

Original paper

## **Acute effects of high-intensity interval training and moderate-intensity continuous training on left ventricular function in women with uncomplicated obesity**

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## **STATEMENTS AND DECLARATIONS**

**Acknowledgements of grants and assistance:** The current study was funded by the Fundação Araucária de Apoio ao Desenvolvimento Científico e Tecnológico do Estado do Paraná (FA) (CP 20/18 PPP), Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES). We would like to thank the Avancor employees for their assistance during the assessments.

**Conflicts of interest:** The authors declare that they have no competing interests.

## **Abstract**

**Purpose:** Obesity is associated with subclinical impairments in cardiac function. Aerobic exercise has positive effects on cardiac-related parameters. However, different exercise intensities may elicit distinct acute responses, leading to chronic adaptations. Therefore, we aimed to investigate the acute effects of high-intensity interval training (HIIT) and moderate-intensity continuous training (MICT) on left ventricle (LV) function in women with uncomplicated obesity.

**Methods:** Fifteen women performed a bout of HIIT (4x4-min at 85-95% of HR<sub>max</sub>), MICT (41-min at 65-75% of HR<sub>max</sub>), and control condition (CO) (30-min sitting at rest). Data were collected immediately before, and five (t5) and 35 (t35) minutes after the performance of each condition.

**Results:** Significant decreases in global longitudinal strain (GLS) ( $p=0.010$ ;  $p=0.002$ ), LV ejection fraction (LVEF) ( $p=0.017$ ;  $p=0.010$ ), LV end-diastolic volume (LVEDV) ( $p=0.001$ ;  $p=0.048$ ), stroke volume (SV) ( $p<0.001$ ;  $p=0.013$ ), early diastolic inflow velocity (E) ( $p=0.001$ ;  $p=0.003$ ) and E/A ratio ( $p=0.001$ ;  $p<0.001$ ) were observed for HIIT at t5 in relation to baseline and CO, respectively. However, GLS, LVEF, LVEDV, and E wave were reestablished near baseline values at t35. LV end-systolic volume decreased after HIIT in comparison to baseline at t5 ( $p=0.050$ ). GLS and E/A ratio decreased following HIIT at t5 compared to MICT ( $p=0.013$  and  $p=0.027$ , respectively).

**Conclusion:** A single bout of HIIT promoted transient reductions in LV function that were almost completely reestablished near baseline values 35 minutes after exercise cessation, not implying, therefore, any risk to HIIT performance by this population.

**Trial registration number:** RBR-3v3dqf. Registered on 07/05/2019.

**Keywords:** Aerobic exercise, diastolic function, female, overweight, systolic function.

## Introduction

Approximately 609 million adults have body mass index (BMI) at levels indicating obesity, a worldwide worrisome scenario.<sup>1</sup> The prevalence of weight excess (i.e. overweight and obesity) represents nearly a third of the entire world population, placing obesity as one of the biggest societal healthcare burdens.<sup>1</sup> Apart from being a disease per se, obesity is the cornerstone for a wide range of physiological impairments, being a risk factor for cardiovascular diseases (CVD), which are the leading cause of death around the globe.<sup>2</sup>

The increase in CVD risk as a consequence of obesity occurs due to the increase in adipose tissue, particularly in visceral depots.<sup>3</sup> The latter negatively affects hemodynamics, impacting the pathogenesis of atherosclerosis and altering heart structure, which promotes a significant deterioration of cardiovascular function.<sup>3,4</sup> In fact, obesity promotes adverse effects on left ventricular (LV) function given that impairments in LV systolic<sup>5</sup> and diastolic function<sup>6</sup> were previously observed in this population. Although previous evidence had speculated that obesity could induce LV eccentric remodelling,<sup>7</sup> recent studies showed that obesity is associated with LV concentric remodelling, by which LV wall thickness increases to a greater extent than LV cavity size.<sup>7</sup> This might lead to adverse loading conditions, contributing to the development of concentric LV hypertrophy. Regarding LV systolic function, conflicting evidence makes unclear the association between obesity and LV ejection fraction (LVEF), wherein a normal<sup>3,7</sup> and reduced<sup>8</sup> LVEF have been shown in individuals with obesity.

A growing body of evidence has pointed to the association between excess body weight and global longitudinal strain (GLS),<sup>9</sup> a relatively new and reliable parameter derived from speckle-tracking echocardiography (STE) for the assessment of LV systolic function.<sup>10</sup> GLS is able to detect subtle changes in LV systolic function. According to Smiseth and colleagues<sup>11</sup>, GLS detects LV systolic dysfunction even when in cases where LVEF is preserved. Abnormal GLS has been already reported in individuals with obesity.<sup>3</sup> Interestingly, Bello and colleagues<sup>3</sup> have found an association between obesity and cardiac function in women, whilst the same associations were not verified in men. This suggests a higher likelihood for women to develop LV dysfunction in comparison to men.<sup>3</sup>

The positive effects of aerobic exercise (AE) on cardiac function have been broadly addressed in the literature.<sup>12-14</sup> The meta-analyses conducted by Pearson et al.<sup>13</sup> and Haykowsky et al.<sup>12</sup> found that AE improved LV diastolic and systolic function by enhancing the E/E' ratio and LVEF, respectively, underlining the potential cardioprotective effect of AE. Recently, high-intensity interval training (HIIT) has gained popularity as an alternative to the traditional moderate-intensity continuous training (MICT) mostly due to its time efficiency, showing also a higher adherence rate and similar enjoyment level in individuals with obesity when compared to MICT.<sup>15</sup> HIIT has demonstrated favourable outcomes regarding enhancements in cardiovascular and metabolic parameters in both healthy and chronically diseased populations,<sup>16</sup> promoting also improvements in cardiorespiratory fitness, an important marker of CVD risk.<sup>17</sup>

In terms of changes in cardiac and vascular structure and function, HIIT has been shown to induce superior cardiac remodelling in hypertensive<sup>18</sup> and heart failure<sup>19</sup> individuals when compared to MICT. In addition, HIIT showed superiority in enhancing LV systolic,<sup>19</sup> and diastolic functions.<sup>20</sup> Way and colleagues<sup>21</sup> showed that an acute bout of HIIT reduced the wave reflection and central blood pressure in individuals with diabetes. They also suggested that these changes could reduce the afterload, and consequently enhance cardiac

function, exerting a cardioprotective effect concerning LV hypertrophy and myocardial ischemia. Similarly, HIIT but not MICT reduced wave reflection and central blood pressure in women with obesity.<sup>22</sup> Despite the robust evidence as regards the chronic effects of HIIT and MICT in cardiac markers in individuals with obesity, less is known about the acute responses induced by HIIT in this population. Considering the positive effects of HIIT on the central vasculature, it becomes crucial to explore its effects on cardiac function and mechanics. Thus, the aim of the present study was to investigate the acute effects of HIIT and MICT on LV function in young women with uncomplicated obesity. We hypothesized that HIIT but not MICT would increase LV function parameters acutely, promoting positive acute adjustments in LV function.

