

Comparison of acute cardiovascular and perceptual responses between moderate-intensity interval and continuous exercise in inactive obese young adults

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ABSTRACT

Background: Obesity dramatically elevates the risk of mortality and morbidity associated with cardiovascular disease (CVD). Obese people exhibit left ventricular structure abnormalities at an early age, in addition to having diminished resting systolic and diastolic function. Furthermore, there is evidence to suggest that autonomic dysfunction may play a role in the increased prevalence of CVD among obese individuals. Engaging in vigorous exercises may place excessive strain on the cardiovascular system, rendering it inappropriate for inactive, obese individuals.

Objective: The crossover design with randomization study aimed to compare the immediate effects of moderate-intensity interval (MIIE) and continuous exercises (MICE) on hemodynamics, heart rate variability (HRV), affective, and enjoyment responses in young obese men.

Materials and methods: A total of eighteen male participants, consisting of nine individuals with normal weight and nine individuals classified as obese, were involved in this study. The participants completed two 30-minute cycling protocols consisting of MIIE (3×5-minute at 90% ventilatory threshold; VT) interspersed with 3×5-minute active recovery cycling at 50% VT) or MICE at 70% VT with a 3-minute warm-up and cool-down at free load. Hemodynamic, HRV, enjoyment, and affective responses were measured at rest and at 5-, 10-, 15-, 20-, 25-, and 30-minute intervals during the exercise sessions of each protocol.

Results: There were no significant differences in stroke volume index, cardiac index, ejection fraction, or systolic blood pressure between the MICE and MIIE protocols after each stage of the exercise protocols, both in normal-weight and obese participants. The MIIE protocol led to significantly lower ratings of perceived exertion (RPE) ($p<0.05$) and higher enjoyment ($p<0.05$) and affective responses ($p<0.01$) relative to MICE after each stage of exercise in obese participants. In addition, the MICE protocol led to a significantly lower standard deviation of normal-to-normal intervals ($p<0.01$) and a very low frequency ($p<0.01$) when compared to the MIIE in obese participants.

Conclusion: Our study's findings indicate that the MIIE and MICE protocols elicit similar cardiac responses in normal-weight and obese participants. Furthermore, the MIIE protocol results in significantly less RPE and exercise-induced fatigue and greater levels of enjoyment and affective response. The potential for heightened enjoyment and affective responses within the MIIE protocol may have significant implications for fostering exercise adherence among individuals with obesity.

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Introduction

The global obesity epidemic is a major public health concern. Obesity raises the risk of cardiovascular disease (CVD) mortality and morbidity.¹ Previous research has demonstrated that young, healthy, obese people have early abnormalities in left ventricular structure as

well as reduced resting systolic and diastolic function.² Furthermore, it has been demonstrated that young, healthy, obese individuals have a higher cardiac response but a lower arteriovenous oxygen difference during exercise. These conditions may precede obesity-related cardiac remodeling and dysfunction.³ The severity of cardiac impairment is related to the degree of obesity.^{4,5} Furthermore, a reduction in autonomic function has been proposed as a possible explanation for the higher prevalence of CVD in obese people.⁶

Regular exercise is one of the most well-known and effective strategies for managing obesity. The ideal exercise program should have a significant negative energy balance, long-term adherence, and psychological and physical benefits.⁷ Obese people frequently experience high attrition and low adherence rates to moderate-intensity continuous training (MICT), which is commonly recommended as the initial step in a weight-loss exercise program.⁸ High-intensity interval training (HIIT) has gained popularity due to its reputation as a time-efficiency and effective exercise modality. Systematic reviews and meta-analyses of supervised and unsupervised exercise training studies have repeatedly shown that HIIT improves cardiorespiratory fitness (CRF), often to a greater extent than conventional MICT.^{8,9}

Nevertheless, recent research indicates that HIIT prescriptions for overweight and obese individuals may not be optimal in practice. Low-active, overweight, or obese participants assigned to HIIT demonstrated a slight decline in net physical activity from baseline to twelve months. In contrast, those in the MICT group became marginally more physically active.¹⁰ Furthermore, a recent report demonstrated a lack of long-term adherence to vigorous-intensity activity among HIIT participants.¹¹ This suggests that these individuals may have encountered difficulties in their ability or willingness to engage in recommended intensity exercise levels. When unsupervised, more of those assigned to HIIT did not adhere to their prescription than those assigned to MICT. Due to nonadherence, initial physiological adaptations tended to diminish over the course of the follow-up.¹¹

Furthermore, it is hypothesized that the anticipated affective responses to future exercise can influence exercise adherence.¹² A significant association has been observed between the level of intensity and affective responses during continuous exercise.¹³ The anaerobic threshold (AT) has been identified as an extremely reliable physiological indicator of affective responses.¹⁴ According to the Dual-Mode Model,¹³ negative affective responses are more common at intensities above AT, and positive affective responses at intensities below AT. Given the low adherence and health concerns associated with vigorous exercise in sedentary and obese individuals, the efficacy of a moderate-intensity interval exercise (MIIE) protocol should be investigated. If reducing exercise intensity and incorporating varying intensity levels during sessions can still elicit physiological and perceptual responses, it is necessary to determine whether or not the protocol is still effective. Coquart *et al.* 2008¹⁵ demonstrated previously

that obese individuals perceived MIIE as less strenuous than moderate-intensity continuous exercise (MICE) protocol despite similar training relative to workload and exercise duration. This led the authors to suggest that MIIE rather than MICE be prescribed to maintain adherence to exercise programs in inactive obese populations. Nonetheless, this remains a contentious issue.¹⁶

It is critical to determine whether MIIE can produce similar favorable cardiovascular outcomes as MICE while preserving effective and enjoyable responses. In addition, to effectively prescribe exercise to prevent or treat cardiac dysfunction associated with obesity, a greater understanding of how cardiac function and autonomic changes during exercise occur in obese participants is required.

