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Effects of moderate- *vs.* high-intensity interval training on physical fitness, enjoyment, and affective valence in overweight/obese female adolescents: a pre-/post-test study

W. ABASSI[1], N. OUERGHI[1,2,3], M. FEKI[2], N. JEBABLI[1], M.S. ANDRADE[4], A. BOUASSIDA[1], C.V. SOUSA[5], P.T. NIKOLAIDIS[6], K. WEISS[8], B. KNECHTLE[7,8]

[1]University of Jendouba, High Institute of Sport and Physical Education of Kef, Kef, Tunisia
[2]University of Tunis El Manar, Faculty of Medicine of Tunis, Rabta Hospital, Tunis, Tunisia
[3]University of Gafsa, High Institute of Sport and Physical Education of Gafsa, Gafsa, Tunisia
[4]Department of Physiology, Federal University of São Paulo, São Paulo, Brazil
[5]Department of Health and Human Sciences, Loyola Marymount University, Los Angeles, CA, USA
[6]School of Health and Caring Sciences, University of West Attica, Athens, Greece
[7]Medbase St. Gallen Am Vadianplatz, St. Gallen, Switzerland
[8]Institute of Primary Care, University of Zurich, Zurich, Switzerland

W. Abassi and N. Ouerghi contributed equally to this work

Abstract. – OBJECTIVE: The aim of this study was to compare the effects of 12-week moderate-intensity interval training (MIIT) vs. high-intensity interval training (HIIT) on body composition, physical fitness, and psychological valence in overweight/obese (OW/OB) female adolescents.

PATIENTS AND METHODS: Thirty-eight OW/OB female students were randomized into HIIT (n=13), MIIT (n=13) or control (n=12) groups. The participants underwent a 12-week interval-training program at 100% to 110% and 60% to 75% of maximal aerobic speed for HIIT and MIIT, respectively. The control group kept their usual physical activity without completing the training program. Pre- and post-training measurements were performed to assess body composition, aerobic capacity, and anaerobic performance (using selected tests evaluating speed, jumping ability, and strength). Ratings of perceived exertion and the feeling scale were evaluated every three weeks. Enjoyment was measured at the end of the program. A two-way analysis of variance with repeated measurements was applied to test for "group×time" interactions for body composition, physical fitness, and affective variables.

RESULTS: Significant "group×time" interactions were detected for aerobic and anaerobic performance, body composition indices, and the feeling scale. HIIT resulted in more noticeable improvements in body composition and physical performance than MIIT, while no significant changes were found in the control group. Throughout the program, the feeling score has progressively increased in the MIIT group but decreased in the HIIT group. Ratings of the perceived exertion have increased in both groups, more noticeably in the HIIT group. At the end of the program, the MIIT group showed a higher enjoyment score.

CONCLUSIONS: Despite offering better body composition improvement and physical fitness enhancement, HIIT offered lesser enjoyment and affective valence than MIIT in OW/OB female adolescents. MIIT might be an alternative time-efficient protocol for improving health in this population.

Key Words:
Aerobic capacity, Enjoyment, Feeling scale, Intermittent training, Obesity, Physical performance, Sprint ability.

Introduction

Childhood obesity is widely recognized as a major worldwide public health issue[1]. Overweight/obese (OW/OB) children/adolescents are at a high risk of health issues such as cardiovascular disease, type 2 diabetes, depression, and early mortality[2,3].

Corresponding Author: Beat Knechtle, MD; e-mail: beat.knechtle@hispeed.ch

Physical exercise is an important component of lifestyle interventions to manage obesity and health conditions related to it[1]. Notably, the risk of cardiovascular mortality is lower in obese people with high physical fitness compared to normal-weight individuals with poor fitness[4]. Therefore, developing fitness with exercise reduces morbidity and mortality. High-intensity interval training (HIIT) that alternates bouts of intensive activity and low-intensity exercise recovery became a popular strategy for reducing cardiometabolic risk[5-7]. Making HIIT a key factor for physical fitness improvement has ensured overall health maintenance in trained[5,8], untrained[6,7], diabetic[9], and obese[6,7,10] populations. Sustained evidence supports the effectiveness of the HIIT protocols on different measures of physical performance, including endurance, strength, sprint, and agility in OW/OB children and adolescents[11,12]. Nevertheless, the near-maximal intensity required during HIIT induces feelings of displeasure[13], causing low tolerance and weak long-term adherence to physical exercise in obese people[14,15]. To overcome this issue, an alternative might be moderate-intensity interval training (MIIT), which consists of bouts of moderate-intensity exercise alternated with recovery periods[10,16]. MIIT has rarely been investigated in obese people and has been focused on its effects on the hormonal and metabolic profiles[10,16]. However, whether MIIT is as effective as HIIT in improving physical fitness and how it affects tolerance and adherence to exercise is still being determined. This study aimed to compare the effects of MIIT *vs.* HIIT on body composition, physical fitness, and affective valence in OW/OB female adolescents. We hypothesized that MIIT is less effective than HIIT in enhancing physical fitness but is more effective for psychological improvement in obese female adolescents.

Patients and Methods

Study Design and Ethical Aspects

A pre-/post- test study was designed involving OW/OB female adolescents. The study was conducted in accordance with the Declaration of Helsinki and the protocol received approval from the ethical committee of the Institute of Sports and Physical Education of Kef (ISSEP-3/2018). A written informed consent to participate was obtained from the girls' guardians.