## **Methods**

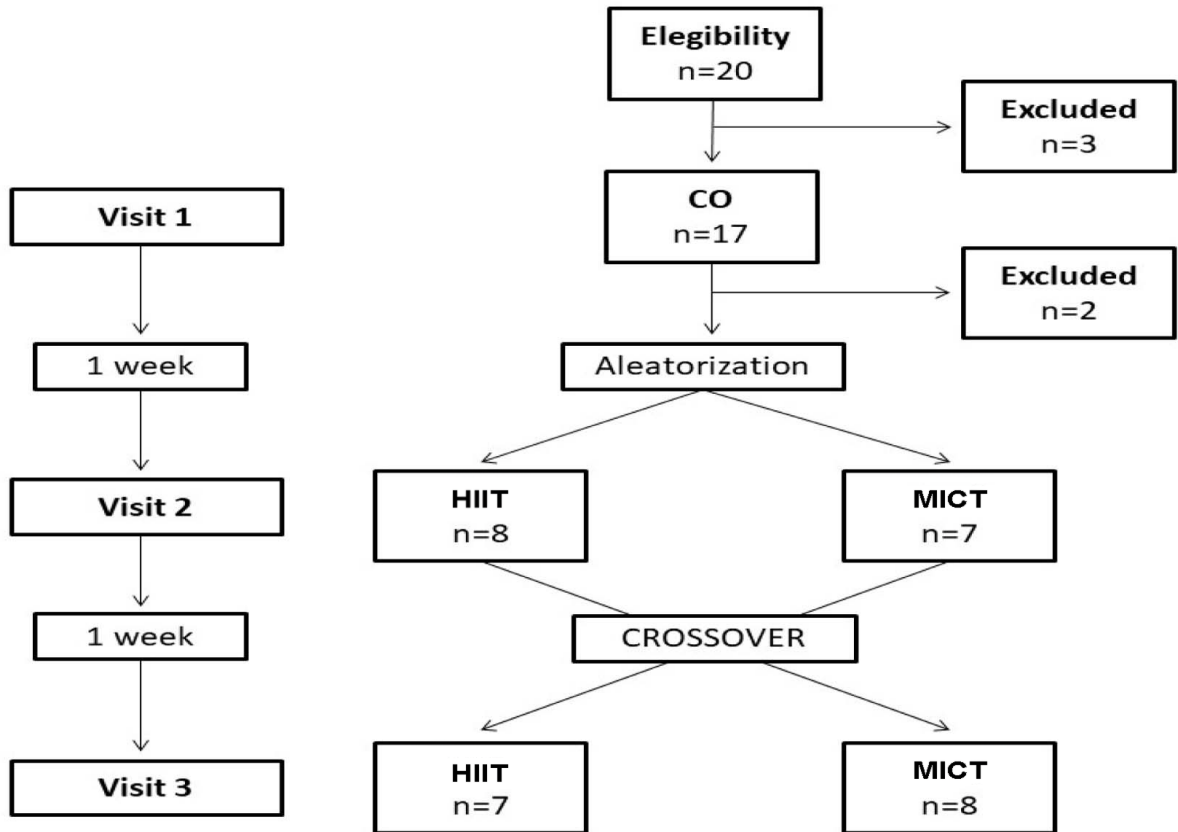
### *Study Design*

The present study has a randomized crossover design. The individuals performed a single session of each HIIT, MICT and control (CO). Each experimental condition was conducted on different days, separated by at least 72h, at the same time of the day in a quiet, temperature-controlled room (24°C) in a random order. Participants were asked to refrain from alcohol and caffeine consumption, and moderate-to-vigorous physical activity for at least 24 hours before the performance of the experimental conditions. Upon arrival in the laboratory, participants were asked to lie down in a cardiology examination bed, remaining there for 10 minutes before the commencement of the baseline echocardiographic and hemodynamic assessments. The experimental conditions were carried out immediately after the completion of their respective baseline assessments. After the completion of the experimental conditions, participants were asked to lie down, and echocardiographic measurements were repeated at 5 (t5) and 35 (t35) minutes after exercise cessation or at the end of the control condition.

### *Participants and ethics*

Twenty women were first recruited from the local community. The eligibility criteria for inclusion consisted of being female, aged 18-35 years, and BMI between 30-40 kg/m<sup>2</sup>. The exclusion criteria were the following: participation in weight reduction programs, weight-related surgical procedures or exercise training programs in the last six months; being physically active according to the International Physical Activity Questionnaire;<sup>23</sup> physical inaptitude to perform the exercise experimental conditions; presence of endocrine, vascular, cardiac diseases or other cardiovascular risk factors apart from obesity; use of medications. A medical evaluation was carried out by an experienced doctor in order to verify if the participants fit in any of the previously established exclusion criteria. The assessment consisted of clinical history, physical examination, and cardiovascular-related exams, which included resting electrocardiogram, exercise treadmill test, transthoracic echocardiogram, and carotid Doppler ultrasonography. Those who did not complete all the experimental conditions and/or did not perform all the assessments were excluded from the analysis. This study was approved by the local ethics committee (Comitê Permanente de Ética em Pesquisa com Seres Humanos – COPEP. Protocol number: 91380218.4.0000.0104) and registered as a clinical trial on the Brazilian Clinical Trials

Registry (RBR-3v3dqf). In addition, the present study is in accordance with the 1964 Declaration of Helsinki and its later amendments, rigorously following the requirements settled on Resolution 466/2012 of the Brazilian National Health Council. Fifteen individuals completed the experimental conditions and were included in the analysis. The inclusion procedure is detailed in Figure 1.