Thus, this study aimed to investigate the acute effects of MIIE and MICE on cardiac function, cardiac autonomic modulation, and affective and enjoyment responses in young obese men.

Materials and methods

Participants

Eighteen young men were recruited to participate in the study. Participants were sought out via word-of-mouth and the widespread distribution of flyers around the campus. All participants had sedentary lifestyles, defined as less than 1 hour of regular weekly exercise for the previous 6 months. According to body mass index (BMI), participants were grouped as normal-weight (18.5-22.9 kg/m²) or obese (BMI ≥ 25 kg/m²). Participants were excluded if they had: 1) a history of hypertension, dyslipidemia, diabetes mellitus, cardiovascular disease, or endocrine disease; 2) were taking any medication that could potentially influence cardiometabolism; 3) smoked or used tobacco within the previous 6 months; 4) were unable to engage in physical activity due to musculoskeletal limitations; 5) had a psychiatric disorder; or 6) were on a weight loss diet within the previous 6 months. Based on a previous study, we estimated that nine men would have 90% power to detect a 33% increase in enjoyment after HIIT.¹⁷ The study protocol was approved by the Kasetsart University Research Ethics Committee (COA no. COA61/076). Before signing a written informed consent form, participants were informed of potential risks and the study procedure.

Protocol

The study employed a crossover design with randomization. Participants were instructed to visit the laboratory on three occasions, including an initial visit and two experimental protocols. At least 72 hours separated the experimental protocols, which were conducted randomly. Participants were instructed to avoid alcohol and caffeine for 12 hours before each trial, to stay hydrated, and to avoid exercise for 24 hours before each trial. Measurements of anthropometry, body composition, blood pressure (BP), and peak oxygen consumption (VO_{2peak}) were taken during the initial visit. At each exercise session, participants engaged in MIIE or MICE

protocols. Figure 1 illustrates the experimental protocol that each experiment employed. All participants were trained on the cycle ergometer and exercise protocols before the testing. Each experimental protocol consisted of a resting condition lasting 10 minutes, followed by a 36-minute MIIE or MICE protocol. Upon arrival at the laboratory for each experimental protocol, participants

were given a standard meal (approximately 70 kcal, 75% carbohydrates, 12% protein, 13% fat, and 50 ml of water) to control variations in energy intake and nutrient composition that could affect exercise performance and physiological responses. The experiments began an hour after the meal had been consumed.

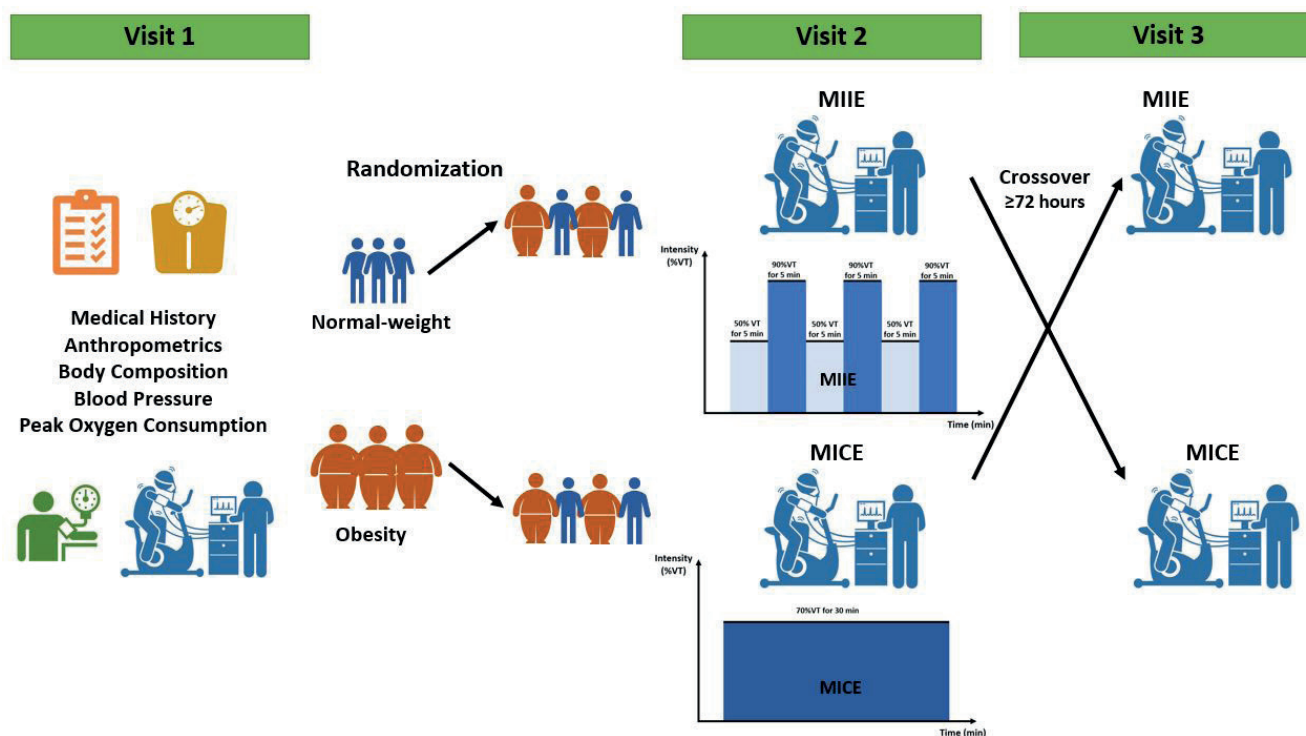


Figure 1. Experimental design.