Participants

Participants were OW/OB female students from two secondary schools in Kalaat Senan (Kef Governorate, Tunisia). Inclusion criteria were female gender, BMI ≥25 kg/m^2; age, 15 to 18 years; and individual or parental/guardian written consent. Non-inclusion criteria were medical conditions that contraindicate intense physical exercise, participation in another physical training program within the past 6 months (except for physical education class), and current or recent (within 3 months) dietary restrictions or therapy for obesity. Exclusion criteria were consenting retirement, non-compliance to the training program, and incomplete data. We estimated that a sample size of 12 participants per group would be required to detect an effect size of 0.55 between exercise groups and the control group, with a power of 0.80 at an alpha level of 0.05 (G*Power 3.1 software, Dusseldorf, Germany). We enrolled 43 girls in the study. Participants were randomized into a high-intensity interval training group (HIIG, n=15), a moderate-intensity interval training group (MIIG, n=15), and a non-training control group (CG, n=13). Participants were asked to maintain nutritional behavior unchanged during the study program. Of the 43 pre-selected participants, five girls dropped out of the training program for personal reasons: two in MIIG, two in HIIG, and one in CG. Finally, 38 girls (age 16.4±1.2 years) completed the intervention; 13 in each experimental group and 12 in the control group (Figure 1).

Experimental Protocol

The experimental protocol was conducted from September to December 2018, with temperatures ranging from 15 to 24°C and humidity varying between 59% and 69%. Physical tests were completed in a regular outdoor field and in a laboratory in the morning and at the same time of day. Test sessions were performed with the same sports equipment and by the same investigator, who was blinded to training-group affiliation. Anthropometric measures [i.e., body height, body mass, waist circumference (WC), body fat (BF), and BMI] were assessed in barefoot, lightly clothed subjects as previously described[17]. The physical tests were undertaken on four non-consecutive days separated by 48 h after the familiarization. On the first day, squat jump (SJ), vertical countermovement jump (CMJ), and 30-m sprint time (with 10- and 20-m splits) were assessed. On the second day, standing long jump (SLJ), med-

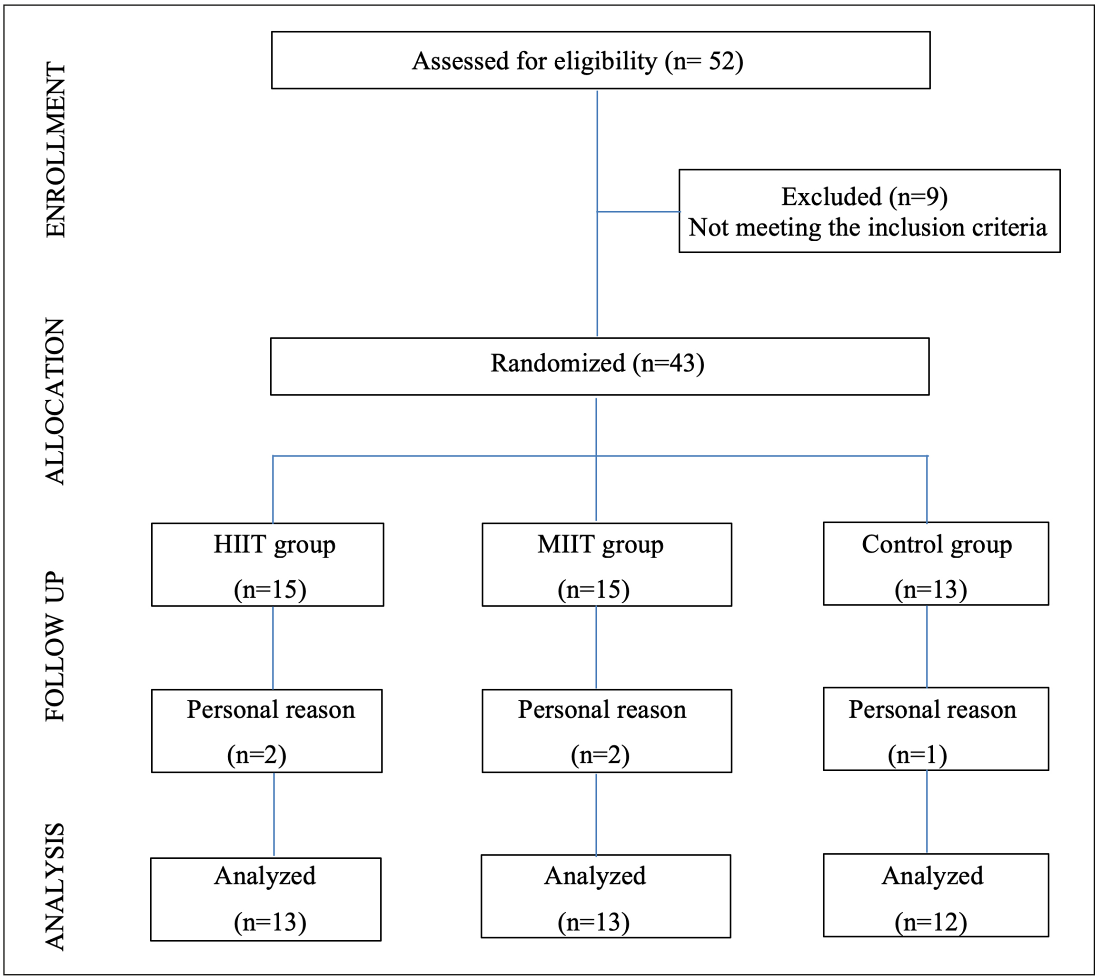

Figure 1. Flow diagram of study participants

icine ball throw (MBT), and agility (*t*-test) tests were performed. Repeated-sprint ability (RSA) and five jumps (FJT) tests were administered on the third day. The Spartacus test was performed on the fourth day. Perceived exertion (RPE) and the feeling scale (FS) were evaluated every three weeks in parallel with the training load increase. Furthermore, enjoyment was assessed at the end of the training program.

Training Program

Participants underwent a 12-week intervention consisting of high- or moderate-intensity interval exercise sessions performed three times per week on nonconsecutive days. They completed a standardized warm-up consisting of 5 min jogging, playing, acceleration running (5 min), and static and dynamic stretching (5 min). Each training session ended with a 10-min cool-down followed by 5-min of static stretching. After the warm-up period, the HIIG performed 2 sets of 6 repetitions of high-intensity exercises at 100-110% of the maximal aerobic speed (MAS) as previously described[6,7]. The HIIT program included 30-second high-intensity (100-110% of MAS) bolts followed by 30-second active recovery bolts (50% of MAS). The rest period between series was 4 min. The MIIG performed 2 sets of 6 repetitions of 30-second moderate-intensity (70-80% of MAS) bolts followed by 30-second active recovery bolts (50 % of MAS), and 4 minutes of passive recovery between sets[10]. The progressions of HIIT and MIIT were as follows: 3 weeks from the start of the program, the number of repetitions increased from 6 to 8. After the 6th week, the intensity was increased by 5% every 3 weeks. A detailed description of the two training programs and their progression is displayed in Table I.