**Figure 1.** Flowchart of the study. CO, control condition; HIIT, high-intensity interval training; MICT, moderate-intensity continuous training.

#### *Anthropometric and body composition assessments*

Body mass (BM) and stature were measured using a mechanical anthropometric scale with a coupled stadiometer (Filizola®, São Paulo, Brazil). Waist circumference was measured by positioning an inelastic metric tape (Sanny®, São Paulo, Brazil) at the bottom of the rib cage and the top of the iliac crest. BMI was calculated and classified according to the World Health Organization cut-off points.<sup>24</sup> Body composition was evaluated with a bioelectrical impedance device (Maltron® BF-906, Rayleigh, UK).

### *Maximal heart rate ( $HR_{max}$ ) and estimated maximal oxygen uptake ( $VO_{2max}$ )*

The adapted Bruce's protocol for the treadmill stress test was performed on a dedicated treadmill (Inbramed®, Porto Alegre, Brazil) to measure maximum heart rate ( $HR_{max}$ ). The protocol starts at 2.7 km/h and 10% inclination, having progressive increments in velocity and 2% increase in inclination each three-minute stage.<sup>25</sup> Heart rate and Borg rating of perceived exertion were collected at the final 30 seconds of each stage, using a heart rate monitor attached to a chest strap (Polar H7®, Kempele, Finland) and an ordinal scale questionnaire, respectively. Verbal encouragements were given to maximize participants' effort and were made only upon initial agreement by the participants. The test was stopped when volitional exhaustion was reached or whenever requested, regardless of the reason.  $HR_{max}$  was collected and used to establish individual HR training zones for MICT and HIIT experimental conditions. In addition, we used the information collected in this test to estimate maximum oxygen uptake ( $VO_{2max}$ ) using a software-provided equation (Micromed®, São Paulo, Brazil).  $VO_{2max}$  values were exclusively used for sample characterization purposes.

### *Exercise training protocols*

HIIT and MICT experimental conditions were carried out on a treadmill (Movement® LX-160i-C4, São Paulo, Brazil). Participants were constantly controlled to maintain the desired HR training zone, and verbal encouragements were given when necessary. The rate of perceived exertion (RPE) was applied throughout the exercise conditions. Both exercise protocols were standardized to guarantee that they were isocaloric by adapting a previously published calculation developed to match workloads from different stimuli to the population studied.<sup>26</sup> In addition, we used the energy expenditure estimation provided by the heart rate monitor dedicated software (Polar Team®, Kempele, Finland) to monitor energy expenditure during exercise conditions.

The applied HIIT protocol is known as the Scandinavian model and started with a 10-minute warm-up (e.g. five minutes at 55-65% of  $HR_{max}$  and five minutes at 65-75% of  $HR_{max}$ ). Thereafter, four bouts of four minutes each were performed at 85-95% of  $HR_{max}$ , interspersed by three-minute active recovery periods at 65-75% of  $HR_{max}$ . The protocol ended with a five-minute cool-down (e.g. three minutes at 65-75% of  $HR_{max}$  and two minutes at 55-65% of  $HR_{max}$ ). The entire exercise session lasted 40 minutes. The MICT session consisted of walking/running at 65-75% of  $HR_{max}$ , with a five-minute warm-up at 55-65% of  $HR_{max}$  and a two-minute cool down at 55-65% of  $HR_{max}$ . The total session lasted 48 minutes. In the CO condition, the individuals remained seated for 30 minutes in a quiet temperature-controlled room.

### *Echocardiographic and hemodynamic assessments*

Echocardiographic examinations were performed by a single experienced sonographer, blinded to the condition performed by participants, using a commercially available ultrasound system (Vivid E 95, GE Healthcare Vingmed Ultrasound AS, Horten, Norway) fitted with a 1.4–4.6 MHz XDclear Active Matrix Single Crystal Phased Array Transducer. Images were stored in a raw DICOM format and exported to an offline workstation (EchoPac, version 13.0, GE Healthcare, Horten, Norway) for subsequent offline analysis. The echocardiographic loops were obtained with the patient in the supine and left lateral decubitus position at the end

of a normal breath, minimising the depth to optimise the frame rate. An apical four-chamber orientation was used maximizing frame rates between 70 and 90 frames/s and optimizing gain, compression and focusing to delineate the endocardial border while maximizing speckle production. Standard measurements were made following the American Society of Echocardiography guidelines.<sup>27</sup> LV end-systolic volume (LVESV), end-diastolic volume (LVEDV), SV and LVEF were measured according to an automated ejection fraction measurement software (Auto -EF – GE Medical Systems®, Milwaukee, WI, USA). A pulsed-wave Doppler spectral display of transmitral filling was acquired in the apical four-chamber view, with the sample volume at the tip of the mitral valve to provide early (E) and atrial (i.e. late) (A) diastolic inflow velocities. TDI was performed in the apical four-chamber view at the septal and lateral annulus and analyzed for myocardial velocities during early (E') and late (A') diastole. GLS was quantified with 2D strain images, being averaged from the 18 segments obtained from 3 different apical views (i.e. apical 4 chamber, apical 3 chamber, and apical 2 chamber views). At least 3 cardiac cycles were acquired, and the highest quality view was used to measure strain. Whenever a view could not be obtained or presented poor quality, GLS was calculated by averaging all segments from the remaining 2 views. GLS was analysed using the automated function imaging (AFI) package. In addition, all analyses underwent visual inspection by an experienced sonographer, who manually adjusted myocardial border tracking when necessary. Images were digitally stored in the cine-loop format and transferred to commercially available software (EchoPac, version 13.0, GE Healthcare, Horten, Norway) for offline analysis to obtain LV strain. The software analyses motion by tracking speckles in the ultrasonic images. Frame-to-frame changes of the speckles were used to derive motion and velocity. The closure of the aortic valve was marked, and the software measured the time interval between the R wave and aortic valve closure. The automated algorithm provided peak systolic strain for each segment. Intraobserver variability was performed on 10 randomly selected individuals. The coefficients of variation of GLS (3.0%), LVEF (2.7%), E wave (4.1%), A wave (6.6%), LVEDV (6.4%), and LVESV (7.9%) showed a good reliability of these measurements.

