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Effects of 24-week Polarized Training vs. Threshold Training in Obese Male Adults

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ABSTRACT

The combination of high volume of moderate-intensity continuous training with a low volume of high-intensity interval training improved body composition and physical capacities in individuals with obesity. However, polarized training (POL) has never been used in adult men with obesity. Thus, the purpose of this study was to investigate changes in body composition and physical capacities induced by a 24-week POL or threshold (THR) program in obese male adults. Twenty male patients (mean age 39.8 ± 6.3 yrs; mean body mass index [BMI] 31.6 ± 2.7 kg·m^{-2}) participated in this study (n: 10 POL, n: 10 THR). After 24-week, body mass (BM) and fat mass (FM) decreased by -3.20 ± 3.10 kg ($P<0.05$) and -3.80 ± 2.80 kg ($P<0.05$), respectively, similarly in both groups. Maximal oxygen uptake ($\dot{V}O_2$max) and $\dot{V}O_2$ at respiratory compensation point (RCP) increased in the POL group (+8.5 ± 12.2 and +9.0 ± 17.0 %, $P<0.05$) and in the THR group (+4.24 ± 8.64 and +4.0 ± 6.70 %, $P<0.05$), as well $\dot{V}O_2$ at gas exchange threshold (GET) increased similarly in both groups (+12.8 ± 12.0 %, $P<0.05$). POL and THR were equally effective in improving body composition and physical capacities in obese subjects. Future studies are needed to determine whether adherence to the training program can be improved by adding a running competition compared with a group without competition at the end of the training program.

Introduction

Excess food intake combined with an increase in time spent in sedentary activities and a decrease in physical activity level [1] has contributed to the recent growth of obese adults in developed countries [2].

Compared to lean subjects, obese subjects show lower cardiorespiratory fitness (CRF) (typically expressed as maximal oxygen uptake, $\dot{V}O_2$max, or peak oxygen uptake, $\dot{V}O_{2peak}$) [3] and lower values of oxygen consumption in both gas exchange threshold (GET) [4] and respiratory compensation point (RCP) [5] in a graded exercise test on a treadmill [5] due to lower aerobic capacity and poor oxygen transport in muscles involved in weight-bearing activities (i. e. walking or running) [4]. However, recent evidence suggests that improvements in CRF in obese adults increase the values of oxygen consumption at ventilatory thresholds [6] while reducing morbidity and mortality levels compared to inactive lean individuals [7]. Thus, endurance training are cornerstones in weight management programs for obese people, first by creating an energy deficit to reduce body mass (BM), particularly fat mass [8], and second by improving CRF [9].

In this context, moderate-intensity continuous training (MICT) (i. e. duration between 20–60 min at < 80 % maximum heart rate (HRmax) or 49–75 % $\dot{V}O_2$max) and high-intensity interval training (HIIT) (i. e. duration between 1–4 min at ≥ 85 % of HRmax or ≥ 80 % of $\dot{V}O_2$max) [10] are the most prescribed exercise modalities in weight management programs [11]. In obese subjects, HIIT improves CRF [11] and body composition [12] more than MICT alone in a short period of time (i. e. between 4 and 12 weeks), although several systematic reviews and meta-analyses revealed similar improvements in $\dot{V}O_{2peak}$ [9] and body composition [13] induced by HIIT and MICT in obese subjects.

In addition, recent studies suggest that the combination of high- and moderate-intensity training, with a polarized (POL) approach, characterized by covering approximately 70–90 % of training volume below the GET and the remaining 10–30 % of training volume near the $\dot{V}O_2$max [14], is useful to maximize physiological parameters (e. g. $\dot{V}O_2$max, ventilatory thresholds) and improve body composition in athletes [15, 16] and obese subjects [17, 18], more than HIIT or MICT modalities alone.

Nevertheless, most studies in which endurance training is applied in obese adults showed that i) the exercise intensity of training is given in relation to percentage of HRmax, or $\dot{V}O_2$max [11], while ventilatory thresholds provide better information about endurance training using the concept of training intensity distribution (TID), typically applied to endurance athletes [19, 20], ii) a paucity of studies have examined the concept of training periodization in obese subjects [21], and iii) endurance training was applied during a limited number of training weeks (i. e. on average 12 weeks) [11].

Finally, the study by Collins et al. [22] indicated that most obese subjects will drop out before or within 2 to 3 months of exercise training onset. Accordingly, to increase the awareness and adherence of participants to the training, adding a challenging sports performance at the end of the training programs would be useful [23]. To date, this strategy has been used on people with multiple sclerosis, achieving excellent results in terms of adherence to training [23]. However, to our knowledge, no study on obese adults compared two types of TIDs, with linear or reverse periodization, for long periods of time (i. e. ≥ 6 months).

