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Research article

Adaptive Responses of Cardiorespiratory Fitness and Cardiometabolic Risk Factors to Polarized Versus Other Types of Training Intensity Distribution in Obese Untrained Females

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Abstract

This study aimed to investigate the effects of 10-week interventions of polarized training (POL), high-intensity interval training (HIIT), and threshold training (THR) on cardiorespiratory fitness (CRF) and cardiometabolic risk factors in untrained, healthy, young obese females. A total of 40 obese, untrained females volunteered to participate in the study and were randomly allocated to four equal groups: POL, HIIT, THR, and a control (CON) group. Training intensity was prescribed relative to ventilatory thresholds (VTs) and categorized into three zones: Zone 1 (Z1; 95% VT_1), Zone 2 (Z2; 50% to 95% VT_2), and Zone 3 (Z3; 90% VO_{2max}). All the training groups performed similar training loads (66% to 93% heart rate max) and the weekly intensity distribution was 75% Z1 and 25% Z3 for POL, 100% Z3 for HIIT, and 50% Z1 and 50% Z2 for THR. CRF, glycemic and lipid profiles, body composition, and cardiovascular variables were assessed before and after the 10-week intervention. After the intervention, total body mass, fat mass, heart rate, fasting glucose, cholesterol, LDL and triglyceride decreased in all exercised-groups (time effect: $p < 0.001$). In addition, the VO_{2max}, VT_1, VT_2, Q_{max} and SV_{max} increased in all exercised-groups (time effect: $p < 0.001$) following the 10-week intervention period. Moreover, the POL group showed more adaptive responses than the HIIT and THR training modalities for the changes in the CRF, glycemic and lipid profiles, body composition, and HR (interaction effect: $p \leq 0.002$) after the 10-week training. In summary, aerobic training models characterized by different intensity distributions are effective in improving CRF, cardiometabolic risk factors, and body composition. However, compared with HIIT and THR, POL elicited superior adaptations across a broader range of CRF and cardiometabolic variables. Collectively, these findings indicate that polarized volume training represents an effective non-pharmacological strategy for simultaneously enhancing CRF and reducing cardiometabolic risk in young, untrained women with obesity.

Key words: Exercise, training intensity distribution, obesity, cardiorespiratory fitness, metabolism.

Introduction

According to the World Health Organization (WHO), there has been a considerable increase in the incidence of obesity around the world since 1975, prompting its designation as a pandemic (Boutari and Mantzoros, 2022). Additionally, low cardiorespiratory fitness (CRF) levels may create risk factors that lead to the development of chronic diseases (Myers et al., 2015). In fact, the combination of obesity and reduced CRF, commonly observed in developed countries, can increase metabolic diseases (Kanter and Caballero, 2012). For women, enhancing CRF can help alleviate obesity-related complications, including insulin resistance, dyslipidemia, and hypertension (Hu et al., 2004). Engaging in physical training is a significant non-pharmacological approach to counteract insufficient CRF and improve metabolic health among women with obesity (Pedersen and Saltin, 2015).

A variety of exercise training strategies are available that can improve physical performance, lead to better health outcomes, and help in the reduction of obesity and cardiometabolicrisk factors (Cox, 2017). To effectively manage cardiometabolic risk factors and improve CRF among women, it is recommended to engage in aerobic training (AT) interventions (Rao et al., 2022). The physiological benefits associated with AT stimuli are influenced by the intensity and volume of the training (Gormley et al., 2008). To our knowledge, numerous studies have addressed the impacts of different AT methods including high-intensity interval training (HIIT) and or moderate-intensity continuous endurance training on health related outcomes in women (Ní Chéilleachair et al., 2017). Regarding the impact of AT intensity and duration on CRF (Myers et al., 2015), it has been documented that determining exercise intensity using the first and second ventilatory thresholds (VT_1 and VT_2) are important for prescription of AT regimen. In order to maximize physiological advantages, it is critical to strategically manage the distribution of training intensity, which is fundamental for optimizing performance. The characterization of training intensity distribution is based on the percentage of training volume dedicated to zones that are defined by established physiological thresholds (i.e., VT_1 and VT_2) (Z1 [below VT_1], Z2 [between VT_1 and VT_2], and Z3 [above VT_2]) (Chiang et al., 2023; Muñoz et al., 2014; Rosenblat et al., 2019).

Prior research has shown that participating in AT through a HIIT method, specifically utilizing interval trials at Z3, is an effective strategy for improving CRF and reducing cardiometabolic risk factors in obese women (Zapata-Lamana et al., 2018). Furthermore, an exercise intervention characterized by a training intensity distribution where 50% of the training time is allocated to Z1 and the remaining 50% to Z2, known as threshold training (THR), has proven effective in enhancing CRF for both men and women (Rosenblat et al., 2019). Evidence from studies suggests that some athletes and general populations engage in a mix of high-volume low-intensity training alongside low-volume high-intensity training regimen. This methodology is known as polarized training (POL) (Muñoz et al., 2014). POL consists of high training volumes in Z1 (75 -

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80%), moderate volumes in Z3 (15 - 20%), and a small fraction in Z2 (< 10%) that could induce greater improvements in endurance performance variables (Stöggl and Sperlich, 2014) compared to HIIT or THR modalities.

Research has demonstrated that POL can enhance CRF and various exercise-related characteristics in both professional and recreational endurance runners, yielding more favorable outcomes compared to other training methods (Muñoz et al., 2014; Stöggl and Sperlich, 2014). Nevertheless, other studies have reported no significant improvement in CRF following POL interventions (Festa et al., 2020; Pérez et al., 2018; Treff et al., 2017). Researchers have indicated that the effects of POL training on maximal oxygen consumption and time to exhaustion are not significantly more effective than those achieved through HIIT (Stöggl and Sperlich, 2014) or THR (Festa et al., 2020; Pérez et al., 2018). Therefore, the optimal distribution of training intensity for enhancing CRF and health related outcomes remains uncertain.