Hemodynamic measurements were taken using the SphygmoCor® device (AtCor Medical, Sydney, Australia). An automated cuff was positioned on the right arm and inflated to assess brachial systolic and diastolic blood pressures. Central systolic blood pressure (cSBP) was determined as the highest pressure during aortic injection, and central diastolic blood pressure (cDBP) was calculated by the minimum pressure recorded in a pulse. Hemodynamic measurements were taken twice, wherein a third measurement was made when the difference between the two first measurements was superior to 5mmHg.

### *Statistical analysis*

Continuous variables are expressed as mean and standard deviation. Sample size calculation was performed with the aid of the software G Power® 3.1., using the one-way repeated measures ANOVA as the statistical test. Statistical power was set at 90%, with a significance level of  $p \leq 0.05$  and an effect size of 0.59, using GLS as the primary outcome.<sup>28</sup> Therefore, the minimum sample size required to reach statistical significance was settled in 12 individuals. We added 15% to the calculated sample size to account for participants' potential withdrawal throughout the study, increasing the sample size to 15 individuals. Comparisons between groups and moments were made via two-way repeated measures ANOVA, followed by

Bonferroni correction. Data were analysed using the Statistical Package for Social Sciences (Version 23) (IBM®, New York, USA).

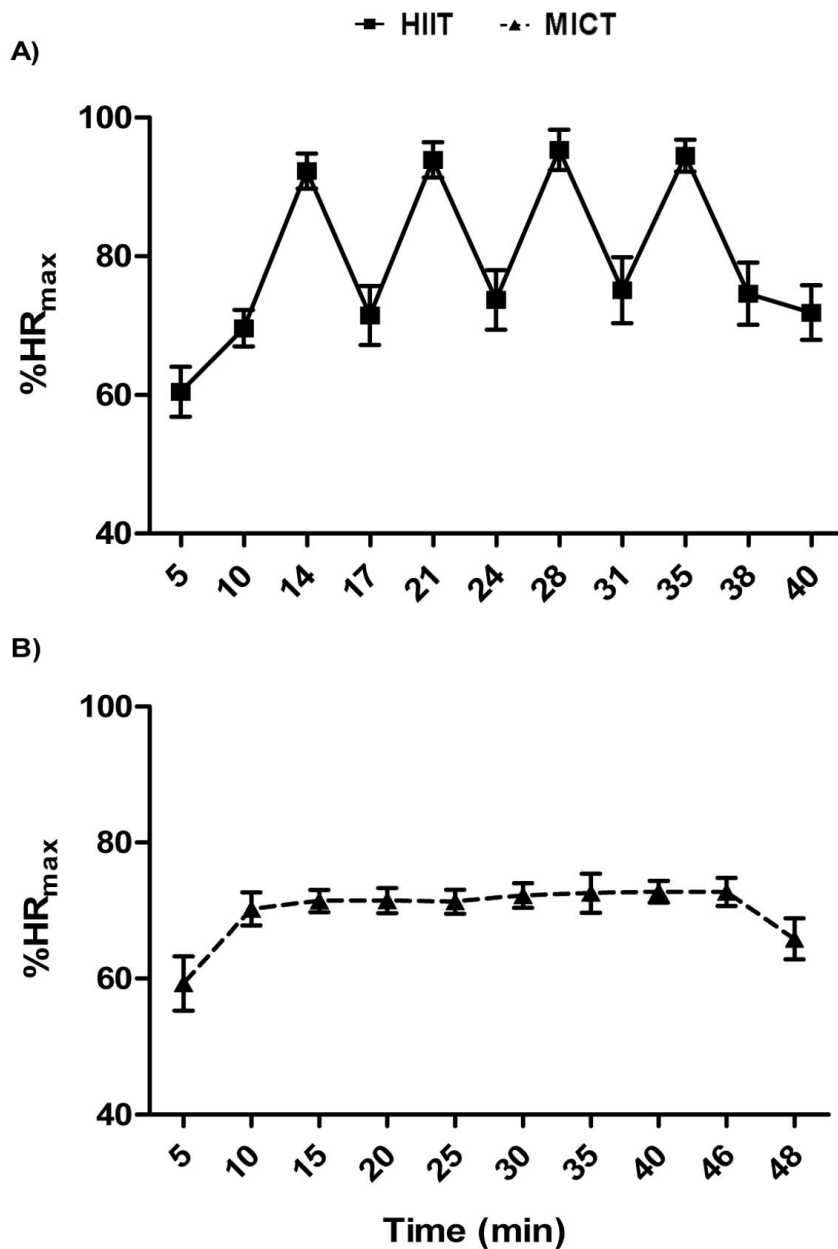
## Results

The general characteristics of the sample are presented in Table 1. Regarding the characteristics of aerobic exercise protocols, HIIT expectedly presented a higher heart rate (HR) ( $179.7 \pm 10.5$  bpm vs.  $137.3 \pm 8.3$  bpm) (Figure 2) and RPE ( $15.0 \pm 2.3$  vs.  $11.0 \pm 2.6$ ) in comparison to MICT. Although MICT presented a higher covered distance ( $3.9 \pm 0.5$  vs.  $3.2 \pm 0.3$  km,  $p < 0.001$ ), the total energy expenditure was similar between both exercise protocols (HIIT:  $386 \pm 38.5$  vs. MICT:  $379.9 \pm 35.2$  kcal,  $p = 0.631$ ).