Table I. Summary of high-intensity interval training (HIIT) and moderate-intensity interval (MIIT) training programs.

	Training progression	HIIT group	MIIT group
Warm-up		5-min jogging at 50% MAS 5-min acceleration running 5-min dynamic stretching	
Main stimuli	Week 1 to 3: 2 sets×6 (30 s/30 s)	100%/50% MAS	70%/50% MAS
	Week 4 to 6: 2 sets×8 (30 s/30 s)	100%/50% MAS	70%/50% MAS
	Week 7 to 9: 2 sets×8 (30 s/30 s)	105%/50% MAS	75%/50% MAS
	Week 10 to 12: 2 sets×8 (30 s/30 s)	110%/50% MAS	80%/50% MAS
	Passive recovery between sets:	4 min	
Cool down		10 min running at 40% MAS 5 min of dynamic stretching exercises	

MAS, maximal aerobic speed.

Participants in all the groups were encouraged to keep their regular diet and habitual routine. Participants continued to partake in the institutional, physical education classes twice a week.

Physical Fitness Assessments

Before the experimental session, participants performed a 12-min standardized warm-up comprising jogging, jumping drills, skipping exercises, jumping, direction changes, short distance accelerations, and a 4-min cool-down period. They were strongly encouraged to achieve maximum performance during testing and the best performance of the three trials was recorded for all performance tests (except for the Spartacus test). The rest period between each attempt was at least 2-min and 5-10 min between different exercises. In the meantime, participants performed low-intensity activities, including ball games, to stay ready for the next test. Before the tests session, participants were instructed to refrain from strenuous exercise and were prohibited from taking any energy beverages, supplements, or depressants 48 h before testing.

Aerobic Velocity

Aerobic velocity was measured with the Spartacus test, which evaluates aerobic capacity in obese adolescents[18]. A rectangle of 750 m (75×10 m) was drawn with regular markings, representing different stages. Participants began at a running speed of 7 km/h, increasing by 1 km/h every 3 minutes. During each stage, the participant had 15 s to reach the corresponding mark and then 15 s of rest. Participants adjusted their running speed simultaneously to cones and audio beep. The test ended when the subject could no longer maintain the pace for two consecutive occasions or when she decided to stop due to exhaustion. Maximal heart rate (HRmax) was recorded during the test using a Polar heart rate monitor (Polar S810, Kempele, Finland).

Explosive Power

Upper body explosive power

This was determined by the MBT test. Subjects were seated with backs glued to the wall and legs fully stretched, facing the direction of the ball throwing, and holding a 2-kg medicine ball. They were instructed to throw the ball straight forward for the maximum possible distance. The distance (m) was measured from the wall to the first point at which the ball landed on the floor and the greatest value of three trials was recorded. Participants were prohibited from removing their backs from the wall[12].

Lower body explosive power

This was measured using the following tests:

Vertical jump: the SJ and CMJ were advocated by Ouerghi et al[6]. Participants were instructed to jump as high as possible from a semi-squat position (90°) for SJ. The CMJ began from a standing position with knees fully extended. Participants performed a rapid downward movement by flexing the knees' angle of approximately 90 and then pushing upward as rapidly as possible. For both jumps, hands are placed on the hips to control for arm assistance. The height of each jump (cm) was measured with an Optojump apparatus (Microgate, Bolzano, Italy).

Standing long jump test: participants were asked to initially stand on a standardized starting line, feet shoulder width, and arms hanging down at the sides of their body. Then, they had to jump forward in the horizontal direction with arms swinging with full strength. Participants were required to land with both feet simultaneously in the long jump pit without falling forward or backward. The jump distance (m) was calculated from the starting line to the landing point at the first heel contact.

Five-jump test: this test began and ended with joined feet. FJT consists of 5 consecutive strides. Participants tried to cover the greatest distance possible with five forward jumps alternating left and right legs. During the last stride, the subject must bring both legs back together. The performance (m) was measured using a tape measure from the front edge of the feet at the starting position to the rear edge of the last feet print[6].

Agility

Agility and body control was measured with the *t*-test as previously described[11]. A T-shaped course was created with 4 cones. The first cone was placed at the course's beginning, and the second one was 9.14 m from the first. The third and fourth cones were placed at 4.57 m on either the right or the left of the second cone. Subjects were instructed to run 9.14 m from the first to the second cone and touch its base with their right hand. Afterward, they had to change direction by traveling 4.57 m to the left towards the third cone, touching it with their left hand without crossing their feet. Next, they had to sprint 9.14 m right to the fourth cone and touch it with their right hand. Afterward, they shuffled 4.57 m left to the second cone and touched its base with their left hand. Then, they had to run backward (9.14 m) from the second cone to the first cone. Participants' times (s) were obtained using an electronic photocell with an accuracy of 0.01 s (Brower Timing System, Salt Lake City, UT) placed at 0.7 m height from the floor.

Ability to Repeat Sprints

The repeated sprint ability (RSA) was performed indoors at the university gymnasium on a synthetic hard floor. RSA consisted of two sets of 5×20 m shuttle sprints, interspersed with a 15 s active recovery between repetitions and with one min between sets[19]. Each sprint was performed with one change of direction (180° turn) and was timed using a photocell system (Brower Timing System, Salt Lake City, UT), positioned approximately 3 m apart, facing each other on either side of the starting line located at the start and finish lines. The following variables were derived from the RSA test: (a) PT: the best time of each RSA test; (b) TT: the sum of all 10-sprint times; (c) the FI calculated according to Fitzsimons et al[20] from sprint running performance using the following formula: $\mathrm{FI}\ (\%) = \left(\frac{\mathrm{TT}}{\mathrm{PT} * \mathrm{NUMBER\ OF\ SPRINT}} - 1\right) * 100$

Sprint Speed

Sprinting performance was evaluated by 10 m, 20 m, and 30 m sprints. Times (s) were recorded outdoors on a track surface using a series of paired photocells with an accuracy of 0.01 s (Brower Timing System, Salt Lake City, UT, USA), which were raised to a height of 0.9 m and placed in pairs at 0 m,10 m, 20 m and 30 m, 1 m apart. Participants started standing with the front foot at 0.5 m from the first infrared photoelectric gate and were instructed to run as fast as possible. The runs were performed individually by each participant.