Thus, the aims of the present study were i) to determine the effects of 24 weeks of either POL TID or threshold (THR) TID (i. e. ≥ 20 % of overall volume conducted at intensity between the ventilatory thresholds) [24] , modified by Veronique Billat (www.billatraining.com) [25], with reverse periodization (i. e. volume increased over the months, while intensity is maintained) [26] on body composition, $\dot{V}O_2$max, and ventilatory thresholds in healthy obese males. ii) At the end of the 24 weeks, a running competition depending on the level reached by each participant, such as a half marathon, 30-km race, or marathon, was employed to encourage adherence to the project.

Materials and Methods

Subjects

Twenty-eight obese adult males were enrolled in the study. These subjects all took part in a previous study that ended two months before the start of this study (under review). All subjects had a full medical history and underwent physical and nutritional examinations. BM was stable during the previous two months. None of the subjects showed cardiovascular, respiratory, neurological, skeletal, metabolic and/or endocrine diseases, and none of the subjects took medications regularly or used drugs known to affect energy metabolism. Of these subjects, 20 participants completed the 24 weeks of training (▶ **Tables 1, 2**).

Experimental Design

The study was approved by the Ethics Committee (protocol number 1764). Before the study began, the purpose and objective were carefully explained to each subject, and written informed consent was obtained.

The training intervention was performed from November 2021 to May 2022 (24 weeks). Between the previous study that had finished in September 2021 and the beginning of this study, an 8-week preintervention period was employed to standardize the training load for all subjects. During the preintervention period, participants were instructed to perform 3 sessions/week, with a progressive working volume from 100 to 200 min/week performed at low intensity (speed corresponding to 60 % of $\dot{V}O_{2peak}$) derived from the previous graded exercise test.

After the 8-week preintervention period, participants followed a 24-week weight management program and were randomly divided into two groups, POL (n = 10) and THR (n = 10), with reverse periodization, using the three zones model to calculate the TID for both groups [27] (see below for details). The participants were trained in their normal living conditions, ensuring the ecological validity of the study. Full testing sessions were conducted before the beginning (PRE) and at completion of the 24-week weight management period (POST). The testing sessions were conducted during one visit, including the assessment of anthropometric characteristics, body composition and graded exercise test on a 400 m track (Gemona del Friuli, Udine, Italy) to measure the ventilatory thresholds and $\dot{V}O_2$max. All tests were performed at the same time of day under similar weather conditions (12.4 °C [3.1 °C], 51.3 % [9.8 %] relative humidity). All tests were performed under medical supervision. The physical capacities were monitored weekly to individually adjust physical training. At PRE and throughout the weight management period, each participant received the same nutritional advice to avoid confounding nutritional variables on the outcomes [28].

At the end of the 24-week training period, a running challenge was proposed consisting of a half marathon, 30-km race or a marathon, depending on the level reached by the participants.

Training program

The training intervention was performed for 24 consecutive weeks, with 3 sessions per week. The sessions consisted of walking or running (or a combination of the two methods) on flat terrain, a track or city circuits. The training was divided into three 8-week macrocycles structured as 3 + 1 mesocycles, with linear periodization (Supplementary Table 1). In both groups, on average, training load (TL) increased by ~30 % between the first and the second 8-week macrocycles. Then, between the second and the third 8-week macrocycles, TL increased by ~10 % (see supplementary data for ex-

▶ **Table 1** Anthropometric characteristics before (PRE) and after 24 weeks (POST) of weight management program in polarized training (POL) and threshold training (THR) groups.

	POL (n: 10)		THR (n: 10)		P		
	PRE	POST	PRE	POST	G	T	G x T
Age (y)	42.1 ± 6.1		40.0 ± 6.5		0.724		
Stature (m)	1.75 ± 0.08		1.78 ± 0.05		0.401		
Body mass (kg)	98.2 ± 11.6	94.6 ± 11.5 *	100.0 ± 9.6	97.3 ± 11.7 *	0.670	0.001	0.443
BMI (kg m^{-2})	32.0 ± 3.3	30.8 ± 3.1 *	31.4 ± 1.8	30.6 ± 2.4 *	0.743	0.001	0.450
Waist (cm)	103.0 ± 7.5	102.3 ± 7.8	102.0 ± 4.5	101.3 ± 5.6	0.695	0.577	0.917
Hip (cm)	110.1 ± 5.1	109.5 ± 5.9	109.0 ± 3.0	108.6 ± 3.4	0.471	0.988	0.478
Waist-to-hip ratio	0.94 ± 0.05	0.93 ± 0.05	0.94 ± 0.05	0.93 ± 0.04	0.981	0.482	0.247
Fat-free mass (kg)	62.3 ± 5.9	62.8 ± 5.9	64.6 ± 5.1	65.6 ± 6.3	0.348	0.050	0.495
Fat Mass (kg)	35.9 ± 7.2	31.7 ± 7.3 *	35.0 ± 6.0	31.7 ± 7.3 *	0.885	0.001	0.514
Fat-free mass (%)	63.6 ± 3.7	66.7 ± 4.3 *	65.0 ± 3.7	67.7 ± 4.6 *	0.532	0.001	0.695
Fat Mass (%)	36.4 ± 3.7	33.3 ± 4.3 *	35.0 ± 3.7	32.3 ± 4.6 *	0.533	0.001	0.700