The existing evidence regarding the comparative effectiveness of various forms of AT, particularly concerning their metabolic benefits for obese women, remains a topic of debate. In this context, POL training presents itself as a viable option to enhance training-related outcomes in clinical populations and Zapata-Lamana et al. (2018) suggested that POL is an effective non-pharmacological treatment strategy for reducing cardiovascular disease risk factors in young overweight and obese women when compared with moderate intensity continuous training. Nevertheless, there is a lack of research investigating the impact of a POL intervention on CRF and metabolic health specifically within non-athletic populations, particularly among obese women when compared to HIIT or THR. Therefore, the aim of the present study was to compare the effects of 10 weeks of HIIT, THR, and POL training regimens on CRF and cardiometabolic risk factors in young women with obesity, compared with a non-exercising control group.

Methods

Study design

This study utilized randomized control trials to assess the impact of POL, HIIT, and THR training intensity distribution on CRF and cardiometabolic risk factors in obese female college students and compared to a control group without exercise (Figure 1). The research spanned a duration of 12 weeks, comprising 10 weeks of training intervention and an additional week allocated for pre- and post-testing, conducted from February to May (Figure 2). During the initial session of week 1 (Monday), participants were oriented to the laboratory setting, where they received an overview of the study's objectives and methodologies (Day 1). Two days following the familiarization session, participants returned to the laboratory for the collection of anthropometric data and cardiovascular measurements, along with blood samples for the analysis of metabolic health indicators (Day 2). After another 48-hour interval, an incremental exercise test (IET) was administered to evaluate CRF (Day 3). All training sessions and CRF assessments for the different groups were scheduled in the afternoon, between 4:00 and 7:00 P.M., while the evaluation of anthropometric and cardiometabolic risk factors took place in the morning, from 9:00 to 11:00 A.M.

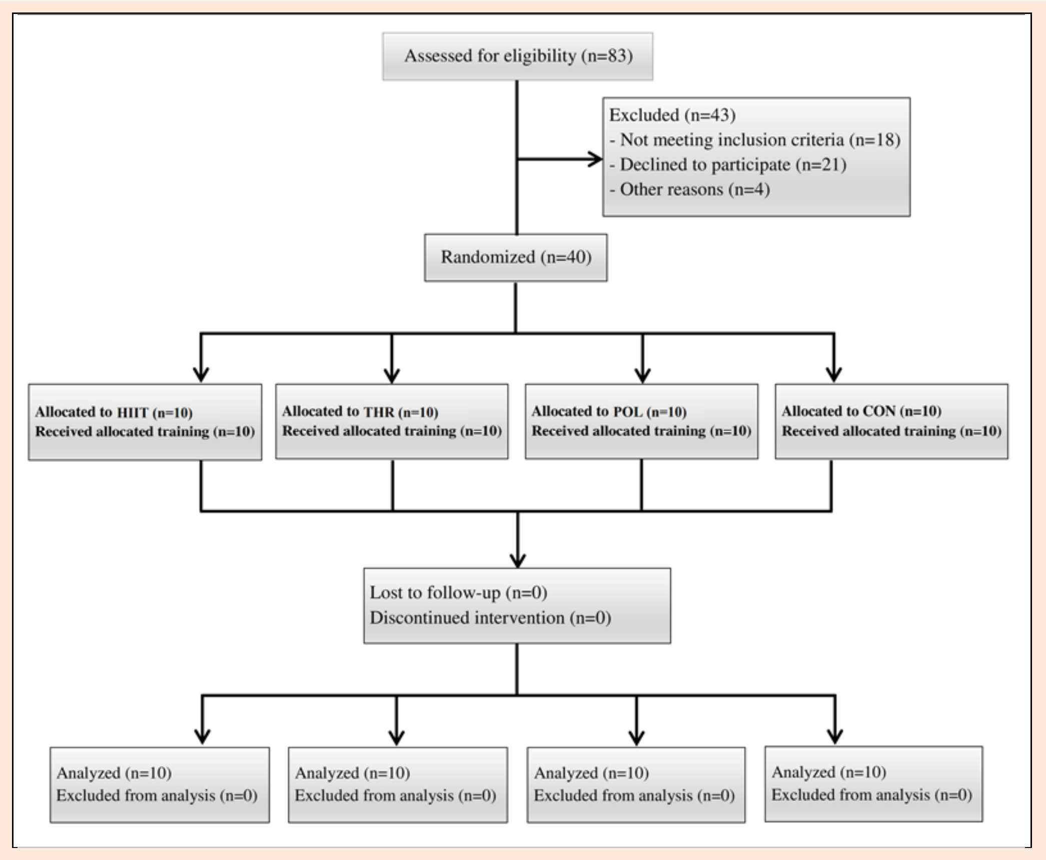

Figure 1. **Study flow.**

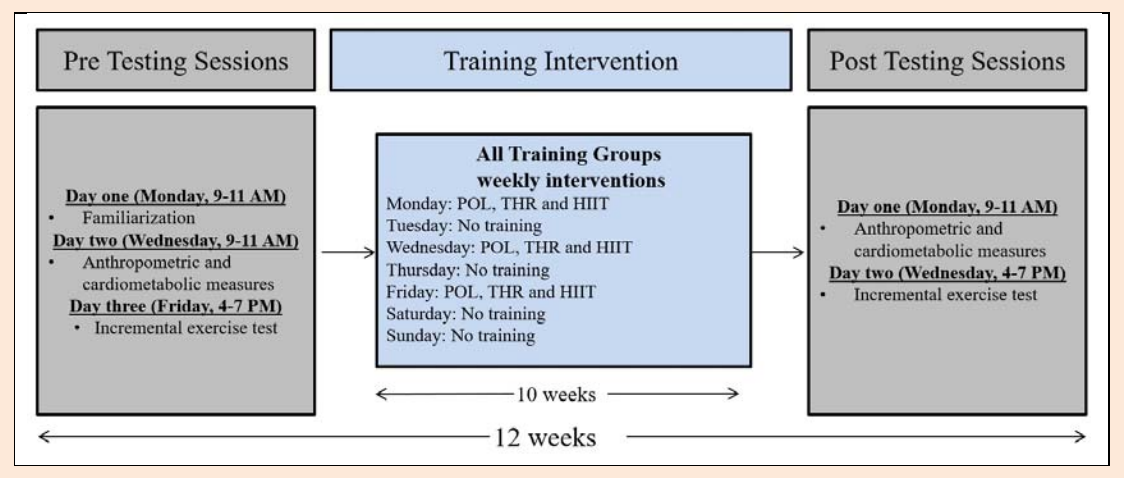

Figure 2. Study design.