MICE and MIIE protocols

The MICE protocol consisted of a 3-minute warm-up with free-load cycling and 30 minutes continuous moderate-intensity cycling at 70% ventilatory threshold (VT) with an intensity workload range of 60-115 watts. The MIIE consisted of a 3-minute warm-up at free-load cycling followed by 3 repetitions of 5 minutes of moderate-intensity interval cycling at 90% VT (3×5 min at 90% VT) with an intensity workload range of 75-146 watts, interspersed with 5 minutes of active recovery cycling at 50% VT (3×5 min at 50% VT) with an intensity workload range of 42-81 watts. The MIIE protocol thus consisted of 15 minutes of moderate-intensity interval cycling followed by 15 minutes of active recovery for a total interval exercise time of 30 minutes. Following the exercise protocols, participants performed a three-minute cool-down of free-load cycling. The exercise protocols were matched in terms of duration (30 minutes) and intensity (70% VT or ~63% $\dot{V}O_{2peak}$). The total energy cost of $\dot{V}O_2$ was calculated for each protocol and matched in both exercise protocols.

Measurement

Anthropometry and body composition

Body mass, fat mass (FM), percentage of body fat (%BF), and fat-free mass (FFM) were measured after an overnight fast using a bioimpedance analysis device

(Inbody 720, Biospace Inc., Seoul, Korea) in light clothing and without footwear. Height was measured on a flat surface with a spring-coil measuring tape and a wall-mounted stadiometer (Bilancia Pesapersona Professionale MPE, Kern & Sohn GmbH, Balingen, Germany). BMI is calculated by dividing body mass (kg) by height squared (m^2).

Blood pressure

BP was measured using an automated brachial sphygmomanometer (Tango M2, SunTech Medical Inc., NC, USA). After a 10-minute period of seated rest, resting BP was taken three times at 2-minute intervals. During exercise protocols, BP was taken in the last 30 seconds of each 5-minute interval. The rate pressure product (RPP) is a hemodynamic parameter that assesses myocardial oxygen demand and workload. RPP was calculated using the formula $RPP = \text{heart rate (HR)} \times \text{systolic blood pressure (SBP)}$.

$\dot{V}O_{2peak}$

Participants performed an incremental exercise test on an electromagnetically braked cycle ergometer (VIAsprint 150P, Ergoline GmbH, Bitz, Germany). The test started with a 5-minute seated rest and 3 minutes unloaded cycling as a warm-up. The incremental protocol

began with a work rate of 50 W and increased it by 25 W every two minutes until voluntary exhaustion, after which they completed a 3-minute cool-down with a free load. Expired gas samples were collected breath-by-breath during the test using a portable metabolic device (JAEGER Oxycon Mobile, CareFusion, Hochberg, Germany). RPE was determined using the Borg scale (6-20) at the end of each.¹⁸ $\dot{V}O_{2peak}$ is the highest value of $\dot{V}O_2$ observed over 30 seconds during the test's final stages.

Cardiac function

Thoracic bioimpedance (PhysioFlow®, Manatec Biomedical, Poissy, France) was used to assess cardiac function. Cardiac output (CO), cardiac index (CI), stroke volume (SV), SV index, HR, and ejection fraction (EF) were continuously measured and averaged over 1 minute at rest and at 5-, 10-, 15-, 20-, 25-, and 30-minute intervals during the exercise sessions of each protocol.

Heart rate variability

Inter-beat (RR) Intervals were measured using an electrocardiogram sensor (eMotion Faros device, Mega Electronics, Kuopio, Finland) during rest, exercise, and recovery periods. The data was imported into an HRV-Scanner application, which corrected artifacts and premature beats. Time domain parameters were calculated using RR intervals, namely the standard deviation of normal-to-normal intervals (SDNN) and the root mean square of sequential deviations (RMSSD). The frequency domain parameters were also determined, including the power of integrals over the high-frequency band (HF; 0.15-0.40 Hz), the low-frequency band (LF; 0.04-0.15 Hz), and the very low-frequency power (VLF; 0.001-0.04 Hz), and the LF/HF ratio was calculated.¹⁹

Affective responses and enjoyment

During the exercise phases, RPE, affective response, and enjoyment were measured at 5-, 10-, 15-, 20-, 25-, and 30-minute intervals. The Borg scale (6-20) was used to assess RPE.¹⁸ All participants reported an RPE 6, indicating no exertion before beginning the protocols. The affective response was assessed using a bipolar 11-point scale, with categories ranging from -5 to 5. The numerical categories

ranged from “very bad” (-5), representing the highest level of displeasure or unpleasantness, to “neutral” (0), representing the lowest level of pleasure, and “very good” (+5), representing the highest level of pleasure.²⁰ The level of enjoyment was graded on a 7-point scale, with 1 indicating no enjoyment and 7 indicating a high level of enjoyment. Participants were asked to select the appropriate point on the scale to indicate their level of enjoyment in response to the question, “Use the following scale to indicate how much you are enjoying this exercise session”.²¹

Statistical Analysis

Standard descriptive statistics were calculated using SPSS version 26 for Windows (SPSS Inc., Chicago, IL, USA) to assess the mean characteristics of the study's participants. To verify the assumption of normality, the Shapiro-Wilk test was administered. Log transformations were applied to variables that were not normally distributed. An independent t-test was utilized to determine the differences between groups at baseline. The dependent t-test or repeated-measures one-way analysis of variance was utilized to conduct within-group analyses. A two-way repeated measures analysis of variance was used to determine whether there was an interaction (condition×group) or any significant differences between conditions for cardiac variables (SV index, CI, EF, HR, SBP, and rate-pressure product; RPP), HRV, and perceptual variables (RPE, enjoyment, and affective response). In post-hoc analyses, the Bonferroni method was used. A $p < 0.05$ was accepted as the minimum level of significance.

Results

Table 1 presents the descriptive characteristics of the participants. Body mass ($p < 0.01$), BMI ($p < 0.01$), %BF ($p < 0.01$), and FM ($p < 0.01$) were significantly higher in the obese group compared to the normal-weight group, whereas relative $\dot{V}O_{2peak}$ ($p < 0.01$), peak CI ($p < 0.05$), and VT ($p < 0.05$) were significantly lower in the obese group. Resting BP, resting and peak HR, HR at VT, RPE at peak exercise and at VT, and peak SV were similar between groups.