All values are presented as mean ± standard deviation.; BMI: body mass index; G: group effect, T: time effect; G × T: groups × time effect. * Significantly different from PRE, $P < 0.05$.

tended program). In all 3 + 1 mesocycles, the last week was a recovery week, and TL was reduced by 30 %. TID was calculated every 8 weeks with the three-zone model using the speed reached at GET, RCP and $\dot{V}O_2$max [29]: zone 1 (Z1), for intensities below GET; zone 2 (Z2), for intensities between GET and RCP; and zone 3 (Z3), for intensities above RCP. POL TID was verified with the polarization index (i. e. polarized: Z1 > Z3 > Z2) [20, 30], POL and THR TID were matched for the same TL. TL was quantified with the training impulse (TRIMP), where each zone has a weighting factor that is multiplied by the duration in this zone [31]. All participants uploaded their own workouts to an online training diary, Polar Flow (Polar Electro Oy, Finland) or Gamin Connect (Garmin, Olathe, USA). Research assistants and physical trainers verified that each subject performed the exercises correctly and registered for each training session: training duration, time spent in each endurance training zone, and rate of perceived exertion (RPE) using the Borg 6–20 Scale [32], as recorded by the participants. When the mean HR decreased by 5 bpm for two consecutive training sessions in one of the three training zones, the speed was increased to maintain the prescribed intensity.

At the end of the 24-week training period, 17 of the 20 participants performed a challenge, running a half marathon, a 30-km race or a marathon, depending on the level reached by the participants at the end of the study. The challenge included a lap of 10.2 km to be repeated according to the distance. For safety reasons, we placed refreshment points with water, mineral salts, and fruits along the track. The challenge was performed under medical supervision. The performance of the subjects was monitored using their Garmin (Garmin, Olathe, USA) or Polar (Polar Electro Oy, Finland) watches.

Measurements

Anthropometric characteristics and body composition

BM was measured with a manual weighing scale (approximation 0.1 kg) (Seca 709, Hamburg, 165 Germany) with the subject dressed only in light underwear and no shoes. A wall-mounted height board was used to measure the stature. BMI was calculated as BM (kg) × stature^{-2} (m). The waist circumference (WC) and hip circumference (HC) were measured with the method of Kagawa et al. [33]. Body composition was measured by bioelectrical impedance (BIA, Human IM Plus; DS 171 Dietosystem, Milan, Italy) [34]. The fat mass (FM) and fat free mass (FFM) values were obtained with the equations described by Gray et al. [35] derived in obese people of either age (fat-specific formula).

Graded exercise test (GRAD)

To determine $\dot{V}O_2$max, HRmax, and ventilatory thresholds, participants carried out a graded exercise test on a 400 m track (Gemona del Friuli, Udine, Italy) under medical supervision. A collaborator with a bike paced the runners, and the participants were instructed to follow the bike. The duration of each step was one minute, and the speed increased by 0.5 km/h every minute until volitional exhaustion. Oxygen uptake ($\dot{V}O_2$), carbon dioxide production ($V'CO_2$) and HR were measured during this test using a wearable metabolic unit (K5; Cosmed, Roma, Italy) and a chest strap (Garmin HRMrun, Olathe, USA), respectively. We calibrated the volume and gas analyzers before every test using a 3-L calibra-

▶ **Table 2** Physiological Parameters before (PRE) and after 24 weeks (POST) of weight management program in polarized training (POL) and threshold training (THR) groups.