Table 1. Participants' characteristics (mean ± SD).

	HIIT group	POL group	THR group	CON group
Age (y)	21.5 ± 1.3	21.8 ± 1.5	20.9 ± 1.1	21.2 ± 1.3
Height (cm)	164.7 ± 3.6	165.1 ± 3.3	162.3 ± 4.1	162.6 ± 4.1
Body mass (kg)	84.2 ± 3.7	83.7 ± 4.1	84.5 ± 3.7	84.8 ± 4.6
BMI (kg·m^{-2})	31.2 ± 2.1	30.7 ± 2.2	32.3 ± 2.4	32.0 ± 2.9

Participants

Eighty-three female collegiate students responded positively to the invitation to participate in the study. Following the application of certain inclusion and exclusion criteria—including an age range of 19 to 23 years, a body mass index (BMI) between 25 and 40 kg/m^2, a classification of untrained (defined as engaging in less than 2 hours of physical activity per week), and the absence of cardiovascular or respiratory diseases, thyroid hormone replacement therapy, antidepressant use, pregnancy, recent involvement in training or dietary interventions (Gharaat et al., 2025) (within the last two months), and being non-diabetic—40 participants were selected. These participants were randomly divided into four groups: a control group (CON, n = 10), a polarized training group (POL, n = 10), a high-intensity interval training group (HIIT, n = 10), and a threshold training group (THR, n = 10) (Table 1). All participants received comprehensive information regarding the research procedures, requirements, benefits, and potential risks before the commencement of the study, and they provided their written consent. The study protocol was approved by the Ethical Committee of the University of Liaoning Normal University, and all procedures were conducted in accordance with the Declaration of Helsinki for human research.

Sample size estimation and randomization

The sample size was determined based on the findings of Chiang et al. (2023), which set an alpha level of 0.05, a power of 0.80 and effect size of 0.21. A priori power analysis was performed using G × Power (Version 3.1.9.2, University of Kiel, Germany) for the F-test based on the study design. This analysis revealed that a sample size of N = 8 for each group would be adequate to detect significant effects of HIIT on CRF. To account for the possibility of attrition during data collection, the sample size was increased during recruitment. Initially, 83 obese females volunteered for the study; however, after applying the necessary criteria, 43 subjects were excluded, leading to a final inclusion of 40 participants. The randomization (1:1:1:1 ratio) was executed using STATA 13.0 (StataCorp, College Station, TX, United States), ensuring that the process remained unpredictable for both researchers and participants. Therefore, the sample size was n = 10 per each group to control the possibility of participant dropout during the data collection process and also through training intervention period.

Pre-post testing

Participants were required to attend the laboratory on two separate occasions, specifically between 9:00 and 11:00 A.M., for the purposes of pre-testing and post-testing to evaluate cardiometabolic risk factors and anthropometric characteristics. Additionally, they were asked to return to the laboratory between 4:00 and 7:00 P.M. for the assessment of CRF. It was emphasized that participants should engage in minimal physical activity, maintain proper hydration, and refrain from any moderate to vigorous physical exercise for at least 48 hours prior to the testing sessions. All measurements were carried out in a controlled laboratory environment, with ambient temperatures maintained between 26 and 28° C and humidity levels ranging from 45 to 55%.

Anthropometric characteristics

A wall-mounted stadiometer (± 0.5 cm, Butterfly, Shanghai, China) was employed to measure the height of the participants. For the measurement of body mass, fat free mass and fat mass, bioelectrical impedance analysis (BIA, Human IM Plus; DS Dietosystem, Milan, Italy) was utilized.

Cardiovascular variables

The resting systolic blood pressure (SBP) and diastolic blood pressure (DBP) were assessed through the indirect auscultatory technique utilizing a mercury column sphygmomanometer (Missouri) in conjunction with a stethoscope (Rappaport). The measurements were conducted while the volunteers were seated on a comfortable couch in a controlled environment, free from noise and temperature fluctuations. Additionally, heart rate (HR) was monitored using a Polar heart rate monitor (OH1, Polar Electro Oy, Kempele, Finland) (Cornelissen and Fagard, 2005).

Cardiorespiratory fitness test

To assess CRF in obese females, a clinical evaluation was performed utilizing an incremental exercise protocol on a treadmill (T676, Sport Art Fitness, UK) after an initial 5-minute walking period. The test commenced at a speed of 5 km/hr, with increments of 2.5% every 2 minutes until the participants reached their maximum voluntary exertion. A breath-by-breath gas analysis system (MetaLyzer 3B-R2, Cortex, Germany) was employed to continuously monitor CRF parameters throughout the duration of the test. This apparatus measured $\dot{V}O_{2max}$, as well as the first and second ventilatory thresholds (VT_1 and VT_2), in accordance with established criteria (Tao et al., 2024). Multiple criteria were utilized to assess whether the athlete achieved $\dot{V}O_{2max}$. These criteria included: a) the observation of a plateau in $\dot{V}O_2$ levels despite an increase in workload, b) a respiratory exchange ratio exceeding 1.10, c) a blood lactate concentration of 8 mmol/L or more, d) a maximum heart rate (HRmax) that is at least 95% of the age-predicted maximum (220 - age), and e) the rate of perceived exertion (RPE) ≥ 8 (Li and Sheykhlouvand, 2025). The VT_2 was determined independently by two specialists, utilizing the criterion of a continuous increase in the VE equivalent for O2 ($\dot{V}E\ \dot{V}O2^{-1}$) and the $\dot{V}E$ equivalent for CO2 ($\dot{V}E\ \dot{V}CO2^{-1}$) ratio curves, in relation to the decline in end-tidal O2 tension (PETO2). The VT_1 was identified as the juncture at which an increase in $\dot{V}E\ \dot{V}O2^{-1}$ and PETO2 occurred without a concurrent rise in $\dot{V}E\ \dot{V}CO2^{-1}$ (Tao et al., 2024). Additionally, cardiac hemodynamics were continuously monitored throughout the test using impedance cardiography (PhysioFlow, Manatec, France), allowing for the non-invasive recording of cardiac output ($\dot{Q}_{max}$) and stroke volume (SV_{max}).