Table 1. Descriptive characteristics of the participants.

	Normal weight (N=9)	Obese (N=9)	p value
Age (yrs)	20.7±1.3	20.9±1.7	0.765
Body mass (kg)	68.1±7.7	92.0±16.9	0.001**
BMI (kg/m ²)	22.2±1.4	32.5±5.9	0.000**
BF (%)	25.6±6.4	36.5±6.9	0.002**
FM (kg)	17.3±4.4	34.3±11.6	0.000**
FFM (kg)	50.8±8.1	57.7±8.1	0.072
Resting HR (bpm)	80.9±13.9	79.6±6.9	0.784
SBP (mmHg)	123.5±7.0	125.6±15.2	0.697
DBP (mmHg)	74.8±9.3	76.5±8.6	0.677
MAP (mmHg)	95.7±5.6	98.0±9.8	0.526
$\dot{V}O_{2peak}$ (mL/kg/min)	33.5±5.3	26.1±6.1	0.009**
HR peak (bpm)	180.0±11.3	181.8±13.6	0.752
RPE at peak exercise	18.8±1.2	18.9±0.9	0.836
Peak CO (L/min)	19.2±6.6	16.0±4.0	0.205
Peak CI (L/min/m ²)	10.7±4.0	7.7±2.0	0.049*
Peak SV (mL)	107.5±35.5	100.1±25.6	0.596
Peak SV index (mL/m ²)	59.9±21.6	47.6±10.5	0.120
VT (mL/kg/min)	24.6±6.6	18.3±5.8	0.034*
VT (% $\dot{V}O_{2peak}$)	73.5±15.9	70.1±17.3	0.675
HR at VT (bpm)	157.6±17.9	152.2±24.5	0.581
RPE at VT	14.8±2.1	15.0±2.2	0.838
Load at VT (watt)	127.5±29.9	122.5±29.9	0.713

Note: Data are expressed as mean±SD, BMI: body mass index, %BF: body fat percentage, FM: fat mass, FFM: fat-free mass, HR: heart rate, DBP: diastolic blood pressure, SBP: systolic blood pressure, MAP: mean arterial blood pressure, $\dot{V}O_{2peak}$: peak oxygen consumption, RPE: rating of perceived exertion, CO: cardiac output, CI: cardiac index, SV: stroke volume, VT: ventilatory threshold, asterisk denote a significant difference between normal-weight and obese participants (* $p<0.05$, ** $p<0.01$).

As for hemodynamic variables, there was no significant difference between the MICE and MIIE protocols in average HR, average %HR peak, average $\dot{V}O_{2peak}$, average CO, %CO peak, average SV, %SV peak, average SBP, %SBP peak, average DBP, %DBP peak, average

MAP, %MAP peak, or average EE (Table 2). In both exercise protocols, however, the average $\dot{V}O_{2peak}$ relative to body mass was significantly lower in obese participants than in normal-weight participants.

Table 2. Hemodynamic responses to the MICE and MIIE protocols in normal-weight and obese participants.

	MICE			MIIE			Main effect of conditions η^2 (p-value)	ConditionxGroup interaction η^2 (p value)
	Normal weight (N=9)	Obese (N=9)	p value	Normal weight (N=9)	Obese (N=9)	p value		
Average HR (bpm)	139.0±14.4	134.4±20.1	0.581	133.4±17.5	131.9±16.7	0.862	0.055 (0.348)	0.009 (0.708)
%HR peak	77.8±7.6	74.2±9.1	0.376	77.0±4.6	74.1±9.8	0.298	0.018 (0.593)	0.000 (0.934)
Average $\dot{V}O_2$ (mL/kg/min)	21.7±4.5	16.5±5.3	0.040*	20.9±3.0	15.8±4.1	0.008**	0.023 (0.550)	0.000 (0.982)
% $\dot{V}O_2$ peak	63.9±12.8	61.8±14.3	0.750	63.0±9.5	63.0±12.9	0.998	0.000 (0.950)	0.007 (0.733)
$\dot{V}O_2$ /HR	10.3±1.6	10.0±4.0	0.850	10.3±1.3	10.7±1.4	0.462	0.023 (0.546)	0.027 (0.515)
Average CO (L/min)	14.1±4.4	15.7±3.0	0.391	13.5±3.7	14.2±1.6	0.653	0.055 (0.351)	0.011 (0.680)
%CO peak	75.9±28.7	101.1±28.9	0.082	72.7±28.2	93.9±23.8	0.103	0.022 (0.560)	0.003 (0.825)
Average SV (mL)	99.8±23.7	117.6±20.1	0.105	99.8±21.0	108.1±19.2	0.397	0.024 (0.543)	0.024 (0.542)
%SV peak	97.8±38.0	121.2±32.8	0.180	96.1±35.0	111.2±20.5	0.284	0.024 (0.540)	0.013 (0.655)
Average SBP (mmHg)	151.1±9.9	151.4±19.1	0.975	149.3±13.6	150.2±15.8	0.901	0.008 (0.725)	0.000 (0.940)
%SBP peak	76.8±8.0	83.6±13.0	0.202	77.0±7.1	81.5±7.9	0.220	0.005 (0.782)	0.008 (0.731)
Average DBP (mmHg)	70.4±6.2	74.5±10.3	0.323	68.9±7.5	74.1±9.3	0.210	0.024 (0.543)	0.007 (0.733)
%DBP peak	78.6±12.2	83.9±16.0	0.441	77.9±15.0	85.6±18.9	0.358	0.001 (0.905)	0.005 (0.789)
Average MAP (mmHg)	102.9±5.5	105.9±12.9	0.523	100.9±4.5	105.0±11.2	0.314	0.039 (0.433)	0.006 (0.760)
%MAP peak	77.2±7.1	82.8±9.4	0.172	76.9±6.0	82.7±10.6	0.172	0.000 (0.944)	0.000 (0.976)
Average EE (kcal/min)	7.3±1.7	7.3±1.7	0.964	7.2±1.5	7.0±0.8	0.778	0.017 (0.608)	0.005 (0.785)

Note: Data are expressed as mean±SD. HR: heart rate, $\dot{V}O_2$ peak: peak oxygen consumption, CO: cardiac output, SV: stroke volume, SBP: systolic blood pressure, DBP: diastolic blood pressure, MAP: mean arterial blood pressure, EE: energy expenditure, η^2 : eta-squared effect size analysis. Asterisks denote a significant difference between normal-weight and obese participants (*p<0.05, **p<0.01).