	POL (n:10)		THR (n: 10)		P		
	PRE	POST	PRE	POST	G	T	G x T
Maximal oxygen uptake							
$\dot{V}O_2$(L min^{-1})	3.65 ± 0.41	3.95 ± 0.52 *	3.93 ± 0.48	4.11 ± 0.44 *	0.265	0.001	0.464
$\dot{V}O_2$(ml kg $^{-1}$min^{-1})	37.4 ± 4.0	42.1 ± 6.4 *	39.4 ± 3.8	42.4 ± 5.4	0.570	0.001	0.283
HRmax (bpm)	177.3 ± 12.7	174.1 ± 8.4	179.5 ± 8.8	175.5 ± 10.8	0.670	0.050	0.796
RER max	1.12 ± 0.05	1.08 ± 0.03	1.09 ± 0.05	1.10 ± 0.04	0.683	0.190	0.110
Speed (km h^{-1})	11.9 ± 1.7	12.9 ± 1.9 *	12.8 ± 1.5	13.2 ± 1.8	0.440	0.001	0.070
Respiratory compensation point							
$\dot{V}O_2$(L min^{-1})	3.20 ± 0.45	3.45 ± 0.50 *	3.55 ± 0.37	3.65 ± 0.37 *	0.119	0.036	0.371
$\dot{V}O_2$(ml/kg/min)	32.7 ± 4.5	36.8 ± 6.2 *	35.8 ± 3.8	37.7 ± 4.8	0.321	0.001	0.181
$\dot{V}O_2$, %max	87.5 ± 5.5	87.3 ± 4.8	90.4 ± 1.8	90.2 ± 5.2	0.040	0.893	0.998
HR (bpm)	164.0 ± 10.6	163.3 ± 9.8	169.2 ± 8.8	165.5 ± 10.7	0.360	0.230	0.385
HR, %max	92.6 ± 3.9	93.8 ± 3.1	94.0 ± 2.0	94.3 ± 2.1	0.312	0.329	0.583
RER	1.02 ± 0.05	0.99 ± 0.03	1.00 ± 0.05	1.01 ± 0.03	0.848	0.468	0.073
Speed (km/h)	10.2 ± 1.6	11.3 ± 1.9 *	11.3 ± 1.4	11.8 ± 1.6 *	0.230	0.001	0.060
Gas exchange threshold							
$\dot{V}O_2$(L min^{-1})	2.52 ± 0.41	2.87 ± 0.40 * °	2.90 ± 0.33	3.21 ± 0.35 *	0.030	0.001	0.746
$\dot{V}O_2$(ml/kg/min)	26.2 ± 6.5	30.8 ± 6.0 *	29.4 ± 3.8	33.1 ± 4.3 *	0.225	0.001	0.482
$\dot{V}O_2$, %max	70.0 ± 12.5	73.2 ± 8.9	75.0 ± 5.4	78.2 ± 7.6	0.129	0.135	0.960
HR (bpm)	143.4 ± 14.1	145 ± 11.6	149.5 ± 10.9	151.7 ± 11.3	0.154	0.528	0.897
HR, %max	81.0 ± 7.1	83.4 ± 7.1	83.0 ± 2.9	86.5 ± 4.0	0.192	0.065	0.692
RER	0.91 ± 0.06	0.90 ± 0.04	0.90 ± 0.06	0.93 ± 0.04	0.496	0.572	0.175
Speed (km/h)	8.60 ± 1.60	9.60 ± 1.72 *	9.23 ± 1.37	10.20 ± 1.50 *	0.327	0.001	0.894

All values are presented as mean ± standard deviation$\dot{V}O_2$: oxygen consumption, HR: heart rate, RER: respiratory exchange ratio, $\dot{V}O_2$ %max: percentage of maxima oxygen uptake, HR %max: percentage of heart rate max.; G: group effect, T: time effect; G × T: groups × time effect.; * Significantly different from PRE, P < 0.05.; ° Significantly different POL vs. THR at baseline, P < 0.05.

tion syringe and calibration gas (16.00 % O2 and 5.00 % C'O2), respectively. We determined the GET and RCP with the V-slope method [36]. $\dot{V}O_2$max was calculated as the average 30-s $\dot{V}O_2$ according to previously established criteria [37]: (i) plateau in $\dot{V}O_2$ (i. e. increase < 150 ml min − 1), (ii) respiratory exchange ratio (RER) > 1.1, and (iii) ≥ 90 % of theoretical maximal heart rate.

Dietary habits

Participants were invited to collect a 4-day dietary record (4-dDR), collecting the food and beverage consumption of 2 weekdays and 2 weekend days, instructions on how to record the type and portion size of the foods consumed, at PRE and POST as previously described [38].

Statistical analysis

The data were analyzed using GraphPad Prism (version 9.4.0), with significance set at $p < 0.05$. The results obtained are expressed as the means and standard deviations (SDs). The Shapiro-Wilk test was used to evaluate the normality of the data. Sphericity was verified by Mauchly's test. A Greenhouse-Geisser correction was used in cases of sphericity assumption violations. For baseline characteristics and training adherence comparison, Student's t test was used for unpaired data. Anthropometric characteristics, body composition, $\dot{V}O_2$max, ventilatory thresholds and training characteristics were analyzed with a 2-way ANOVA that included the between-subjects factor of the training model (POL and THR groups) and the within-subjects factor of time (PRE vs. POST, i. e. repeated measured analysis). Significant main effects were further analyzed by the Bonferroni post hoc test. Finally, effect sizes comparing pre-post changes within each group were calculated as the corrected effect size (ES) [39]. ES < 0.20 was considered small, < 0.50 medium and > 0.50 large [40]. To determine the sample size a priori, power analysis showed seven participants per group selected an F test for ANOVA-repeated measures-within factors analysis with a statistical power of 0.80, a probability α level of 0.05, and an effect size f of 0.35 (G-Power software, v. 3.1.9.2, University of Kiel, Kiel, Germany).