Metabolic health factors

Blood samples were collected from each participant prior to the commencement of the training program and again following the conclusion of the final training session. To maintain uniformity, participants were instructed to arrive at the laboratory after a fasting period of 12 hours and following 8 hours of sleep, which was verified through a personal interview conducted before the measurements. A total of 15 mL of blood was drawn from the antecubital vein into plain evacuated test tubes. The blood was allowed to clot at room temperature for 30 minutes before being centrifuged at 1500 g for 10 minutes. The serum layer obtained was then separated and stored in multiple aliquots at -20°C for future analysis. Cholesterol, HDL, LDL, and triglyceride levels were measured using the photometric End Point method with available kits (Novus Biologicals, USA), utilizing auto-analyser devices (Hitachi®, models 704 and 902, Japan). For glucose level assessment, the ELISA kit (Eagle Biosciences, USA) was employed. The coefficient of variation for these measurements was maintained at less than 6%.

Training intervention

The training intervention was structured to include 30 sessions over a period of 10 weeks, with three sessions per week (i.e., Monday, Wednesday, and Friday) taking place in the afternoon under the guidance of a professional trainer. Participants in the CON did not engage in any training intervention and were advised against participating in formal physical activities or making dietary changes. Training intensity in all intervention groups was prescribed relative to individually determined VTs obtained from the incremental CRF exercise test and categorized into three zones: Zone 1 (Z1, $< VT_1$ [~65-67% HRmax]), Zone 2 (Z2, between VT_1 and VT_2 [~81-82% HRmax]), and Zone 3 (Z3, $> VT_2$ [~92-93% HRmax]). The weekly training intensity distribution for the groups were differed between groups. In the POL group, approximately 75% of the total weekly exercise time was performed in Z1 and 25% in Z3, with almost no time spent in Z2. In the HIIT group, 100% of the prescribed exercise time was accumulated in Z3 using repeated high-intensity intervals interspersed with active recovery at very low intensity. In the THR group, the weekly exercise volume was distributed as ~50% in Z1 and ~50% in Z2, with no planned bouts in Z3 (Figure 3).

To quantify the training load, the rating of perceived exertion (RPE) was assessed using the Borg 0 - 10 scale, recorded 10 minutes after each training session (Arazi et al., 2020). In addition, training load was matched across the intervention groups by monitoring and comparing the percentage of maximal heart rate (%HRmax) achieved during the sessions. Using this approach ensured that all participants were exposed to an equivalent internal load despite differences in external training structure or intensity distribution (i.e., POL = 68% and THR = 66% in the Z_1 and HIIT

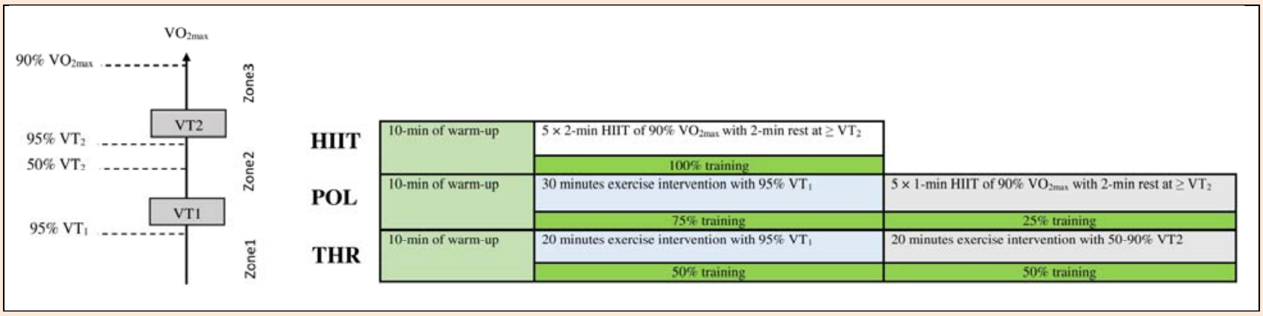

Figure 3. **Training intervention.**

= 93% and POL = 91% in the Z_3 with the same RPE following the intervention, POL = 8.7 ± 1.1, HIIT = 8.2 ± 0.9, and THR = 7.9 ± 1.3). These data confirm that all exercise training groups reached to maximal efforts during the intervention period as described in method by (Tschakert and Hofmann, 2013; Chiang et al., 2023).

Monitoring training intensity

Before each training session, every participant was equipped with a HR monitor (OH1, Polar Electro Oy, Kempele, Finland). The training speed was tailored for each individual to ensure they reached their designated HR zone. If a participant's heart rate fell outside the target zone associated with their desired exercise intensity (Z1, Z2, or Z3), the instructor made slight adjustments to the speed (≤0.5 km/h) to ensure the HR remained within the target zone. Additionally, if a participant's RPE or average HR (5 - 10 bpm) decreased over two consecutive weeks of training (Zapata-Lamana et al., 2018), the initial speed was raised by 0.5 km/h for the following training session to preserve the training load.

Statistical analysis

The data was presented using the mean ± SD. The normality of the data was assessed using the Shapiro-Wilk test for both pre and post-test values, and Levene's test was employed to evaluate the homogeneity of variances. A repeated-measures ANOVA (4 [group] × 2 [time]) was conducted to determine significant differences between the groups for each variable tested. In cases where a significant F value was obtained, Bonferroni post hoc procedures were employed to identify the pairwise differences between the means with aiming to control Type 1 error. Effect sizes (ES) were calculated using Hedges' g and categorized as trivial (< 0.20), small (0.20-0.60), moderate (0.60 - 1.20), large (1.20 - 2.00), or very large (> 2.00) (Ning and Sheykhlouvand, 2025). The 95% confidence interval (CI) was also reported (Hopkins et al., 2009). The statistical analyses were performed using SPSS software version 24.0 (IBM Corp., Chicago, IL). The significance level was set at 0.05.

Results

Every subject participating in this study demonstrated total compliance, resulting in a flawless success rate of 100%. Furthermore, there were no incidents of injury reported in relation to the training and testing procedures implemented. Prior to the intervention, the groups showed no significant differences; however, after the intervention, significant differences ($p < 0.05$) emerged between the control and training groups. It is also noteworthy that the CON group, which engaged in their usual daily activities, did not exhibit any significant changes in the measured variables from pre- to post-intervention.