Affective Responses Measures

Feeling scale

General affective valence (i.e., pleasure and displeasure) was measured using the FS questionnaire[21]. FS is scored on an 11-point bipolar scale ranging from -5 (very bad) to +5 (very good), with anchors at zero (Neutral) in line with previous work in adolescents[22].

Physical Activity Enjoyment scale

Enjoyment was measured using the Physical Activity Enjoyment scale[23]. This scale was used to assess the level of enjoyment following HIIT and MIIT using the participants' responses to 18 items rated on a 7-point bipolar rating scale. The assessment consists of questions related to the enjoyment after intervention with the instruction, "Please rate how you feel about the physical activity you have been doing at the moment". Overall enjoyment of physical activity score was generated by summing the individual item scores. Scores ranged from 18-126, with higher scores reflecting higher levels of enjoyment.

Perceived exertion rating

RPE was assessed with the extensively validated RPE[24], a 15-point scale ranging from 6 ("no exertion at all") to 20 ("maximal exertion").

Statistical Analysis

Data were analyzed using the Statistical SPSS 18.0 software (SPSS Inc, Chicago, IL, USA). The Kolmogorov-Smirnov test was performed to check for normal distribution. The homogeneity of variance was tested using the F-test. The reliability of all testing performances was assessed by the intra-class correlation coefficient, 95% confidence intervals, and coefficient of variation. One-way ANOVA was used to compare physical fitness components between groups. If the appropriate statistical significance was identified, then the LSD post hoc test was used to further distinguish differences between all groups. The enjoyment, FS, and RPE scores were assessed using an independent *t*-test between two groups (HIIG and MIIG). A two-way analysis of variance with repeated measures (3 groups: HIIG, MIIG, and CG×2 times: pre- and post-intervention) was conducted. Significant "group×time" interactions were followed by post hoc analyses to identify significant pairwise comparisons. Partial eta squared (η_p^2) effect size for the "time×group" interaction effects was calculated. A further two-way analysis of variance with repeated measures (2 groups: HIIG, MIIG × 4 times: week 3, week 6, week 9, and week 12) was applied for RPE and FS. Cohen's effect size (ES) statistic with 95% confidence intervals was used to determine the practical significance of observations, where the values 0.2, 0.5, and 0.8 represent small, medium, and large differences, respectively[25]. A two-tailed *p*-value lower than 0.05 was considered significant.

Results

Test's Reliability

Test-retest reliability was above the established thresholds for all physical measures, ranging from 0.277 to 0.921 for the intra-class correlation coefficient and from 4.22 to 41.7 for the coefficient of variation (Table II).

Anthropometric and Physical Measures

Table III displays pre- and post-intervention values for anthropometric and physical measures in the HIIT, MIIT, and control groups as well as "group×-time" interactions. No baseline differences between the three groups were found for all variables. Repeated measures revealed significant "group×time" interactions for all anthropometric and physical variables. Intragroup analyses showed no significant changes for all the variables in CG. However, both HIIT and MIIT resulted in a decrease in body mass (p=0.009, ES=0.53 and p=0.025, ES=0.11, respectively), but only HIIT-induced BF (p=0.002, ES=0.49) and WC (p=0.002, ES=0.48) decrease. In both HIIT and MIIT groups, MAS (p<0.001, ES=1.28 and p=0.011, ES=0.91, respectively), 10-m (p<0.001, ES=1.79 and p=0.016, ES=0.09, respectively), 20-m (p<0.001, ES=0.66 and p<0.001, ES=0.07, respectively), and 30-m (p<0.001, ES=1.44, and p=0.025, ES=0.5, respectively) sprint times, *t*-test (p<0.001, ES=0.95 and p=0.014, ES=0.26, respectively), SJ (p<0.001, ES=1.35 and p<0.001, ES=0.46, respectively), CMJ (p<0.001, ES=2.17 and p=0.034, ES=0.65, respectively), FJT (p<0.001, ES=5.03 and p=0.019, ES=0.84, respectively) and SLJ (p<0.001, ES=0.24 and p=0.007, ES=0.06, respectively) performances. Only HIIT resulted in significant improvements in the MBT test (p<0.001, ES=1.30), RSA-TT (p<0.001, ES=1.49), and RSA-PT (p=0.002, ES=1.22) (Table III).

Table II. Reliability and coefficient of variation of performance tests.

		Intraclass correlation Coefficient	95% CI	CV
10-m sprint		0.742	0.515-0.869	7.77
20-m sprint		0.921	0.848-0.959	4.47
30-m sprint		0.612	0.253-0.798	3.39
Squat jump		0.845	0.701-0.919	5.49
Contremouvement jump		0.413	0.129-0.695	4.22
Five jump test		0.277	0.391-0.621	5.59
t-test		0.887	0.783-0.942	7.25
Med ball throw		0.892	0.793-0.944	16.8
Standing long jump		0.499	0.036-0.740	10.7
Maximal aerobic speed		0.501	0.039-0.741	10.6
Repeated sprint ability	Total time	0.394	0.166-0.685	8.27
	Pic time	0.504	0.046-0.742	8.18
	Fatigue index	0.483	1.854-0.229	41.7

CI = confidence interval; CV = coefficient of variation.

Table III. Anthropometric and physical parameters at baseline (Pre) and after (Post) the intervention program and time×group interaction in high-intensity (HIIT) and moderate-intensity (MIIT) interval training groups, and control group (CG).