There were no significant differences in SV index, CI, EF, or SBP between the MICE and MIIE protocols after each stage of the exercise protocols, both in normal-weight and obese participants (Figure 2). However, there were statistically significant differences between the MICE and MIIE protocols in HR at 5-minute intervals ($F_{(1,16)}=25.064$, $\eta^2=0.610$, $p<0.01$), HR at 10-minute intervals ($F_{(1,16)}=8.292$, $\eta^2=0.341$, $p<0.05$), and RPP at 5-minute intervals ($F_{(1,16)}=8.461$, $\eta^2=0.346$, $p=0.01$) (Figure 2). Post-hoc analyses revealed that the MIIE protocol led to significantly lower HR at 5-minute intervals in obese ($p<0.01$) and normal-weight participants ($p<0.01$), and at 10-minute

intervals in only normal-weight participants ($p<0.05$) relative to MICE. In contrast, there was no difference between the MICE and MIIE protocols in HR at 15-, 20-, 25-, and 30-minute intervals in obese and normal-weight participants (Figure 2C). It was also discovered that the MIIE protocol led to significantly lower RPP at 5-minute intervals in obese participants ($p<0.01$) compared to the MICE protocol but not in normal-weight participants. In contrast, there was no difference between the MICE and MIIE protocols in RPP at 10-, 15-, 20-, 25-, and 30-minute intervals in obese and normal-weight participants (Figure 2E).

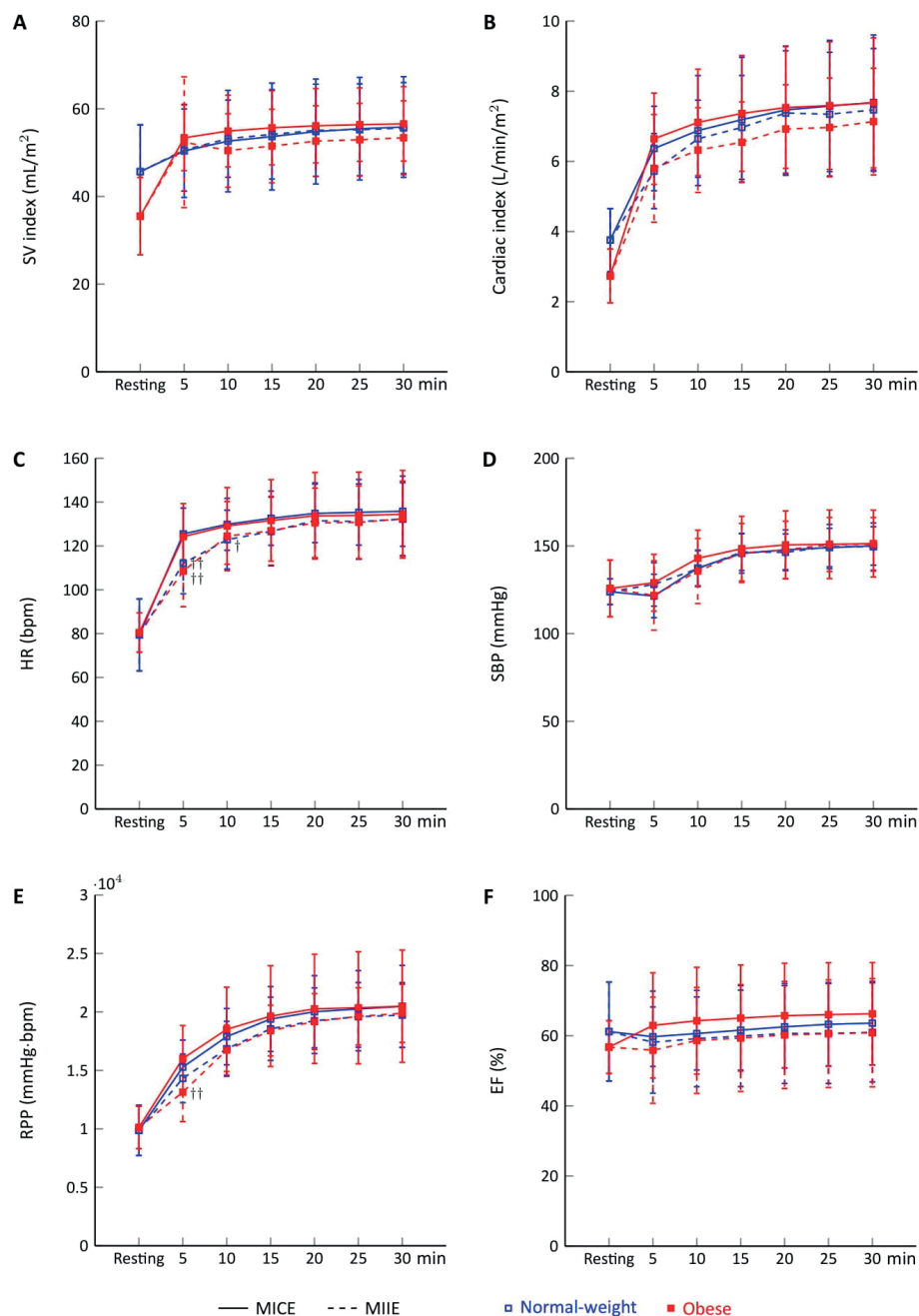


Figure 2. Stroke volume index (A), Cardiac index (B), heart rate (C), systolic blood pressure (D), rate-pressure product (E), and ejection fraction (F) after each stage of the MICE (—) and MIIE (---) in normal-weight (□) (N=9) and obese participants (■) (N=9). Data are expressed as mean±SD. SV: stroke volume, HR: heart rate, SBP: systolic blood pressure, RPP: rate-pressure product, EF: ejection fraction. Daggers denote a significant difference between MICE and MIIE within the group († $p<0.05$, †† $p<0.05$).