Anthropometric measures

Total body mass and fat mass decreased significantly (time effect, $p < 0.001$) for the training groups following the 10-week intervention period with ESs ranging between trivial to moderate (Table 2). The POL group indicated more decrements in the total body mass (interaction effect, p = 0.002) and fat mass (interaction effect, p = 0.001) than the HIIT (total body mass, standardized mean difference [SMD] = -0.49, 95% CI = -1.38 to 0.40, Small differences; fat mass, SMD = -0.29, 95% CI = -1.17 to 0.59, Small differences) and THR (SMD = -0.59, 95% CI = -1.48 to 0.31, Small differences; fat mass, SMD = -0.33, 95% CI = -1.21 to 0.56, Small differences) groups after training. No significant main effect of time (p = 0.201) and group by time (p = 0.580) interactions were observed in the fat free mass following the training interventions in all groups.

Cardiovascular variables

No significant main effect of time (p = 0.236, 0.211) and group by time (p = 0.907, 0.775) interactions were observed in the SBP and DBP following the training interventions in all groups, respectively. The HR decreased significantly (time effect, $p < 0.001$) for the training groups following the 10-week intervention period with moderate ES (Table 3). The POL group indicated more decrements in the HR (interaction effect, p = 0.001) than the HIIT (SMD = -0.49, 95% CI = -1.49 to 0.30, Small differences) and THR (SMD = -0.64, 95% CI = -1.54 to 0.26, Moderate differences) groups after training.

Cardiorespiratory fitness variables

The CRF variables including VO_{2max}, VT_1, VT_2, Q_{max}, and SV_{max} increased significantly (time effect, $p < 0.001$) for the training groups following the 10-week intervention period with ESs ranging between small to very large (Table 4). The POL group indicated greater adaptive responses in CRF variables (interaction effect, p = 0.001) than the HIIT (VO_{2max}, SMD = 0.89, 95% CI = -0.03 to 1.71, Moderate

Table 2. Changes in anthropometric measures from pre to post-intervention for the experimental groups (mean ± SD).

Variables	Variables	Pre-intervention	Post-intervention	Interaction effect	Hedges' g (95% CI)	
Body mass (kg)	**HIIT**	84.2 ± 3.7	83.0 ± 3.6*	p = 0.002	-0.31 (-1.20 to 0.57)	Small ↓
	POL	83.7 ± 4.1	81.0 ± 4.2*†		-0.62 (-1.52 to 0.27)	Moderate ↓
	THR	84.5 ± 3.7	83.4 ± 3.7*		-0.28 (-1.17 to 0.60)	Small ↓
	CON	84.8 ± 4.6	84.7 ± 4.4		-0.02 (-0.90 to 0.86)	Trivial ↓
Fat free mass (kg)	**HIIT**	42.8 ± 3.1	43.0 ± 3.0	p = 0.580	0.06 (-0.81 to 0.94)	Trivial ↑
	POL	43.8 ± 3.3	44.4 ± 3.2		0.18 (-0.70 to 1.06)	Small ↑
	THR	42.5 ± 3.0	42.9 ± 3.0		0.13 (-0.75 to 1.01)	Trivial ↑
	CON	42.2 ± 2.9	42.1 ± 3.1		-0.03 (-0.91 to 0.84)	Trivial ↓
Fat mass (kg)	**HIIT**	38.4 ± 2.8	37.9 ± 2.7*	p = 0.001	-0.17 (-1.05 to 0.70)	Trivial ↓
	POL	38.5 ± 2.8	37.1 ± 2.6*†		-0.50 (-1.39 to 0.39)	Small ↓
	THR	38.5 ± 2.7	38.0 ± 2.7*		-0.19 (-1.06 to 0.70)	Trivial ↓
	CON	38.9 ± 2.9	38.8 ± 2.7		-0.03 (-0.91 to 0.84)	Trivial ↓

*denotes significant differences compared to pre and CON. † denotes significant differences compared to other training groups.

Table 3. Changes in cardiovascular variables from pre to post-intervention for the experimental groups (mean ± SD).

Variables	Variables	Pre-intervention	Post-intervention	Interaction effect	Hedges' g (95% CI)	
SBP (mmHg)	**HIIT**	122.5 ± 5.0	121.1 ± 3.6	$p = 0.907$	-0.31 (-1.19 to 0.57)	Small ↓
	POL	123.4 ± 6.0	121.9 ± 5.4		-0.25 (-1.13 to 0.63)	Small ↓
	THR	125.1 ± 5.7	123.5 ± 5.6		-0.27 (-1.15 to 0.61)	Small ↓
	CON	124.8 ± 4.9	124.6 ± 4.3		-0.04 (-0.92 to 0.84)	Trivial ↓
DBP (mmHg)	**HIIT**	80.6 ± 3.5	80.3 ± 2.7	$p = 0.775$	-0.09 (-0.97 to 0.79)	Trivial ↓
	POL	80.8 ± 4.2	80.5 ± 4.4		-0.07 (-0.94 to 0.81)	Trivial ↓
	THR	80.7 ± 2.9	80.6 ± 2.9		-0.03 (-0.91 to 0.84)	Trivial ↓
	CON	80.3 ± 3.3	80.2 ± 3.7		-0.03 (-0.90 to 0.85)	Trivial ↓
HR (bpm)	**HIIT**	75.5 ± 3.5	73.1 ± 3.2*	$p = 0.001$	-0.69 (-1.59 to 0.22)	Moderate ↓
	POL	75.8 ± 4.2	70.9 ± 3.9*†		-1.16 (-2.11 to -0.21)	Moderate ↓
	THR	75.8 ± 3.0	73.2 ± 2.9*		-0.84 (-1.76 to 0.07)	Moderate ↓
	CON	76.1 ± 3.4	75.8 ± 3.1		-0.09 (-0.97 to 0.79)	Trivial ↓

*denotes significant differences compared to pre and CON. † denotes significant differences compared to other training groups.

differences; VT$_1$, SMD = 0.91, 95% CI = -0.01 to 1.83, Moderate differences; VT$_2$, SMD = 0.42, 95% CI = -0.37 to 1.30, Small differences; Q$_{max}$, SMD = 0.36, 95% CI = -0.52 to 1.25, Small differences, and SV$_{max}$, SMD = 0.75, 95% CI = -0.16 to 1.65, Moderate differences) and THR (VO$_{2max}$, SMD = 0.78, 95% CI = -0.13 to 1.69, Moderate differences; VT$_1$, SMD = 0.64, 95% CI = -0.25 to 1.54, Moderate differences; VT$_2$, SMD = 0.84, 95% CI = -0.08 to 1.75, Moderate differences; Q$_{max}$, SMD = 0.73, 95% CI = -0.18 to 1.63, Moderate differences, and SV$_{max}$, SMD = 0.63, 95% CI = -0.27 to 1.53, Moderate differences) groups after training period.