	Control group (n=12)		MIIT group (n=13)		HIIT group (n=13)		Interaction time×group	
	Pre	Post	Pre	Post	Pre	Post	F	η_p^2
Body mass (kg)	83.3±10.3	84.1±9.40	83.1±11.1	81.9±11.5*	84.0±10.7	78.3±11.6**	4.51†	0.205
BMI (kg/m²)	33.2±5.70	33.3±4.32	33.1±5.62	32.5±5.51*	32.6±3.61	30.2±3.32**	4.12†	0.191
Body fat (%)	33.0 ±3.09	33.5±3.20	33.8±2.94	32.9±2.93	33.7±3.44	32.1±3.42**	5.54††	0.240
WC (cm)	100±8.05	101±6.99	105±10.8	102±9.43	105±9.00	101±8.51**	3.33†	0.160
MAS (km/h)	11.0 ±0.73	10.9±0.90	11.0 ±0.91	11.8±0.92*,#	10.1±1.32	11.9±1.60***,#	7.92††	0.312
10-m sprint (s)	2.50±0.07	2.50±0.08	2.51±0.22	2.49±0.22*	2.48±0.19	2.20±0.13***,#,§	25.85†††	0.596
20-m sprint (s)	4.69±0.21	4.73±0.19	4.64±0.15	4.63±0.15***	4.63±0.20	4.49±0.24***,#	16.78†††	0.489
30-m sprint (s)	6.67±0.09	6.71±0.10	6.66±0.15	6.58±0.18*	6.67±0.19	6.29±0.34***,#,§	18.56†††	0.515
t-test (s)	15.2±0.97	15.3±0.92	15.2±1.07	14.9±1.08**	15.2±1.10	14.2±1.19***,#	15.28†††	0.466
SJ (cm)	17.6±0.98	17.7±1.00	17.8±0.74	18.2±0.79***	17.8±0.86	19.1±1.15***,#	21.82†††	0.555
CMJ (cm)	20.4±0.60	20.3±0.72	20.1±0.75	20.6±0.82*	20.1±0.71	21.8±0.91***,#,§	16.73†††	0.489
FJT (m)	7.11±0.34	7.10±0.35	6.99±0.26	7.24±0.35*	7.01±0.14	8.11±0.29***,#,§	44.43†††	0.717
MBT (m)	2.70±0.52	2.62±0.54	2.77±0.43	2.84±0.52	2.60±0.34	3.02±0.33***	18.77†††	0.517
SLJ (m)	10.7±8.16	10.6±9.53	10.6±12.1	11.3±11.9**	10.2±8.42	12.7±12.5***,#,§	24.75†††	0.586
RSA-TT (s)	49.1±3.12	49.3±3.68	49.9±4.28	48.3±2.73	49.3±4.40	44.4±2.05***,#,§	6.30†††	0.265
RSA-PT (s)	4.46±0.33	4.49±0.38	4.52±0.46	4.36±0.19	4.41±0.40	4.06±0.13**,#,§	3.36†	0.162
RSA-FI (%)	10.2±3.22	9.70±2.62	10.5±4.18	10.8±3.53	11.8±4.66	9.14±3.43	1.26	0.067

Data are expressed as mean ± SD; BMI, Body mass index; CMJ, countermovement jump; FJT, Five-jump test; HRmax, maximal heart rate; MAS, maximal aerobic speed; MBT, Medicine ball throw; RSA-TT, repeated sprint ability total time; RSA-PT, repeated sprint ability pic time; RSA-FI, repeated sprint ability fatigue index; SJ, Squat jump; SLJ, Standing long jump; WC, waist circumference. †p<0.05; ††p<0.01; †††p<0.001 (interaction time × group); *p<0.05, **p<0.01, ***p<0.001 (compared to the pre-intervention value in each group); #p<0.05 (compared to the control group); §p<0.05 (compared to moderate intensity interval training group).