Results

Anthropometric characteristics and body composition

At baseline, no differences in the anthropometric characteristics and body composition were observed between groups (▶ **Table 1**).

At POST, BM decreased in both groups by 3.66 ± 3.11 kg (ES = 0.31 *medium*) and 2.73 ± 3.17 kg (ES = 0.24 *medium*) for the POL and THR groups, respectively (time effect P < 0.001). BMI was reduced by 1.22 ± 1.04 kg m^{-2} (ES 0.37 *medium*) for the POL group and 0.75 ± 0.96 kg m^{-2} (ES 0.37 *medium*) for the THR group (time effect P < 0.001). FM (kg) decreased by 4.21 ± 3.10 kg (ES 0.57 *large*) in the POL group and 3.34 ± 2.45 kg (ES 0.47 *medium*) in the THR group (time effect P < 0.001). FM (%) decreased in both groups (3.10 ± 2.34 and 2.73 ± 2.00 %, time effect P < 0.001) for POL (ES 0.74 *large*) and THR (ES 0.57 *large*). FFM (%) increased on average by 2.93 ± 2.13 (%) (time effect P < 0.001) in the POL (ES 0.74 *large*) and THR (ES 0.57 *large*) groups. FFM (kg), WC, HC and waist-to-hip ratio did not change significantly in either group (▶ **Table 1**).

Physical capacities

At PRE, the percentage (%) of $\dot{V}O_2$max at RCP was greater in the THR group than in the POL group by + 3.83 ± 6.17 % (P = 0.004), and $\dot{V}O_2$ at GET (P = 0.004) was greater in the THR group than in the POL group by + 12.0 ± 14.3 % (P = 0.047) (▶ **Table 2**). However, the other physiological parameters were not significantly different between the groups (▶ **Table 2**).

At POST, $\dot{V}O_2$max (L min^{-1}) increased by 0.30 ± 0.41 and 0.18 ± 0.28 L min^{-1} in the POL (ES 0.61 *large*) and THR (ES 0.37 *medium*) groups, respectively (time effect P < 0.001). $\dot{V}O_2$max (L kg^{-1} min^{-1}) increased in the POL (+ 19.1 ± 13.0 %, ES 0.87 *large*) and THR (+ 7.81 ± 8.10 %, ES 0.50 *large*) groups (time effect P < 0.001). The speed at $\dot{V}O_2$max (v $\dot{V}O_2$max) increased in the POL group by 0.95 ± 0.72 km h^{-1} (ES 0.53 *large*) and by 0.35 ± 0.70 km h^{-1} (ES 0.21 *medium*) (time effect P < 0.001) in the THR group. No difference was found for HRmax and RER at $\dot{V}O_2$max in either group (▶ **Table 2**).

$\dot{V}O_2$ (L min_{-1}) under RCP increased by 0.25 ± 0.47 L min^{-1} in the POL group (ES 0.50 *large*) and 0.10 ± 0.21 L min^{-1} in the THR group (ES 0.27 *medium*) (time effect P = 0.034). $\dot{V}O_2$ (L kg^{-1} min^{-1}) under RCP increased in the POL (+ 13.0 ± 15.8 %, P = 0.004, ES 0.70 *large*) and THR (+ 6.0 ± 6.2 %, P = 0.200, ES 0.48 *medium*) groups (time effect P < 0.001). The speed at RCP increased in both groups (1.10 ± 0.53 and 0.55 ± 0.73 km h^{-1}, time effect P < 0.001) in the POL (ES 0.60 *large*) and THR (ES 0.32 *medium*) groups. No difference was found for HR, RER, % of $\dot{V}O_2$max and HRmax under RCP in either group (▶ **Table 2**).

$\dot{V}O_2$ (L min^{-1}) at GET increased in both groups (0.35 ± 0.34 and 0.30 ± 0.26 L min^{-1}, time effect P < 0.001) in the POL (ES 0.83 *large*) and THR (ES 0.88 *large*) groups, respectively. $\dot{V}O_2$ (L kg^{-1} min^{-1}) at GET increased in the POL (4.59 ± 3.20 ml kg^{-1} min^{-1}, ES 0.71 *large*) and THR (3.77 ± 2.31 ml kg^{-1} min^{-1}, ES 0.87 *large*) groups (time effect P = 0.001). The speed at GET increased in both groups (1.00 ± 0.55 and 0.95 ± 0.93 km h^{-1}, time effect P < 0.001) in the POL (ES 0.60 *large*) and THR (ES 0.61 *large*) groups. No difference was found for HR, RER, % of $\dot{V}O_2$max or HRmax at GET in either group (▶ **Table 2**).