**Table 1.** Baseline sample characteristics ( $n=17$ ).

Variables	Baseline
Age (years)	25.2±4.8
<i>Anthropometry and body composition</i>	
Body weight (kg)	88.2±11.5
Body mass index (kg/m <sup>2</sup> )	33.5±3.3
Waist circumference (cm)	91.1±7.2
Body fat (%)	43.4±3.7
Fat mass (kg)	38.5±7.8
Fat free mass (kg)	49.8±4.6
<i>Physical activity level</i>	
Light (min/week)	60.0(25.0-135.0)
Moderate (min/week)	90.0 (25.0-140.0)
Vigorous (min/week)	0.0 (0.0-60.0)
<i>Cardiorespiratory fitness</i>	
Heart rate (beats/min)	190.5±12.0
Treadmill speed (km/h)	6.3±0.6
Treadmill gradient (%)	15±1.0
VO <sub>2max</sub> (ml/kg/min)	33.2±4.8
<i>Hemodynamics</i>	
Resting HR (beats/min)	72.7±13.5
Peripheral SBP (mm Hg)	124.6±12.6
Peripheral DBP (mm Hg)	74.1±8.5
Central SBP (mm Hg)	110.6±9.9
Central DBP (mm Hg)	75.1±8.6

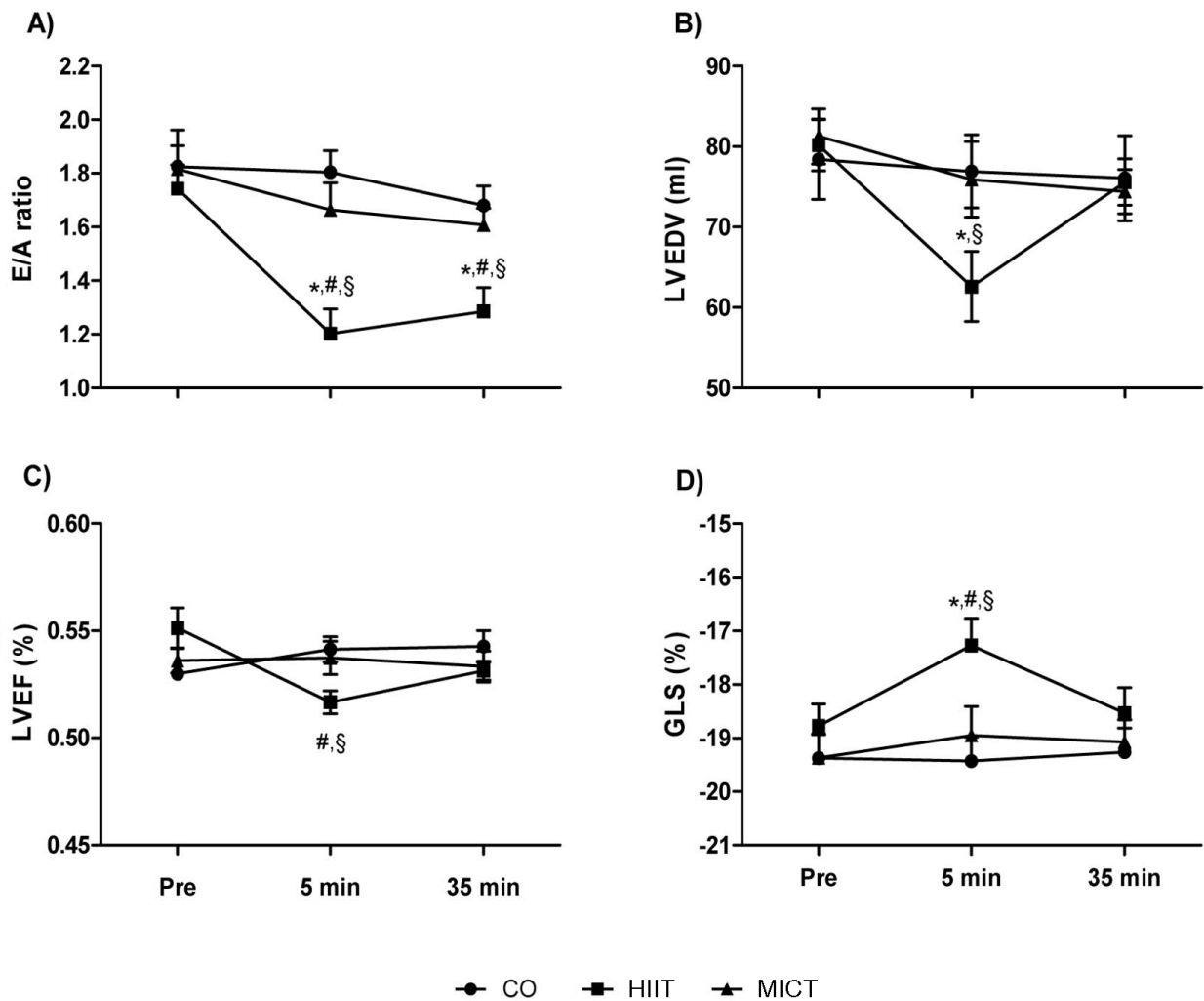
VO<sub>2max</sub>, maximal oxygen intake; HR, heart rate; SBP, systolic blood pressure; DBP, diastolic blood pressure.



**Figure 2.** (a) Heart rate (HR) during high-intensity interval training (HIIT); (b) HR during moderate-intensity continuous training (MICT).

Changes in LV diastolic (i.e. E/A ratio and LVEDV) and systolic (i.e. GLS and LVEF) parameters after the experimental conditions are shown in Figure 3. Significant time and group interactions were observed for E/A ratio ( $p=0.006$ ), LVEDV ( $p=0.007$ ), GLS ( $p=0.040$ ) and LVEF ( $p=0.028$ ). At t5, LVEF and LVEDV presented significant reductions after HIIT in comparison to CO ( $p=0.010$  and  $p=0.048$ ) and baseline ( $p=0.017$  and  $p=0.001$ ), respectively. GLS and E/A ratio reduced significantly after HIIT in comparison to MICT ( $p=0.013$  and  $p=0.027$ ), CO ( $p=0.002$  and  $p<0.001$ ), and baseline ( $p=0.010$  and  $p=0.001$ ) at t5, respectively. Only

E/A ratio showed a significant reduction for HIIT when compared to baseline ( $p= 0.001$ ), MICT ( $p= 0.008$ ) and CO ( $p= 0.001$ ) at t35.



**Figure 3.** a) The ratio between E and A waves (E/A ratio); b) Left ventricular end-diastolic volume (LVEDV); c) Left ventricular ejection fraction (LVEF); and d) Global longitudinal strain (GLS) according to the experimental conditions.

\*Difference to control group; #Difference to exercise group; \$Difference to baseline.