Metabolic health factors

No significant main effect of time ($p = 0.457$) and group by time ($p = 0.643$) interaction was observed in the HDL following the training interventions in all groups (Figure 4). The fasting glucose, cholesterol, LDL and triglyceride decreased significantly (time effect, $p < 0.001$) for the training groups following the 10-week intervention period with small to large ESs. The POL group indicated greater adaptive responses in the metabolic health factors (interaction effect, $p = 0.001$) than the HIIT (fasting glucose, SMD = -0.68, 95% CI = -1.58 to 0.23, Moderate differences; cholesterol, SMD = -0.26, 95% CI = -1.14 to 0.62, Small differences; LDL, SMD = -0.82, 95% CI = -1.73 to 0.09, Moderate differences, and triglyceride, SMD = -0.63, 95% CI = -1.52 to 0.27, Moderate differences) and THR (fasting glucose, SMD = -0.55, 95% CI = -1.44 to 0.34, Small differences; cholesterol, SMD = -0.21, 95% CI = -1.09 to 0.67, Small differences; LDL, SMD = -0.55, 95% CI = -1.44 to 0.34, Small differences, and triglyceride, SMD = -0.72, 95% CI = -1.62 to 0.19, Moderate differences) groups following the training intervention.

Discussion

The present study demonstrates that while all three training modalities—HIIT, THR, and POL—significantly improved indices of CRF, body composition, and metabolic health in young obese women, the POL protocol yielded consistently superior adaptations.

Specifically, POL resulted in notably greater reductions in body mass and fat mass, more pronounced increases in VO$_{2max}$, VTs, stroke volume, and cardiac output, as well as larger improvements in fasting glucose, lipid profiles, and overall metabolic health relative to both HIIT and THR protocols. These findings align strongly with and

Table 4. Changes in cardiorespiratory fitness variables from pre to post-intervention for the experimental groups (mean ± SD).

Variables	Variables	Pre-intervention	Post-intervention	Interaction effect	Hedges' g (95% CI)	
VO$_{2max}$ (ml·kg^{-1}·min^{-1})	**HIIT**	27.8 ± 2.0	30.7 ± 2.0*	***$p = 0.001$***	1.39 (0.41 to 2.37)	Large ↑
	POL	28.3 ± 1.7	32.7 ± 2.3*†		2.08 (0.99 to 3.17)	Very large ↑
	THR	28.2 ± 1.8	30.9 ± 2.1*		1.32 (0.35 to 2.29)	Large ↑
	CON	28.1 ± 2.2	27.9 ± 1.8		0.05 (-0.83 to 0.92)	Trivial ↑
VT$_1$ (%VO$_{2max}$)	**HIIT**	55.6 ± 3.5	57.5 ± 3.3*	***$p = 0.001$***	0.53 (-0.36 to 1.43)	Small ↑
	POL	56.3 ± 3.2	60.5 ± 3.0*†		1.30 (0.33 to 2.26)	Large ↑
	THR	55.9 ± 2.3	58.7 ± 2.3*		1.17 (0.22 to 2.11)	Moderate ↑
	CON	56.1 ± 3.1	56.2 ± 2.9		0.03 (-0.84 to 0.91)	Trivial ↑
VT$_2$ (%VO$_{2max}$)	**HIIT**	66.7 ± 3.0	69.9 ± 2.9*	***$p = 0.001$***	1.04 (0.10 to 1.97)	Moderate ↑
	POL	66.3 ± 3.2	71.1 ± 2.6*†		1.58 (0.57 to 2.58)	Large ↑
	THR	66.8 ± 2.8	68.6 ± 3.1*		0.58 (-0.31 to 1.48)	Small ↑
	CON	67.1 ± 3.2	67.2 ± 2.9		0.03 (-0.85 to 0.91)	Trivial ↑
Q$_{max}$ (L·min^{-1})	**HIIT**	17.5 ± 1.0	18.1 ± 1.1*	***$p = 0.001$***	0.55 (-0.35 to 1.44)	Small ↑
	POL	17.4 ± 1.2	18.5 ± 1.0*†		0.92 (-0.01 to 1.84)	Moderate ↑
	THR	17.2 ± 1.1	17.7 ± 1.1*		0.44 (-0.45 to 1.32)	Small ↑
	CON	17.1 ± 1.0	17.2 ± 1.0		0.10 (-0.78 to 0.97)	Trivial ↑
SV$_{max}$ (mL·b^{-1})	**HIIT**	92.5 ± 2.6	94.9 ± 2.9*	***$p = 0.001$***	0.83 (-0.08 to 1.75)	Moderate ↑
	POL	92.3 ± 3.7	97.8 ± 4.4*†		1.30 (0.33 to 2.26)	Large ↑
	THR	92.7 ± 2.6	95.3 ± 3.1*		0.87 (-0.05 to 1.79)	Moderate ↑
	CON	92.1 ± 2.4	92.2 ± 2.7		0.04 (-0.87 to 0.91)	Trivial ↑

*denotes significant differences compared to pre and CON. † denotes significant differences compared to other training groups.