As for HRV variables, there were no significant differences in RMSSD, LnHF, LnLF, or the LF/HF ratio between the MICE and MIIE protocols during exercise, both in normal-weight and obese participants. During the exercise phase, there were statistically significant differences between the MICE and MIIE protocols in SDNN ($F_{(1,16)}=7.194$, $\eta^2=0.310$, $p<0.05$) and LnVLF ($F_{(1,16)}=18.568$, $\eta^2=0.537$, $p<0.01$) (Figure 3). Post-hoc analyses revealed that the MICE protocol led to a significantly lower SDNN ($p<0.01$) in obese participants relative to MIIE. In contrast, there was no difference between the MICE and MIIE protocols in normal-weight participants (Figure 3A).

It was also discovered that the MICE protocol led to significantly lower LnVLF in both normal-weight ($p<0.05$) and obese ($p<0.01$) participants when compared to the MIIE protocol. In addition, it was discovered that LnVLF ($p<0.05$) decreased in obese versus normal-weight participants during only the MICE protocol but not the MIIE protocol (Figure 3E). During the recovery periods, there were no significant differences in HRV variables between the MICE and MIIE protocols in both normal-weight and obese participants. However, LnHF ($p<0.05$) was found to be lower in obese versus normal-weight participants only in the MICE protocol but not in the MIIE protocol (Figure 3C).

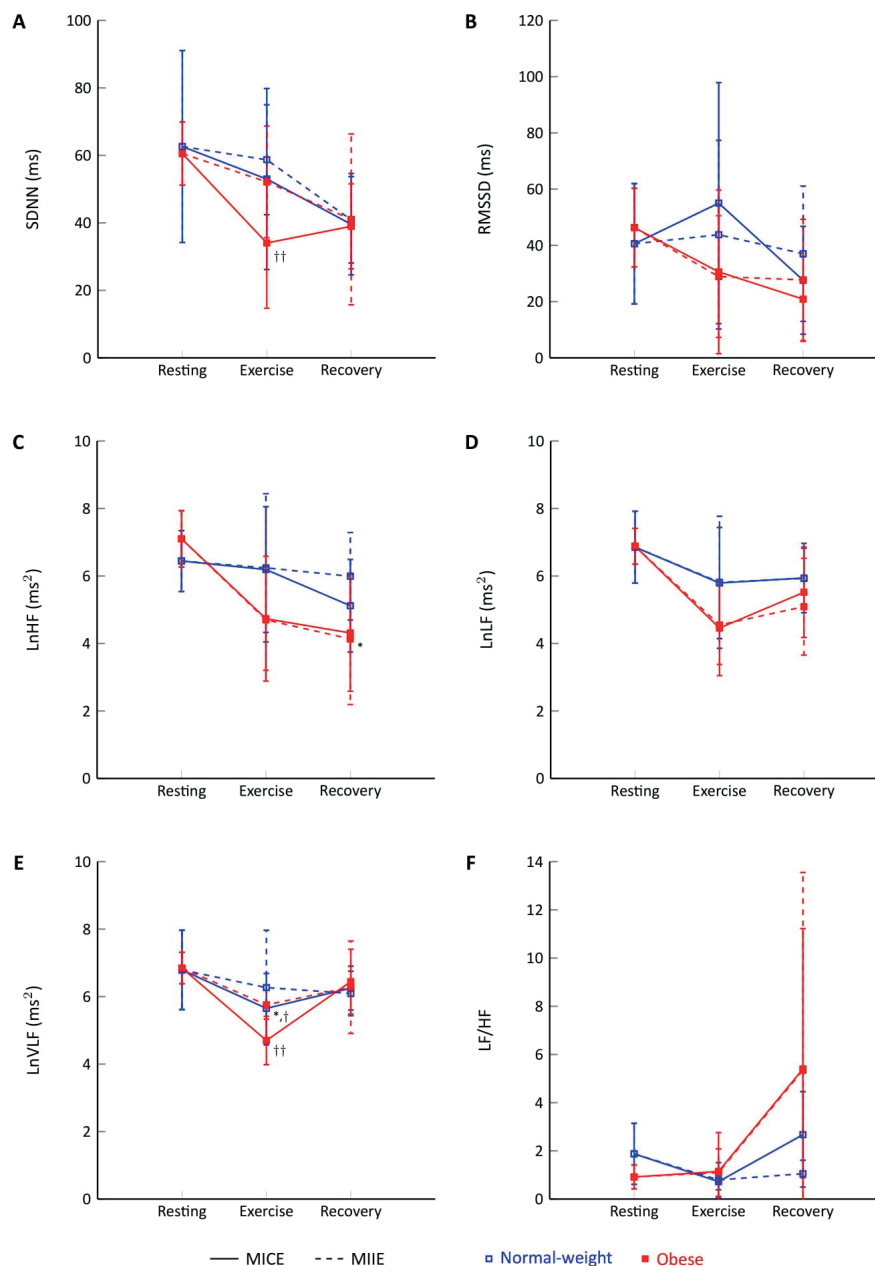


Figure 3. SDNN (A), RMSSD (B), LnHF (C), LnLF (D), LnVLF (E), and LF/HF (F) at rest, during the exercise [MICE (—) and MIIE (---)], and recovery phases in normal-weight (□) (N=9) and obese participants (■) (N=9). Data are expressed as mean±SD. Ln: natural logarithm, SDNN: standard deviation of all RR intervals, RMSSD: root mean square of differences of successive RR intervals, HF: high frequency, LF: low frequency, VLF: very low frequency, LF/HF ratio: ratio of absolute LF power to HF power. Asterisks denote a significant difference between normal-weight and obese participants (* $p<0.05$). Daggers denote a significant difference between MICE and MIIE within the group († $p<0.05$, †† $p<0.01$).