Changes in the other echocardiographic parameters are presented in Table 2. Significant time and group interactions were observed for E wave ( $p < 0.001$ ), A wave ( $p= 0.015$ ), E' septal ( $p= 0.031$ ), SV ( $p < 0.001$ ) and HR ( $p < 0.001$ ). There was a significant decline in E wave at t5 after HIIT in comparison to baseline ( $p= 0.001$ ) and CO ( $p= 0.003$ ). A significant increase in A wave was observed after HIIT in relation to CO ( $p= 0.032$ ;  $p= 0.034$ ) and MICT ( $p= 0.019$ ;  $p= 0.039$ ) at t5 and t35, respectively. These changes in HIIT were significant when compared to baseline at both t5 ( $p= 0.011$ ) and t35 ( $p= 0.019$ ). Regarding E' septal, a significant reduction was observed after MICT in comparison with baseline at t5 ( $p= 0.040$ ), whilst this difference was observed for both MICT ( $p= 0.007$ ) and HIIT ( $p= 0.006$ ) in comparison to baseline values at t35. Moreover, E' septal was significantly reduced after HIIT in comparison to CO at t35 ( $p= 0.039$ ).

A significant reduction in LVESV was observed after HIIT when compared to baseline at t5 ( $p= 0.050$ ). As regards SV, it significantly reduced following HIIT in comparison to baseline at t5 ( $p < 0.001$ ) and t35 ( $p=$

0.050), as well as it was significantly reduced in comparison to both MICT ( $p= 0.038$ ) and CO ( $p= 0.013$ ) at t5. HIIT also increased S' lateral at t5 in comparison to baseline and CO ( $p<0.001$ ), while MICT increased S' lateral in comparison to baseline at t5 ( $p<0.001$ ). Finally, HR predictably increased after HIIT when compared to MICT ( $p< 0.001$ ,  $p< 0.001$ ) and CO ( $p< 0.001$ ,  $p< 0.001$ ) at t5 and t35, respectively. In addition, HR values following HIIT were significantly different from baseline to t5 ( $p< 0.001$ ) and t35 ( $p< 0.001$ ). Meanwhile, HR was only different following MICT when baseline comparing baseline values with t5 ( $p= 0.002$ ).

**Table 2.** Echocardiographic parameters at baseline and post (t5 and t35) experimental conditions.

		Pre	Post				Time	ANOVA	
			5 min		35 min			Trial	Time x Trial
			MD	MD	ES	MD			
E (m/s)	<i>CO</i>	0.87±0.15	0.88±0.12		0.82±0.02		<0.001	0.007	<0.001
	<i>HIIT</i>	0.85±0.12	0.69±0.14**‡	1.79	0.71±0.11	0.75			
	<i>MICT</i>	0.82±0.11	0.77±0.13	0.89	0.78±0.11	0.10			
A (m/s)	<i>CO</i>	0.49±0.09	0.49±0.06		0.49±0.07		0.012	0.001	0.015
	<i>HIIT</i>	0.49±0.07	0.60±0.12**‡‡	1.01	0.58±0.13**‡‡	0.93			
	<i>MICT</i>	0.46±0.07	0.48±0.07	0.26	0.49±0.05	0.35			
E' septal (m/s)	<i>CO</i>	0.12±0.01	0.12±0.01		0.12±0.02		0.001	0.118	0.031
	<i>HIIT</i>	0.12±0.01	0.11±0.03	0.46	0.10±0.02*‡	1.04			
	<i>MICT</i>	0.12±0.02	0.11±0.02‡	1.04	0.11±0.02‡	0.65			
E' lateral (m/s)	<i>CO</i>	0.18±0.02	0.18±0.02		0.18±0.02		0.149	0.067	0.051
	<i>HIIT</i>	0.19±0.03	0.16±0.05	0.82	0.16±0.04	0.65			
	<i>MICT</i>	0.18±0.03	0.18±0.02	0.00	0.18±0.03	0.00			
E/E' septal	<i>CO</i>	7.26±1.19	7.27±1.33		6.89±1.71		0.603	0.799	0.360
	<i>HIIT</i>	7.03±1.48	6.65±1.73	0.30	7.37±2.42	0.37			
	<i>MICT</i>	6.75±1.09	6.83±0.93	0.08	7.01±1.13	0.53			
E/E' lateral	<i>CO</i>	4.99±0.97	4.91±0.83		4.57±0.93		0.799	0.307	0.695
	<i>HIIT</i>	4.63±0.86	4.66±1.36	0.03	4.83±2.10	0.34			
	<i>MICT</i>	4.46±0.69	4.39±0.79	0.15	4.32±0.64	0.23			
Average E/E'	<i>CO</i>	5.89±1.02	5.83±0.90		5.43±0.98		0.872	0.409	0.448
	<i>HIIT</i>	5.89±1.01	5.41±1.37	0.05	5.76±2.19	0.41			
	<i>MICT</i>	5.39±0.63	5.29±0.67	0.07	5.32±0.66	0.47			
S' lateral (m/s)	<i>CO</i>	0.11 ± 0.02	0.12 ± 0.02		0.11 ± 0.02		<0.001	0.026	0.242
	<i>HIIT</i>	0.12 ± 0.03	0.13 ± 0.03**‡‡	0.35	0.12 ± 0.02	0.00			
	<i>MICT</i>	0.11 ± 0.02	0.13 ± 0.02‡	1.04	0.11 ± 0.02	0.00			
S' septal (m/s)	<i>CO</i>	0.08 ± 0.01	0.08 ± 0.01		0.08 ± 0.01		0.114	0.437	0.195
	<i>HIIT</i>	0.09 ± 0.01	0.09 ± 0.01	0.00	0.09 ± 0.01	0.00			
	<i>MICT</i>	0.09 ± 0.01	0.09 ± 0.01	0.00	0.09 ± 0.01	0.00			
LVESV (ml)	<i>CO</i>	36.26±8.30	35.46±8.45		34.93±10.18		0.032	0.510	0.139
	<i>HIIT</i>	36.07±7.28	30.26±8.38‡	0.75	35.60±6.09	0.13			
	<i>MICT</i>	37.86±6.41	34.93±8.24	0.33	34.66±5.02	0.26			