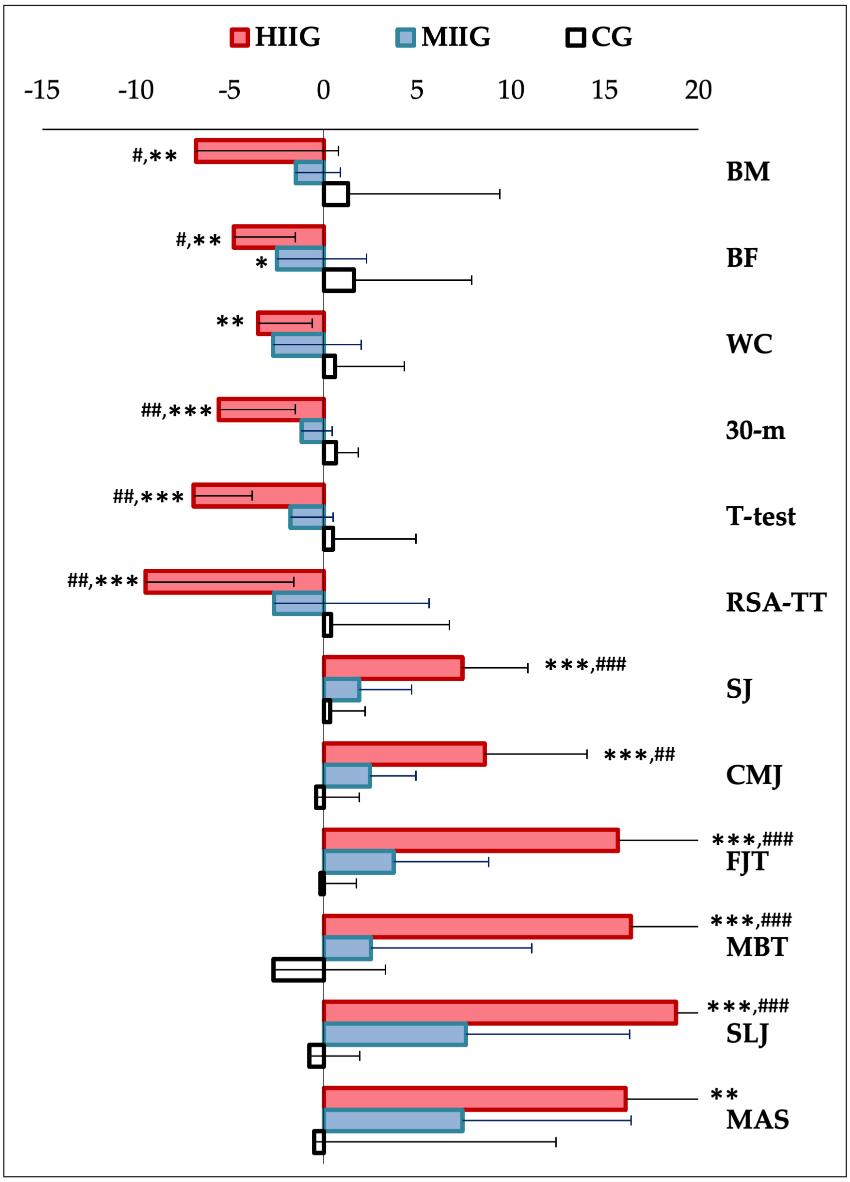

Figure 2. Twelve-week intervention-induced changes in selected anthropometric and physical variables in moderate-intensity interval training (MIIG, n=13), high-intensity interval training (HIIG, n=13), and control (CG, n=12) groups. 30-m, 30-m sprint test; CMJ, vertical countermovement jump; FJT, five jump test; MAS, maximal aerobic speed; MBT, medicine ball throw; SJ, squat jump; SLJ, standing long jump; RSA-TT, repeated-sprint ability-total time; WC, waist circumference; *p<0.05; **p<0.01; ***p<0.001 (compared to control group; t-test for independent samples); $^{\#}p$<0.05; $^{\#\#}p$<0.01 (compared to moderate-intensity interval training group; t-test for independent samples).

Between-group analyses showed no differences in post-intervention anthropometric variables. Post-intervention values of 10 m and 30 m times and RAS indices were lower, while CMJ, FJT, SLJ, and MAS values were higher in HIIG compared to MIIG and CG. HRmax, 20 m, and t-test times were lower, while SJ was higher in HIIG compared to CG. Post-intervention MAS was significantly higher in both training groups compared with the control group but did not significantly differ between the two training groups (Table III). Figure 2 displays the training program-induced changes in anthropometric and physical variables. The changes were significant for all the variables in the HIIT group when compared to the control group. The changes between the two training groups were significant for body mass, BF, 10 m, 20 m, CMJ, SLJ, and RAS indices.

Psychological Parameters

A significant "time×group" interaction was found for FS (p<0.001, ES=0.71), but no interaction was found for RPE. Figure 3 illustrates changes over time in FS and RPE during the two training modalities. FS score has gradually increased over

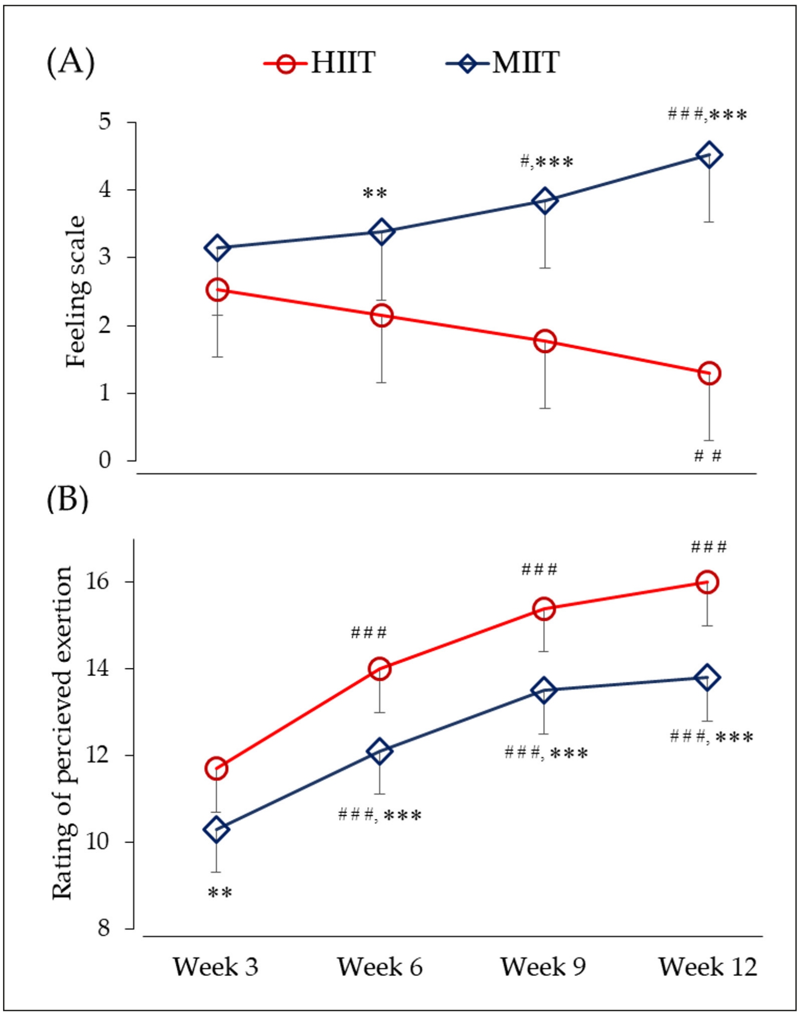

Figure 3. Feeling scale (**A**) and rating of perceived exertion (**B**) scores in moderate-intensity interval training (MIIT, n=13) and high-intensity interval training (HIIT, n=13) groups after 3, 6, 9, and 12 weeks of physical intervention. $^{\#}p<0.05$; $^{\#\#}p<0.01$; $^{\#\#\#}p<0.001$ (compared to baseline value in the same group; *t*-test for paired samples); $^{**}p<0.01$; $^{***}p<0.001$ (compared to HIIT group at the same week; *t*-test for independent samples).