As for affective responses and enjoyment, there were statistically significant differences between the MICE and MIIE protocols after each stage of the exercises in RPE at 5-minute ($F_{(1,16)}=16.840$, $\eta^2=0.513$, $p<0.01$), 15-minute ($F_{(1,16)}=10.318$, $\eta^2=0.392$, $p<0.01$), and 25-minute intervals ($F_{(1,16)}=9.590$, $\eta^2=0.375$, $p<0.01$). Post-hoc analyses revealed that the MIIE protocol led to significantly lower RPE at 5-minute ($p<0.05$) and 25-minute intervals ($p<0.05$) in obese participants and at 5-minute ($p<0.01$), 15-minute ($p<0.05$), and 25-minute intervals ($p<0.05$) in normal-weight participants relative to MICE (Figure 4A).

After each stage of the exercise protocols, enjoyment scales showed significant differences between the MICE and MIIE protocols at 20-minute ($F_{(1,16)}=4.585$, $\eta^2=0.223$, $p<0.05$), 25-minute ($F_{(1,16)}=13.444$, $\eta^2=0.457$, $p<0.01$), and 30-minute intervals ($F_{(1,16)}=5.046$, $\eta^2=0.240$, $p<0.05$). Enjoyments were significantly higher in MIIE at 20-minute

($p<0.05$), 25-minute ($p<0.01$), and 30-minute intervals ($p<0.05$) in obese participants and at a 25-minute interval ($p<0.05$) in normal-weight participants relative to MICE (Figure 4B).

It was also discovered that there were statistically significant differences between the MICE and MIIE protocols after each stage of the exercises in affective responses at 15-minute ($F_{(1,16)}=12.470$, $\eta^2=0.438$, $p<0.01$), 20-minute ($F_{(1,16)}=10.827$, $\eta^2=0.404$, $p<0.01$), 25-minute ($F_{(1,16)}=26.672$, $\eta^2=0.625$, $p<0.01$), and 30-minute intervals ($F_{(1,16)}=17.495$, $\eta^2=0.522$, $p<0.01$). Post-hoc analyses revealed that the MIIE protocol led to significantly higher affective responses at 15-minute ($p<0.05$), 20-minute ($p<0.01$), 25-minute ($p<0.01$), and 30-minute intervals ($p<0.01$) in obese participants and at 15-minute ($p<0.05$), 25-minute ($p<0.05$), and 30-minute intervals ($p<0.05$) in normal-weight participants relative to MICE (Figure 4C).

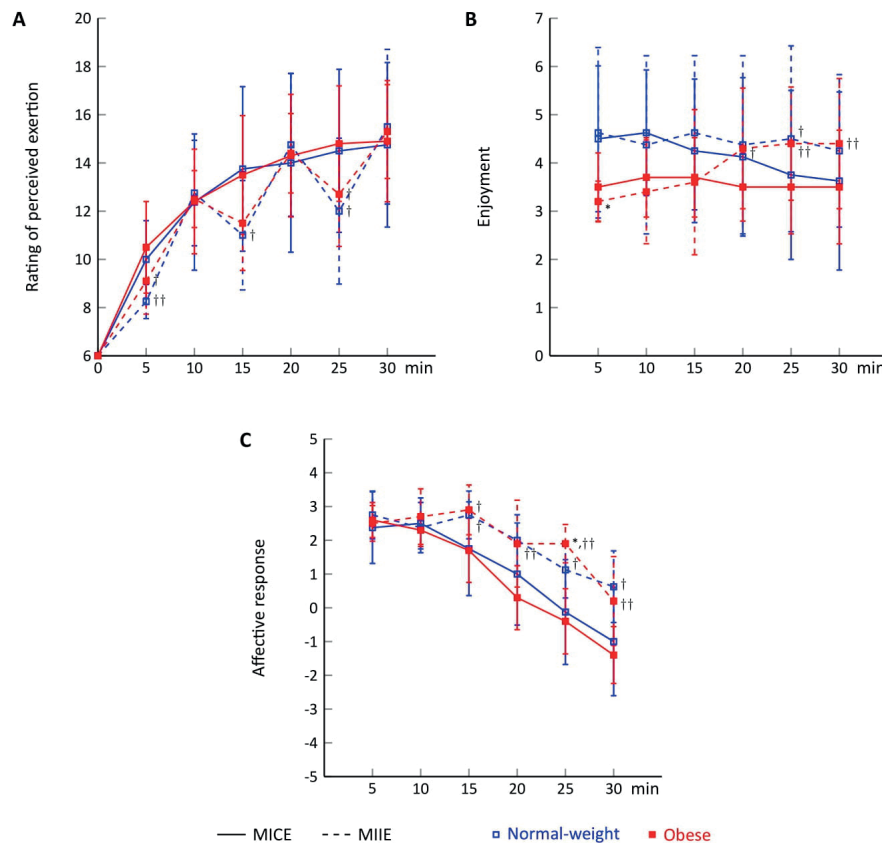


Figure 4. Rating of perceived exertion (A), enjoyment (B), and affective response (C) after each stage of the MICE (—) and MIIE (---) in normal-weight ($\square$) ($N=9$) and obese participants ($\blacksquare$) ($N=9$). Data are expressed as mean $\pm$ SD. Asterisks denote a significant difference between normal-weight and obese participants (* $p<0.05$). Daggers denote a significant difference between MICE and MIIE within the group († $p<0.05$, †† $p<0.01$).