<b>SV</b> (ml/bpm)	<b>CO</b>	42.13±11.10	41.46±10.18		41.13±10.58				
	<b>HIIT</b>	44.13±6.15	32.33±8.56*†‡	2.89	40.00±5.31‡	0.47	0.002	0.337	<0.001
	<b>MICT</b>	43.40±7.46	41.00±10.51	1.90	39.73±6.46	0.34			
<b>HR</b> (bpm)	<b>CO</b>	72.73±13.51	73.13±11.93		70.26±11.97				
	<b>HIIT</b>	76.66±12.22	100.13±8.94*†‡	2.89	93.66±10.87*†‡	3.29	<0.001	<0.001	<0.001
	<b>MICT</b>	77.00±11.22	86.13±10.45*†‡	1.11	77.60±9.85*†	0.47			

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\*Difference to control group; †Difference to exercise group; ‡Difference to baseline. Values are means ± SD. CO, control group; HIIT, high-intensity interval training; MICT, moderate intensity continuous training; E, early diastolic inflow velocity; A, atrial diastolic inflow velocity; E/A, ratio between early and atrial diastolic inflow velocities; E', mitral annular tissue velocity; LVESV, left ventricle end-systolic volume; SV, stroke volume, HR, heart rate. ES, Effect Size. Cohen's *d*, negligible effect ( $\geq -0.15$  and  $< .15$ ); small effect ( $\geq .15$  and  $< .40$ ); medium effect ( $\geq .40$  and  $< .75$ ), large effect ( $\geq .75$  and  $< 1.10$ ), very large effect ( $\geq 1.10$  and  $< 1.45$ ), huge effect  $> 1.45$ .

## Discussion

The present study investigated the acute effects of HIIT and MICT on LV function in young women with uncomplicated obesity. Contrary to our initial hypothesis, the results showed that a single bout of HIIT promoted a transient decline in LV function, wherein no changes were observed after MICT. HIIT-induced changes in LV function were reestablished 35 minutes after exercise cessation.

Previous studies have reported a positive effect of HIIT on cardiovascular markers in different populations.<sup>19,20,29,30,31</sup> In fact, HIIT reduced blood pressure in adults with pre-to-established hypertension,<sup>31</sup> with significant improvements in vascular function in individuals with obesity.<sup>30</sup> When considering cardiac-related changes, HIIT promoted significant enhancements in cardiac function in individuals with type 2 diabetes<sup>20</sup>, being also responsible for improvements in cardiac mechanics<sup>32</sup> and remodelling<sup>19</sup> in sedentary individuals and heart failure patients, respectively.

From the perspective of changes in LV diastolic function, reductions in E wave and E/A ratio, and an increase in A wave were observed following HIIT. This corroborates with previous evidence that observed a reduction in E wave and E/A ratio after high-intensity aerobic exercise in individuals with type 2 diabetes and individuals with obesity.<sup>33</sup> Physical exercise increases HR, which remains elevated after exercise performance, particularly for a longer period in sedentary individuals.<sup>34</sup> This increase in HR causes a shortened diastolic filling time and a consequent decline in E wave.<sup>35</sup> An increase in A wave was also reported after HIIT, potentially due to the large amount of blood remaining in the left atrium as a consequence of a shortened early filling (e.g. E wave),<sup>36</sup> acting as a compensatory mechanism to mitigate the shortened early filling (i.e. decrease in E wave) by increasing late filling (i.e. increase in A wave).<sup>37</sup> Considering the early to late peak diastolic mitral inflow velocity (E/A ratio), there was a decrease in this variable after HIIT performance. This suggests that the increase in A wave reported after HIIT was not sufficient to counterbalance the decrease in E wave, decreasing hence E/A ratio and consequently reducing LVEDV. Noteworthy, this result opposes the findings from a previous study that despite showing a reduction in the E/A ratio, no significant reduction was reported for LVEDV after a bout of high-intensity aerobic exercise.<sup>33</sup> E/A ratio has been previously reported to be inversely proportional to HR.<sup>38</sup> A meta-analysis conducted by Donaldson et al.<sup>36</sup> predicted a reduction of 0.03 in the E/A ratio for each bpm increase in HR. Having in mind that HIIT promotes a substantial increase in HR, noticeably higher than MICT, this might explain why this transient impact in LV diastolic function was observed following HIIT but not MICT or CO. Despite the observed transient reduction five minutes after HIIT performance, the LV diastolic function parameters returned close to baseline values 35 minutes after HIIT cessation. According to Middleton and colleagues<sup>39</sup>, the prompt return of any alteration induced by exercise on the diastolic filling proposes that the clinical impact of this phenomenon is minimal. Therefore, although worthy of consideration, the temporary reductions in LVEDV and E/A ratio following HIIT do not seem to be associated with any cardiovascular risk.

A transient decrease in LV systolic function, represented by a decrease in GLS, was also observed after HIIT at t5, being reestablished at baseline levels at t35. In agreement with our findings, previous evidence also reported an acute decrease in GLS after high-intensity aerobic exercise in different populations.<sup>40,41</sup> Lembo and colleagues<sup>42</sup> reported an independent association between LVEDV and GLS. In addition, higher HR is significantly associated with lower GLS.<sup>43</sup> Reduced LVEDV, as a consequence of an increase in HR, leads to shorter diastolic filling time and consequent diminished myocardial deformation, related to a smaller amount of