Training characteristics

Twenty-eight obese adult males were recruited for the study. Of these, 20 subjects completed the 24-week training. Of the eight who dropped out, five had family or work reasons, while three were injured. One of three injured participants showed ankle problems outside the training program; the other two injuries were caused by algodystrophy to the knee in one subject and medial meniscus inflammation of the left knee in the other subject.

At the end of the training intervention, subjects performed 92.3 ± 10.1 and 87.7 ± 10.8 % of training sessions for the POL and THR groups, respectively (P = 0.253). Average weekly TL (a.u. $week^{-1}$), time spent in Z1 (min $week^{-1}$) and time spent in Z3 (min $week^{-1}$) increased similarly in both groups by 16.9 ± 21.2, 18.0 ± 26.5 and 30.7 ± 40.6 % over the three 8-week macrocycles (time effect P < 0.001), without differences between the values of weekly TL (a.u. $week^{-1}$) and time spent in Z3 (min week-1) (▶ **Table 3**). Moreover, the POL group spent more time in Z1 (+ 61.0 ± 20.4 min $week^{-1}$,

▶ **Table 3** Average training intensity distribution and training load for week 1–8, week 9–16 and week 17–24 before of weight management program in polarized training (POL) and threshold training (THR) groups.

	POL (n: 10)									**THR (n: 10)**									**P**		
	Week 1–8			**Week 9–16**			**Week 17–24**			**Week 1–8**			**Week 9–16**			**Week 17–24**			**G**	**T**	**G x T**
Z1 (min week⁻¹)	154	±	20	183	±	31	204	±	60	95	±	17	129	±	26	135	±	51	0.001	0.008	0.715
Z2 (min week⁻¹)	5	±	2	8	±	3	10	±	0	39	±	21	29	±	15	37	±	20	0.001	0.601	0.890
Z3 (min week⁻¹)	10	±	2	14	±	3	14	±	2	8	±	5	10	±	9	13	±	8	0.340	0.040	0.731
∑ volume (min week⁻¹)	167	±	22	205	±	30	223	±	66	141	±	20	176	±	31	185	±	42	0.001	0.030	0.520
TL (a.u. week⁻¹)	191	±	28	240	±	32	260	±	55	188	±	33	239	±	34	249	±	36	0.793	0.001	0.958

All values are presented as mean ± standard deviation; Z1: time spent at intensity below gas exchange threshold, Z2: time spent at intensity between gas exchange threshold and respiratory compensation point, Z3: time spent at intensity between respiratory compensation point and maximal oxygen uptake, ∑ volume: average total weekly volume, TL: training load. G: group effect, T: time effect; G × T: groups × time effect.

$P < 0.001$) than the THR group over the three 8-week macrocycles. The average weekly time in Z2 (min week^{-1}) was greater in the THR group by + 31.0 ± 20.2 min week^{-1} than in the POL group ($P < 0.001$), without an increase over the 8-week macrocycles (▶ **Table 3**). The total volume (min week^{-1}) was greater in the POL group than in the THR group (+ 31.3 ± 23.0 min week^{-1}, $P < 0.001$) over the three 8-week macrocycles in both groups (▶ **Table 3**), without differences between the two groups for the mean RPE during the 24 weeks of the training intervention (▶ **Fig. 1**). The POL group spent more time (%) in Z1 than the THR group (91.0 ± 2.4 vs. 71.3 ± 9.6 %, $P < 0.001$), while the POL group spent less time (%) in Z2 than the THR group (4.0 ± 4.0 vs. 23.0 ± 11.2 %, $P < 0.001$) over the 8-week macrocycles (▶ **Fig. 2**). The time (%) spent in Z3 did not differ between the two groups (▶ **Fig. 2**).

At the end of the 24 weeks of training, eight participants completed the half marathon distance in 2:47:50 ± 0:7:44 h:m:s, range [2:38:57–3:01:06 h:m:s], three completed the 30-km race in 4:03:04 ± 0:42:03 h:m:s, range [3:35:59–4:51:30 h:m:s], and six participants completed a marathon distance in 4:19:46 ± 0:40:50 h:m:s, range [3:28:14–5:18:19 h:m:s].