Discussion

This study aimed to examine the immediate physiological effects of MIIE and MICE on cardiac function and HRV, as well as the subjective perceptions of enjoyment and affective responses elicited by a single bout of MIIE and MICE in young, healthy, normal-weight, and obese men. Our findings show that males, regardless of weight status (normal or obese), prefer MIIE in terms of enjoyment and experience a smaller decrease in affective

response compared to MICE. During interval exercise sessions, participants report lower RPE and exercise-induced fatigue, as indicated by SDNN and LnVLF. It is worth noting that the MIIE and MICE protocols produce comparable cardiac responses. Furthermore, this is the first study to compare MIIE and MICE's duration, average intensity, average $\dot{V}O_2$, and energy expenditure.

A total of 78% of the obese participants remained positive, and 22% of the obese participants evoked

a negative feeling at the end of their work in MICE. In contrast, 100% of the obese participants' affective responses in MIIE remained positive. Additionally, it was observed that MIIE resulted in a higher level of immediate enjoyment following a 20-minute exercise session than MICE. Also, 20 minutes after performing the MICE protocol, the participant's level of enjoyment decreased, whereas there was no such decline in the MIIE protocol. Enjoyment may be a factor associated with psychological responses to exercise. Those who enjoy physical activity may exhibit more positive affective responses than those who enjoy it less.²² Our study's results support this hypothesis, as they reveal a statistically significant positive correlation ($r=0.601$, $p<0.01$) between the level of enjoyment and affective responses observed following the MIIE. Several studies^{17,23,24} investigated the relationship between enjoyment and exercise adherence, concluding that enjoyment appears to be a relevant predictor of the intention to continue exercising, exercise habits, and adherence.²⁵ Thus, implementing MIIE in obese people may lead to higher adherence rates.

The MIIE protocol in this study consisted of three sets of five-minute exercise sessions performed at 90% of the subject's VT, then three sets of five-minute active recovery cycling at 50% of the subject's VT. This approach aligns with the Dual-Mode Model,¹³ which states that exercise intensities exceeding the AT tend to elicit negative affective responses. In contrast, intensities below the AT are associated with positive affective responses. A previous study suggested that, despite identical physiological and perceived exertion responses, obesity is associated with diminished affective responses to exercise, even at self-paced intensities.²⁶ Affect-regulated prescriptions, shorter bouts of self-paced exercise, and distraction away from internal cues are required to directly increase pleasure and/or decrease the perception of effort in this population. The potential for increased enjoyment and a lesser decrease in affective response in MIIE may have implications for promoting exercise adherence among obese individuals. In addition, it has been observed that RPE serves as an indicator of affective responses. A negative correlation between RPE and affective responses has been demonstrated.²⁷

This study reveals a lesser increase in RPE, and exercise-induced fatigue is observed following each stage of MIIE in comparison to MICE. The manifestation of exertional responses, such as fatigue, can be observed by the elevation of physiological indicators, such as HR. As a result, in the context of the MICE protocol, it is observed that physiological cues assume a prominent role, particularly within the initial 10-minute period of exercise. This is supported by HRV measurements, particularly SDNN and LnVLF, which indicate a smaller decrease in these markers during interval exercise sessions. According to the study, the findings indicate that the SDNN and the LnVLF exhibited significantly fewer reductions during the MIIE protocol exercise phase than the MICE protocol. This observation suggests an elevation in sympathetic activity within the autonomic nervous system, resulting in an

increased HR during exercise-induced fatigue in the MICE protocol.

Both sympathetic and parasympathetic activities influence the SDNN, with a tendency toward sympathetic dominance reducing the SDNN.²⁸ Moreover, the intrinsic nervous system and sympathetic activity can alter the amplitude and frequency of the heart's oscillations, potentially influencing VLF power.²⁹ This study revealed that the MICE protocol stimulated more sympathetic activity than the MIIE protocol, particularly in obese subjects. These results are comparable to HRV findings in people who exercise strenuously.³⁰ Furthermore, the observed reduction in LnHF during the recovery period among obese individuals compared to those with normal weight indicated a decline in vagal activity. As a result, obese participants may require more than rest to restore cardiac autonomic balance. If they continue to exercise, they may have to increase their rest periods.

The study found that obese men (32.5 ± 5.9 kg/m²) had similar SV index, CI, EF, HR, SBP, and RPP after each stage of MIIE and MICE as normal-weight men (22.2 ± 1.4 kg/m²) of the same age and gender. Overall, the data indicates that obese participants have a similar cardiac response to MIIE and MICE as normal-weight participants. These findings suggest that the cardiovascular system can adjust to the level of exercise intensity. It is critical to understand the risks and limitations of high-intensity exercise. It may increase the risk of injury and impose more cardiovascular strain on the obese population.³¹ Therefore, the MIIE program is likely safe and effective for improving cardiovascular fitness.

Limitation

Despite our findings' significant contribution, this study has some limitations. It is advisable to expand the sample size. It is worth noting, however, that all participants successfully completed all sessions, reducing the possibility of interference with the results. This finding suggests that the MIIE protocols may effectively achieve positive psychological outcomes. However, more research is needed to determine the effectiveness of MIIE in encouraging long-term adherence to exercise routines. In addition, the study included young male adult volunteers who are less likely to develop age-related CVD. The findings' generalizability is limited by a lack of representation from all age groups, including those who are more vulnerable to these conditions. Furthermore, because the study only included male participants, potential gender differences in cardiovascular health were not considered. Therefore, the findings may not apply to women.

Our findings suggest that the MIIE protocol significantly reduces RPE and exercise-induced fatigue while increasing enjoyment and affective response. Furthermore, it is worth noting that the MIIE and MICE protocols produce similar cardiac responses. The MIIE protocol's potential for greater enjoyment and affective response may have significant implications for promoting exercise adherence among inactive, obese people.

Conflict of interest

The authors have no conflict of interest to declare.

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