time during the MIIT program but gradually decreased over time during the HIIT program. The between-group comparison showed a higher FS score in MIIG than HIIG at week 6 (3.38±0.86 *vs.* 2.15±1.06, *p*=0.004, ES=1.70), week 9 (3.84±0.68 *vs.* 1.77±1.01, *p*<0.001, ES=2.50) and week 12 (4.53±0.66 *vs.* 1.30±1.18, *p*<0.001, ES=3.52), but no difference was found at week 3 after starting the program (Figure 3A). The RPE score has progressively increased over time during both training programs, being significantly higher in the HIIG than the MIIG at week 3 (11.7±0.94 *vs.* 10.3±1.25, *p*=0.003, ES=1.31), week 6 (14.0±0.81 *vs.* 12.1±0.86, *p*<0.001, ES=2.40), week 9 (15.4±0.76 vs. 13.5±0.87, *p*<0.001, ES=2.36), week 12 (16.0±0.91 *vs.* 13.8±0.89, *p*<0.001, ES=2.50) after program onset (Figure 3B). The enjoyment score was noticeably higher in MIIG than HIIG (81.7±3.72 *vs.* 60.1±4.32, *p*<0.001, ES=7.36) by the end of the training program (i.e., week 12) (Figure 4).

Discussion

This study compared the effects of 12 weeks of MIIT and HIIT on body composition, physical fitness, and affective responses in OW/OB adolescent girls. It showed greater body composition and physical fitness improvements in the HIIT group than in the MIIT group. Participants performing MIIT improved anthropometric and physical parameters compared to the control group and demonstrated higher scores of enjoyment and affective valence than HIIT participants.

Both HIIT and MIIT programs resulted in weight loss and BF decrease, although results were more significant in the HIIT group. The HIIT protocols resulted in beneficial effects on body mass and fat in overweight and obese individuals[6,16,26]. The impact of interval training on body composition depends on the training intensity, frequency, and duration[6].

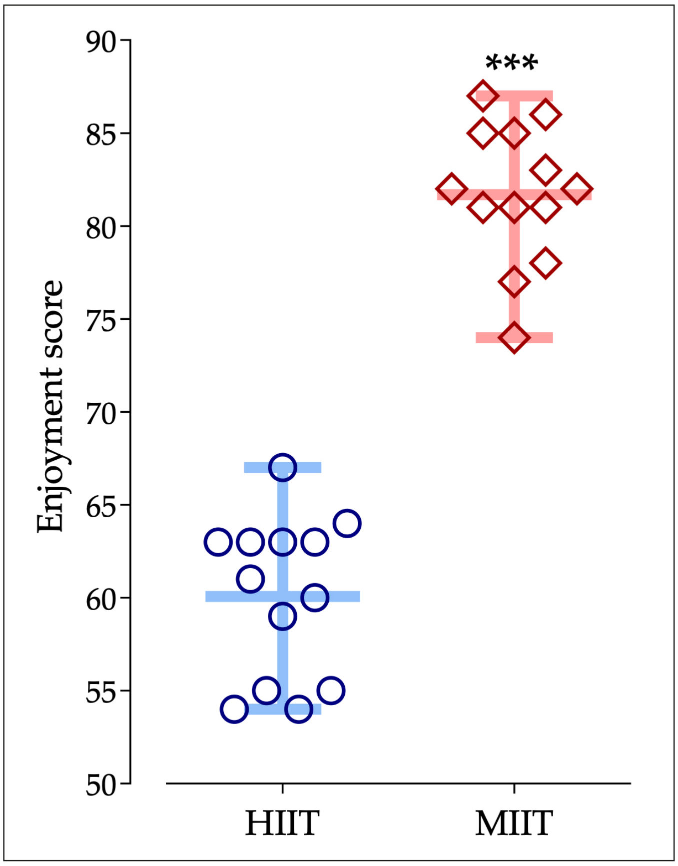

Figure 4. Post-intervention enjoyment level in high-intensity (HIIT, n=13) and moderate-intensity (MIIT, n=13) interval training groups. ***$p<0.001$ (compared to HIIT group; *t*-test for independent samples).

The twelve-week programs for both HIIT and MIIT improved lower body performance with respect to sprint times and vertical and horizontal jumps with greater effect for HIIT. Previous studies[6,10,12,27] reported enhanced running speed and vertical and horizontal jump performances in OW/OB adolescents and youth after 8- or 12-week HIIT. Enhanced sprint performance is likely due to anthropometric changes (i.e., body mass reduction). Moreover, training programs specific to running performance positively influence running velocity[28]. Muscle morphology and neural adaptations, including enhanced motor unit activation of lower extremity muscles, better synergistic, improved intermuscular coordination, and decreased co-activation of antagonistic muscles[29] might participate in maximal force production and thus improves explosive performance. HIIT, but not MIIT, resulted in gains in upper body limb strength as demonstrated by the improved MBT test. This finding further supports the observation that high effort elicits physiological responses independent of exercise modality. Ramos Da Silva et al[12] reported enhanced MBT in OW/OB adolescents after 12 weeks of HIIT. Improvement in upper-body muscle strength might result from the interference of lower limb muscle enhancements with arm muscle hypertrophy and strength[30].

Agility enhanced with both HIIT and MIIT protocols. Previous research[11] showed increases in change-of-direction speed after 12-week HIIT in OW/OB children. The high number of change-of-direction maneuvers might cause enhanced change-of-direction speed occurring in interval training. The improvement could reflect improvements in the anaerobic metabolism, recruitment of fast-twitch muscle fibers, and better control of peripheral and central nervous system activity. However, the exact mechanisms are still unclear[31]. The improvements in agility were more noticeable in the HIIT group. The superior gains with higher loads may be related to higher muscle activation when compared with lower loads[29]. RSA-PT and RSA-TT improved in HIIT but not MIIT participants. Previous research[32] confirmed a significant effect of the HIIT program over 6 weeks on RSA in healthy young athletes, but no previous studies investigated the effect of HIIT or MIIT on RSA in obese individuals. The present study highlighted the role of HIIT in increasing the ability of obese girls to repeatedly produce maximal sprints and to recover between these sprints. HIIT-induced RSA improvement might result from enhanced anaerobic metabolism, a faster rate of phosphocreatine resynthesis[33], and improved muscle ion transports[34]. The lack of an effect of MIIT on RSA is in line with previous data[35] on the association of muscle failure and lack of RSA improvement with low-load training programs.