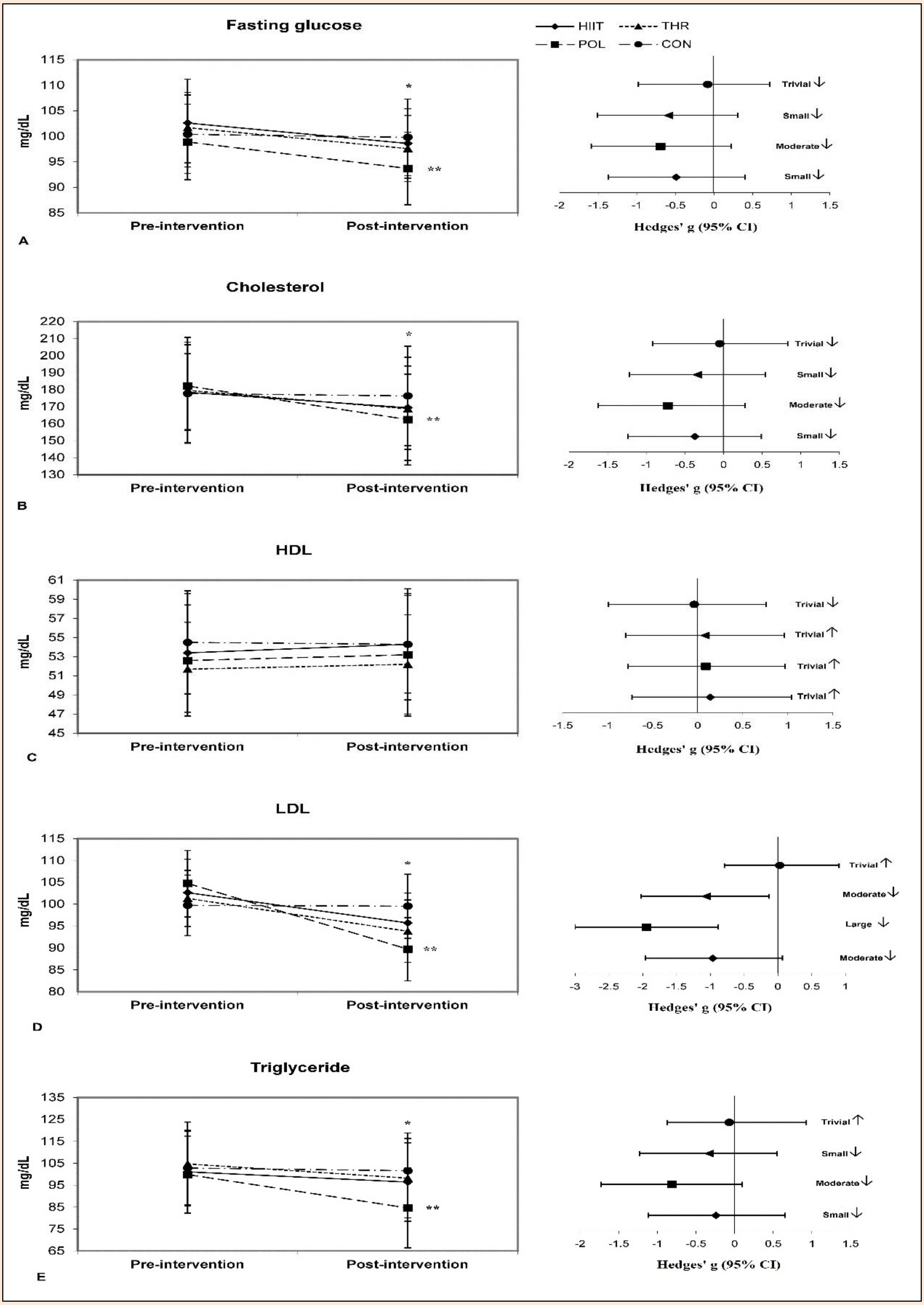

Figure 4. Changes in glucose and lipid profiles from pre to post-intervention. *significant differences compared with the pre-training for all the training groups. **significant differences between the POL vs. HIIT and THR training groups following the intervention period.

reinforce evidence from previous research, including systematic reviews and randomized trials (Rosenblat et al., 2019; Chiang et al., 2023; Zapata-Lamana et al., 2018), which have consistently reported advantageous effects of polarized intensity distribution training—characterized by a majority of training time spent at low intensities (Zone 1), a smaller proportion at very high intensities (Zone 3), and minimal training near or at threshold (Zone 2)—in optimizing both performance and health-related outcomes. The physiological mechanisms underlying these superior adaptations are likely multifaceted and are supported by previous research.

The reductions in body mass and fat mass observed in the present study are consistent with previous interventions in overweight and obese individuals (Rosenblat et al., 2019; Chiang et al., 2023; Zapata-Lamana et al., 2018). It is well established that exercise alone typically produces modest reductions in body weight compared with dietary interventions, as negative energy balance achieved through caloric restriction often leads to larger short-term weight loss (Ahmadizad et al., 2007; Cox, 2017). However, exercise interventions provide several important benefits beyond weight reduction, including improvements in cardiorespiratory fitness, metabolic health, and the preservation of lean body mass (Carnelissen et al., 2005). In addition, regular physical activity contributes to long-term weight maintenance and cardiometabolic risk reduction (Cox, 2017; Myers et al., 2015). Therefore, although the magnitude of weight loss observed in exercise interventions may be more but smaller than that CON who typically achieved controlled dietary intake without exercise intervention, the combined improvements in body composition and physiological function highlight the important role of structured exercise programs in obesity management.

Foremost, the high volume of low-intensity exercise inherent to POL supports sustainable fat oxidation and mitochondrial biogenesis in skeletal muscle, as this intensity level is known to predominantly rely on lipid metabolism, thereby promoting reductions in both body mass and adiposity (Chiang et al., 2023; Stöggl and Sperlich, 2014). This is further consistent with the observations of Zapata-Lamana et al. (2018), who found that only POL, as opposed to HIIT or moderate-intensity continuous training, significantly increased fat oxidation rates and improved glycemic control among overweight and obese women. The improved insulin sensitivity observed following POL can be attributed to enhanced GLUT4 translocation and increased capillary density, facilitating more efficient glucose uptake and utilization by skeletal muscle, which is further amplified by the frequent recruitment of type I muscle fibers during prolonged low-intensity efforts. The inclusion of brief, high-intensity intervals in POL (Z3), which are strategically spaced to maximize recovery and minimize cumulative physiological stress, delivers potent stimuli for central cardiovascular adaptation, including increases in stroke volume and maximal cardiac output, which are central determinants of elevated VO_{2max} as noted in the reviews by Rosenblat et al. (2019) and Chiang et al. (2023). Substantial evidence suggests that such high-intensity bursts trigger neuromuscular and cardiac remodeling via augmented sympathetic stimulation, increased myocardial contractile-ity, and favorable alterations in cardiac preload and afterload, mechanisms which are less optimally engaged either by continuous low/moderate-intensity exercise or exclusive HIIT regimens (Rosenblat et al., 2019). Moreover, by limiting the time spent training at or just above the ventilatory threshold (Zone 2)—an intensity domain associated with higher perceptions of effort, greater cortisol release, and an increased risk of overreaching or overtraining—the POL approach may reduce training monotony and mitigate the risk of cumulative fatigue. In the present study, training load was monitored and adjusted using %HRmax and RPE to ensure comparable internal training loads across the intervention groups. However, due to the inherent characteristics of the different training models, some variation in the resulting weekly training volume and intensity distribution may have occurred (Chiang et al., 2023). This concept is further supported by cohort data in endurance athletes (Stöggl and Sperlich, 2014), which demonstrate a natural tendency toward polarized intensity distributions for producing adaptations in physiological process.