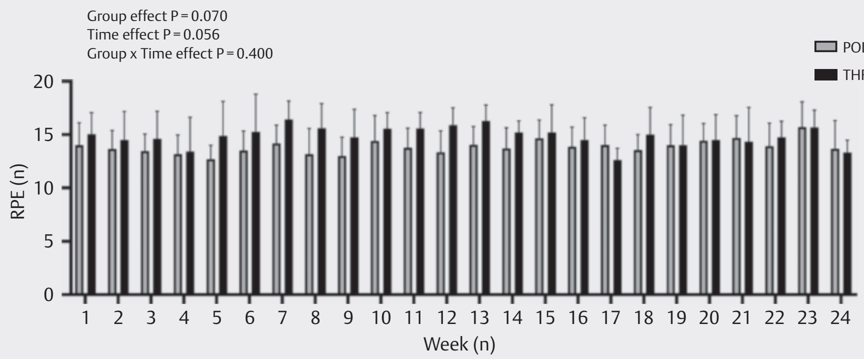
Nutritional habits

At PRE, no significant differences were found between the POL and THR groups in terms of energy intake (6405 ± 611 vs. 8185 ± 2306 kJ day^{-1}, group effect $P = 0.060$) and macronutrient percentage contribution to total energy intake: carbohydrates (39.5 ± 7.9 vs. 42.4 ± 12.1 %E, group effect $P = 0.628$), fats (35.6 ± 5.3 vs. 31.3 ± 6.1 %E, group effect $P = 0.091$) and proteins (19.3 ± 5.2 vs. 19.2 ± 6.2 %E, group effect $P = 0.920$). At POST, mean energy intake was unchanged in both groups (time effect $P = 0.701$), without differences between groups (interaction G × T, $P = 0.701$). The carbohydrate, lipid, and protein percentage contributions to total energy intake did not change significantly in either group.

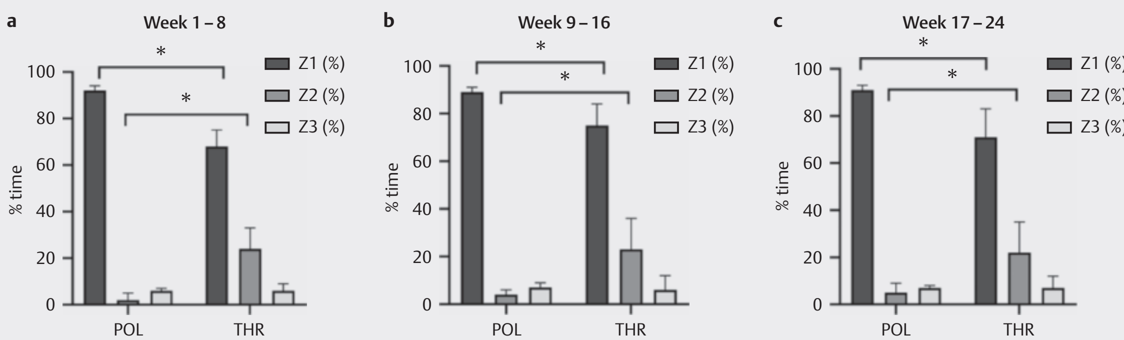
Discussion

The present study shows that a 24-week of POL or THR TID, with reverse periodization, applied in obese adult males, induced the following in both groups: (1) significant reductions in BM and FM; (2) significant improvements in $\dot{V}O_2$max and ventilatory thresholds; and (3) high adherence to training during the training period and a lower dropout rate.

The first outcome obtained in our study was that POL and THR TID combined with a no reduction in caloric intake resulted in similar reductions in BM and FM of ~4 and ~12 %, respectively. Although weight loss of at least 5 % of BM should be achieved for “successful” obesity treatment [41], we observed that reduced caloric intake combined with physical exercise reduced BM (i. e. ~4 kg) more than physical exercise alone (i. e. ~1.7 kg) [42]. The positive effects of POL and THR TID on reducing BM and FM have previously been noted in endurance athletes [43] and confirmed in the present study in obese volunteers. These results could be due to long-term adaptations to endurance training, such as increasing skeletal muscle capacity for fatty acid uptake and oxidation and concomitant increases in glycogen content and glycogen utilization with higher levels of glycolytic enzymes [44], which are typically impaired in obese individuals [45]. Thus, to our knowledge, this study



▶ **Fig. 1** Average values of rating of perceived exertion (RPE) during the 24 weeks of the training intervention between POL (grey columns) and THR (black columns) groups.



▶ **Fig. 2** Total running time in each zone (% time) for week 1–8 (panel A), week 9–16 (panel B) and week 17–24 (panel C) during the weight management program in polarized training (POL) and threshold training (THR).

is the first to apply a TID -approach using POL or THR training with reverse periodization in obese adult men and confirms that this approach may be equivalent or superior to classic HIIT or MICT in reducing BM and FM loss. In addition, the role of physical exercise was important in maintaining FFM, consistent with Reljic et al. [46].