Both interval training protocols in OW/OB girls resulted in an increase in MAS, which was more noticeable in the HIIT group. The findings agree with a relevant meta-analysis, which concluded a greater aerobic capacity increase in OW/OB youth following high- than low-intensity interval training[36]. Increases in oxygen availability from central effects such as cardiac output, total hemoglobin, and blood plasma volume insured by intermittent exercise could explain the enhancement of aerobic capacity[37]. Increased muscle oxidative potential[38] and mitochondrial enzymes[39] might also participate in such improvements.

Affective valence, enjoyment, and RPE responses are paramount for exercise adherence[40]. HIIT is deemed to cause unpleasant sensations and displeasure in sedentary obese people[13-15,41], resulting in poor exercise tolerance and adherence to the training program. However, some studies[42,43] have shown a beneficial or a null effect of HIIT on affective valence and enjoyment. High enjoyment levels were reported in OW/OB adults over 3 weeks of very high-intensity training[42]. Another research revealed no differences in enjoyment and adherence to training between HIIT and moderate aerobic training[43]. Discrepancies in exercise enjoyment responses could be attributed to differences in the exercise protocols (e.g., work-to-rest ratio, exercise intensity, and total exercise duration)[44]. The current study presents novel data on affect, enjoyment, and RPE responses for HIIT and MIIT in adolescent obese girls. The FS score has gradually increased over time throughout the program period in the MIIG but has gradually decreased in the HIIG. MIIT caused higher enjoyment, greater affective valence, and lower perceived exertion to exercise compared to HIIT. Unlike enjoyment, the RPE score has progressively increased over time in both training groups, being higher in the HIIT group. This finding is predictable since HIIT applies intense physical exercises that are disproportionate to the low cardiorespiratory fitness and muscle performance in these sedentary untrained OW/OB girls. Hence, it could be assumed that MIIT elicits higher tolerance and adherence to physical training than HIIT.

Study Strengths and Limitations

This is the first study to investigate the effects of interval training at different intensities on anthropometric, physical, and psychological traits in OW/OB female adolescents. It is one of the rare studies to examine the effects of interval training protocols on anaerobic performance in obese individuals. We examined the effects of interval training on multiple facets of aerobic and anaerobic physical performance and affective valence. The inclusion of a non-training control group allows us to attribute the observed changes to the effect of the training program with high confidence. Despite its original aspects, the study has limitations that should be acknowledged. A key limitation was the difference in energy expenditure between groups. The HIIT group had a higher energy expenditure during each session, which makes it not equivalent to the MIIT group. This parameter would significantly influence body composition, but its impact on physical fitness and psychological valence would be weaker. Future research should address this limitation by increasing the duration or the frequency of MIIT sessions. The study involved adolescent girls with gender-specific hormonal and body composition characteristics. Thus, the results are not necessarily applicable to male adolescents. The study did not control for dietary intake and physical activity. However, no participant changed their eating habits or usual tasks (apart from the training program) during the intervention period, making it unlikely that these factors influenced the results. BF was estimated based on the bioelectric impedance method, which is less accurate than DEXA scanning and MR imaging for this purpose. The latter methods are unreachable by the research team. However, the latter techniques are expensive, less available, and not accessible to the research team. Finally, no mechanistic explanations can be identified underlying the training-induced gains.

Practical Applications

The study findings could help to optimize training gain in OW/OB adolescents. Either HIIT or MIIT could be employed, depending on the training goal. If the goal is to improve body composition or physical fitness, HIIT may offer more significant gains than MIIT. If the training aims to achieve physical and psychological gains and adherence to the training program is paramount, MIIT can be an effective and time-efficient alternative protocol.

Conclusions

The study findings suggest that HIIT is more efficient than MIIT in improving body composition and physical fitness in obese adolescent girls. MIIT seems to elicit greater enjoyment and better affective responses in obese people than HIIT, which warrants its implementation to improve health in this population. Our results would be taken cautiously since the two training groups' differences in workload and energy expenditure might have influenced the results. Future studies should compare the physical and psychological effects of MIIT protocols to other workload-equivalent physical protocols. MIIT could be an alternative time-efficient protocol to improve body composition and physical fitness in obese people with low tolerance to high-intensity exercise. However, larger studies are needed to confirm this proposal and evaluate the long-term effect of MIIT on cardiovascular risk in obese people.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of Interest

The authors declare that they have no conflict of interest.

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Ethics Approval

The study was carried out in accordance with the Declaration of Helsinki. The protocol received approval from the Ethical Committee of the Institute of Sports and Physical Education of Kef (ISSEP-3/2018). Written informed consent was obtained from the girls' parents/guardians.

Authors' Contributions

WA, NO, MF, and BK conceived and designed the study and revised the manuscript. WA, NO, and NJ performed field and laboratory work and gathered the data. WA, NO, MF, and BK analyzed the data and drafted the manuscript. MSA, AB, CVS, PTN, and KW helped in drafting the final version. All authors were given the opportunity to comment on and revise the manuscript. All authors read and approved the final version of the manuscript.

ORCID ID

Wissal Abassi: 0000-0001-6418-6711
Nejmeddine Ouerghi: 0000-0002-8840-1735
Moncef Feki: 0000-0003-1585-4052
Nidhal Jebabli: 0000-0002-6328-4915
Marilia S. Andrade: -0002-7004-4565
Anissa Bouassida: 0000-0003-0971-0183
Caio Victor Sousa: 0000-0002-0499-2372
Pantelis T. Nikolaidis: 0000-0001-8030-7122
Katja Weiss: 0000-0003-1247-6754
Beat Knechtle: 0000-0002-2412-9103

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