is often ignored in similar studies (Trapp et al. 2008; Gillen et al. 2013), and these measures did not change from baseline to post-training, suggesting that our results are due to training and not changes in participants’ lifestyle during the study. Finally, we used a verification protocol to verify ‘true’ VO_2max at all time points of the study, which gives us greater confidence that this measure of cardiorespiratory fitness was maximal and not a ‘peak’ value.

Overall, VO_2max was significantly increased in response to either regime, and traditional HIIT improved various measures of body composition, while periodized HIIT only maintained body composition in sedentary obese women. Training did not improve muscular strength, which suggests that obese women desiring to increase strength should initiate more intense HIIT or partake in formal resistance training. Further studies should investigate the utility of different regimens of high-intensity interval training to determine if a single HIIT protocol can modify VO_2max , body composition, and muscular strength due to their relationship to health status. In addition, researchers should utilize participants with more severe obesity, as their physiological responses may differ from those who are overweight or slightly obese.

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Author contribution statement The corresponding author TAA conceived the study, helped AC and ABD analyze the data, and with their assistance, wrote the final draft of the manuscript. AC and ABD assisted the corresponding author with the development of the study protocol, recruited participants, collected the data, and developed the first draft of the final manuscript. JLD helped the research team collect

data and read and approved the final manuscript. All authors declare that they have no conflict of interest in the execution of this study and dissemination of these results.

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