The cardiometabolic improvements observed with POL, such as reduced fasting glucose and improved cholesterol, LDL, and triglyceride concentrations, can be ascribed to enhanced mitochondrial function and lipid oxidation, decreased systemic inflammation, and an improved hormonal milieu, which collectively support both cardiovascular health and metabolic flexibility (Ahmadizad et al., 2007). Notably, our results are in agreement with Zapata-Lamana et al. (2018), who found that POL induced greater improvements in substrate oxidation, glycemic control, and blood lipids than other modalities. In comparison, HIIT protocols, despite their efficacy for quickly improving aerobic capacity, tend to elicit lower overall training volumes, generate considerable anaerobic and psychological stress, and may compromise adherence or increase the likelihood of injuries and overuse, particularly in untrained or clinical populations (Alkhatib et al., 2020). Similarly, threshold training, although effective for raising lactate thresholds, can become monotonous and induce excessive physiological stress due to the challenging nature of sustained efforts near or just above the first ventilatory threshold; this may limit both compliance and the capacity for continued improvement over time (Muñoz et al. 2014). By combining the benefits of both low- and high-intensity training within a balanced and periodized framework, POL appears to leverage a synergy of physiological adaptations: enhanced peripheral adaptations (increased mitochondrial density, capillarization, substrate utilization) from high-volume low-intensity sessions, and robust central/cardiac adaptations from regular, well-timed high-intensity intervals, all while supporting optimal recovery and adherence (Chiang et al., 2023; Rosenblat et al., 2019). The design of our study, with matched training impulse across all groups, allows us to attribute these differences specifically to the intensity distribution rather than differences in training dose or volume—an important methodological strength supported by Chiang et al. (2023). The present findings thus support the utility of POL as a non-pharmacological intervention with high potential for public health, particularly for young women with obesity who are at increased risk of developing metabolic syndrome, and cardiovascular disease. Beyond the physiological mechanisms, another possible explanation for the higher compliance and lower dropout observed in POL groups, both in our cohort and in studies like those of Zapata-Lamana et al. (2018), may be psychological: alternating easy and hard training days could enhance enjoyment, reduce perceived exertion, and improve long-term adherence compared to monotonous routines of continuous or repetitively intense exercise. An additional consideration relates to the potentially optimal distribution of training intensity within a polarized model. In the present study, approximately 25% of the training volume in the POL group was performed at high intensity (Zone 3) (Muñoz et al., 2014). While this proportion is commonly used in experimental polarized training interventions, evidence from observational studies in endurance athletes suggests that the high-intensity component may range from approximately 5% to 15% of total training volume (Rosenblat et al., 2019). Importantly, even relatively small amounts of high-intensity exercise may be sufficient to stimulate meaningful improvements in CRF and metabolic health (Rao et al., 2022). From a practical perspective, particularly in previously untrained individuals with obesity, prescribing excessively large volumes of high-intensity exercise may negatively affect adherence, compliance, and long-term participation due to greater perceived effort and fatigue (Pedersen and Saltin, 2015; Kanter and Caballero, 2012). Therefore, future research should further explore the minimal effective dose of high-intensity training within a polarized framework, with careful consideration of both physiological adaptations and behavioral factors such as adherence and dropout rates.

Limitation

Several limitations of the present study should be acknowledged. First, the intervention lasted 10 weeks, which may not fully capture the long-term sustainability of the observed benefits. Second, the sample consisted exclusively of female participants, which may limit the generalizability of the findings to other populations. Third, direct mechanistic measurements (e.g., muscle biopsies or mitochondrial assays) were not performed, limiting the ability to further elucidate the physiological mechanisms underlying the observed adaptations. In addition, training intensity during the intervention sessions was monitored primarily through HR responses, without verification through blood lactate measurements as a metabolic control. Because HR responses may lag behind rapid metabolic changes, particularly during high-intensity interval exercise, the absence of lactate-based verification may reduce the precision of intensity prescription. Furthermore, although training load was monitored using %HRmax and RPE to promote comparable internal loads across the intervention groups, the intensity distribution and resulting weekly training volumes may not have been perfectly matched due to the inherent characteristics of the polarized, high-intensity interval, and threshold training models. Consequently, the distribution of training intensity and volume should be considered when interpreting the observed adaptations. At the same time, applying comparable internal load monitoring across groups may also be considered a methodological strength of the study. Future research should further investigate whether strict matching of training volume across different training intensity distributions is necessary, particularly in relation to both physiological adaptations and long-term adherence to exercise programs.

Conclusion

In summary, our findings complement and extend the evidence supporting POL as the most effective and pragmatic approach for improving body composition, cardiovascular function, and metabolic health in young obese women, likely owing to its unique capacity to maximize physiological adaptations across multiple systems while promoting greater training enjoyment and sustainability compared to HIIT or threshold strategies.

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The datasets generated during the current study are not publicly available but are available from the corresponding author upon reasonable request. The authors declare that they have no conflict of interest. All experimental procedures were conducted in compliance with the relevant legal and ethical standards of the country where the study was carried out. The authors declare that no Generative AI or AI-assisted technologies were used in the writing of this manuscript.

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Key points

- All aerobic training modalities, including POL, HIIT, and THR protocols, have demonstrated efficacy in eliciting significant physiological adaptations in obese female populations.
- The POL training program appears to elicit superior adaptive responses in cardiorespiratory fitness and improvements in cardiometabolic risk profiles compared to other training modalities among females with obesity.

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