The second outcome achieved in the present study was that the POL and THR groups significantly improved their physical capacities (i. e. $\dot{V}O_2$ at ventilatory thresholds and $\dot{V}O_2$max), confirming previous research conducted in recreational and highly trained endurance athletes [15, 20]. $\dot{V}O_2$ at GET, expressed both in absolute values or relative to BM, increased by ~15 and 20 % for the POL group and ~11 and 13 % in the THR group, without differences between the two groups. This amount is greater than the 9 % increase in $\dot{V}O_2$ at GET reported in a previous study conducted in obese subjects after 16 weeks of HIIT [6]. Previous studies on endurance athletes have shown that $\dot{V}O_2$ at GET increased only with POL training [27], while THR training increased $\dot{V}O_2$ at GET in untrained subjects [47]. The high volume in Z1 performed in both groups may have led to favorable adaptations, such as enhanced mitochondrial content and respiratory function [48], as well as improved fat and glucose utilization during endurance exercise [44, 49]. $\dot{V}O_2$ at RCP, expressed both in absolute and relative values, increased by ~9 and 13 % for the POL group and ~ 5 and 3 % in the THR group. This increase confirms that in people with obesity, intensity training above or below the RCP increases the values of $\dot{V}O_2$ associated with the RCP [6] However, in our study, we observed that the effect of POL training in improving $\dot{V}O_2$ values at RCP was greater than the effect of THR training, as shown by comparing pre-post changes within each group (i. e. ES *large* vs. *medium* for POL and THR, respectively). This finding agrees with previous studies in which POL training improved $\dot{V}O_2$ and speed at RCP more than THR training when applied to endurance athletes [15, 27]. However, to our knowledge, this study is the first to compare two different TIDs with POL and THR approaches in obese subjects, precluding direct comparisons with a population sample similar to ours. From a physiological prospective, the high training volume spent in Z1 by the POL group may have increased type I muscle fiber density [50] while simultaneously increasing capillary density [51]. Indeed, the proportion of type I skeletal muscle fibers and capillary in contacts with type I fibers were positively correlates with RCP [52]. Alternatively, a weekly training routine (i. e. ≥ 30 % of the overall training volume) conducted below and above the RCP might be very demanding for the THR group and therefore not produce greater adaptations compared to the use of greater volumes in Zone 1 [53]. $\dot{V}O_2$max, expressed both in absolute or relative values, increased by ~8 and 12 % for the POL group and ~ 4 and 6 % in the THR group, but these improvements were smaller than the improvements reported in previous studies (i. e. ranged between 9 and 25 %) [6, 18, 54], probably because the participants of our study were not totally deconditioned. Additionally, for the values of $\dot{V}O_2$ at RCP, comparing pre-post changes within each group showed that POL training improved $\dot{V}O_2$max to a greater extent than THR training (i. e. ES large vs. medium for POL and THR, respectively) in agreement with previous studies in which POL training improved $\dot{V}O_2$max more than THR when applied to endurance athletes [15, 27]. Since peripheral factors limit $\dot{V}O_2$max in untrained subjects [55], exercise volume is more effective than exercise intensity in increasing O_2 extraction capacity and mitochondrial content during whole-body maximal exercise in overweight and diabetic male adults [56].

The third outcome of our study was that the participants in both groups had high adherence to training and a lower dropout rate during the 24 weeks of the training intervention, and this adherence did not differ between groups. Recent studies in which endurance training was applied in obese subjects over a long period of time (i. e. ≥ 6 months) showed a high dropout rate (i. e. ranged between 31 and 44 %) [22, 57], while this rate was ~ 26 % in our study. Specifically, we observed that using the concept of TID with POL or THR training with reverse periodization together with a running competition at the end of the study may helped to maintained high adherence to training in our study (i. e. ~90 %), in line with previous studies on nonobese subjects [23]. In addition, ~7 % of our participants left the study due to an injury. Typically, the rate of running-related injuries (RRIs) among novice runners is ~30 % [58], and obesity is a major risk factor for RRIs [59]. Since the rate of progression in training volume and intensity may contribute to the risk of RRI [60], an approach to running through periodizing POL or THR may represent an efficacious strategy to increase adherence to training while reducing both RRI and dropout rate over a long period of training in obese subjects.

Limitations

Our study presents some limitations. First, although our study showed that 24 weeks of POL or THR TID improved body composition and physical capacities in healthy obese male, with low injury rates at POST, the low number of participants, already trained, and the absence of a control group, do not allow to draw definitive conclusions. Second, our study was carried out on obese subjects not totally deconditioned, thus it is not possible to extend our results to obese people completely deconditioned. Third, since our study was conducted only in obese male adults, further studies will be needed to confirm our results in obese female adults. Fourth, for the evaluation of BM in our study, we did not perform DEXA assessment (i.e., the gold standard) because this measurement is associated with high costs and higher x-ray exposure. Finally, although our results are promising, further studies will be needed to confirm what has been found through addition of a control group.

Practical Applications

Obese adult males who want to approach running and simultaneously improve their body composition and physical capacities while minimizing the risk of injury should choose TIDs with POL or THR approaches, both with a high volume of training below the GET.

Conclusions

In conclusion, 24-week training with POL or THR TID with reverse periodization improves body composition and physical capacities in obese adult men and may reduce injury risk compared to data in the literature. Future studies will be needed to determine whether exercise adherence can be improved by adding competition compared to a group without competition at the end of the exercise program.

Conflict of Interest

The authors declare that they have no conflict of interest.

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