blood in the LV. This explains the worsening in GLS after HIIT performance. Interestingly, this transient reduction in GLS was rapidly adjourned to baseline values. Stewart and colleagues<sup>41</sup> reported that since cardiac remodelling is a long-term process, it is improbable that a single acute bout of exercise is capable of inducing deleterious cardiac remodelling and consequently cardiac dysfunction. Instead of that, it seems that repeated bouts of exercise could drive structural and functional changes in the LV, inducing a physiological cardiac remodelling. Normally, there is a gain in contractility at moderate-intensity aerobic exercise as a result of improved preload and the Frank-Starling mechanism. It causes a greater systolic fibre shortening, and thereupon a diminished end-systolic volume, increasing the diastolic elastic recoil.<sup>44</sup> Provided that GLS is the quantification of the deformation of myocardial length from relaxed to before contraction periods,<sup>45</sup> we speculate that this may promote an increase in GLS. However, these acute effects appear to be influenced by exercise intensity. It is believed that LVEDV, one of the main determinants of preload, increases during low- to moderate exercise intensities (e.g., 40% - 70% HR<sub>max</sub>).<sup>46</sup> Therefore, at higher exercise intensities (e.g., HIIT), a larger increase in HR results in a reduced filling time that may compromise preload, whereas an increase in filling pressure gradient can no longer sustain LVEDV, reducing hence GLS. In addition, we also found a reduction in LVEF following HIIT at t5 that was restored near baseline values at t35. This finding differs from previous research that observed no changes in LVEF after a bout of high-intensity aerobic exercise in individuals with type 2 diabetes and individuals with obesity.<sup>33</sup> Taken together, although decreased, GLS and LVEF values achieved did not indicate the presence of LV systolic dysfunction.<sup>47</sup> In agreement with this, recent findings have reported a reduction in blood pressure between 30 and 60 minutes after HIIT.<sup>22</sup> This blood pressure reduction could lead to a reduced afterload, decreasing LV overload, which is believed to increase LV systolic function. Nonetheless, our findings showed a transient decline in the LV function. This indicates that the decrease in LV systolic function after HIIT can be attributed to a decrease in preload caused by an increase in HR and shorter filling time and is not related to changes in blood pressure and arterial-related markers.

There is a debate surrounding HIIT and MICT modalities and their capacity to elicit health benefits as well as the ever-increasing comparisons aiming to define which one is superior to exert health-related effects. Nevertheless, the clear lack of consensus highlights that this issue still requires further elucidation.<sup>48</sup> Additionally, the difference between these aerobic exercise regimens on cardiovascular parameters following exercise performance in women with obesity is still unclear. A plethora of studies in special populations have demonstrated greater enhancement in cardiac parameters following HIIT rather than MICT in chronic experiments. Shi and colleagues<sup>30</sup> showed that both HIIT and MICT improved hemodynamics; However, only HIIT elicited significant improvements in artery diameter, shear stress, pulsatility index, and arterial stiffness. In addition, a similar study showed that 12 weeks of HIIT enhanced systolic function in adults with type II diabetes.<sup>49</sup> On the other hand, robust up-to-date evidence did not find differences between HIIT and MICT regarding improvements in LV systolic function, wherein both aerobic exercise regimens induced similar increases in LVEF.<sup>14</sup>

From an acute perspective, less is known about the differences between these aerobic exercise regimens on cardiovascular parameters in chronically diseased populations. Previous data reported that HIIT instead of MICT promoted transient acute improvements in wave reflection and cSBP in women with obesity.<sup>22</sup> In agreement with these findings, Way and colleagues<sup>21</sup> found a reduced wave reflection and cSBP after an acute bout of HIIT in individuals with diabetes. Although this is an interesting initial group of evidence towards a

positive effect of HIIT on cardiovascular parameters in populations with chronic diseases, further investigations are pivotal to properly investigate the role of intensity in aerobic exercise-related changes in cardiovascular markers. The recent American College of Sports Medicine exercise testing and prescription guideline recommends the practice of intense or moderate aerobic exercise, or the combination thereof for cardiovascular health maintenance. It also states that HIIT may be an excellent alternative due to its time efficiency in comparison to MICT.<sup>50</sup> In spite of all the concerns on the safety profile of HIIT, it seems to be harmless for young women with uncomplicated obesity, considering that the reductions in LV diastolic and systolic function were almost fully reestablished to baseline values 35 minutes after exercise cessation.

To our knowledge, the present study is the first to investigate and compare the acute effects of HIIT and MICT on LV systolic and diastolic function in young women with obesity. In addition, our sample was exclusively composed of subjects without obesity-related comorbidities (i.e. uncomplicated obesity). This conferred the possibility to assess the acute effects of both exercise regimens in obesity only, with no confounding effects from associated comorbidities. Also, the crossover study design allowed us to verify different experimental conditions in the same individuals, improving the reliability of the outcomes. Nonetheless, the study has some limitations that need to be mentioned. We demonstrated that HIIT caused acute adjustments in cardiac function that were rapidly reestablished to baseline levels. Nevertheless, the results from the present study need to be interpreted with caution. Provided the two aerobic modalities investigated in this study have a different impact on HR, the decrease in cardiac function might have occurred due to an increase in HR by HIIT instead of acute cardiovascular adjustments. The present study aimed to investigate the acute effects of different aerobic exercise modalities on cardiac function, and despite the discussion provided, a thorough mechanistic explanation of the changes observed is beyond the scope of this study. Although GLS has a closer association with cardiac events and all-cause mortality in comparison to the other cardiac strain measures, the inclusion of cardiac circumferential and radial strain, as well as the inclusion of cardiac mechanics variables (e.g. twisting, untwisting, torsion) could improve understanding about the dynamic acute changes on LV function and mechanics. Moreover, the lack of comprehensive details on potential changes in blood pressure is a limitation of this study. Despite we discuss the acute effects of exercise on hemodynamics using data very similar studies, simultaneous data on blood pressure and LV function after experimental conditions would provide complementary evidence to discuss and explain the main findings from the present study. Lastly, the change in body posture from experimental conditions performance (upright position) to echocardiographic assessment (left lateral decubitus position) might be interpreted as a limitation. This can lead to a higher sympathetic nervous system activation, promoting rapid hemodynamic adjustments. Nonetheless, we believe that these acute cardiovascular adjustments are not able to elicit significant changes or reverse acute changes in cardiac function induced by exercise, as observed in our study.

## **Conclusion**

HIIT was not associated with acute improvements in LV function in young women with uncomplicated obesity. Our findings revealed a transient reduction in both LV diastolic and systolic function following HIIT. However, the reduction observed was rapidly and almost fully restored to baseline values, indicating that this

aerobic exercise modality does not seem to elicit negative acute effects on LV function in this population. In addition, the putative superiority of HIIT to MICT in eliciting greater adaptations in cardiac function is yet to be better elucidated. Studies investigating the effects of these aerobic exercise modalities on cardiac function and mechanics in populations at higher cardiovascular risk are mandatory to clarify the exercise-related benefits on cardiac-related outcomes.

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