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ORIGINAL RESEARCH

Hemodynamic responses during inspiratory muscle exercise in healthy young adults

Respostas hemodinâmicas durante o exercício muscular inspiratório em jovens saudáveis

Respuestas hemodinámicas durante el ejercicio de los músculos inspiratorios en adultos jóvenes sanos

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ABSTRACT | The literature on hemodynamic responses during inspiratory muscle exercise (IME) lacks a consensus. To evaluate and compare hemodynamic responses during an IME session with and without resistive load, 15 sedentary men were subjected to two randomized IME sessions: one with 40% of maximal inspiratory pressure (IME 40%) and another without a resistive load (Sham), both of which were performed for two minutes over eight sets with one-minute intervals. Systolic blood pressure (SBP), diastolic blood pressure (DBP), mean blood pressure (MBP), total peripheral resistance (TPR), stroke volume (SV), cardiac output (CO), and heart rate (HR) were measured by infrared digital photoplethysmography during five basal minutes and during the IME sessions. One-way ANOVA analysis of variance and the Student's t test for paired data were used to analyze hemodynamic response and delta values between sessions, respectively. Effect size was evaluated by Cohen's D. A 5% significance level was adopted. SBP responses (sham: Δ−1±2 vs. 40%: Δ−4±2mmHg, p=0.27), DBP (sham: Δ2±1 vs. 40%: Δ1±2mmHg, p=0.60) and MBP (sham: Δ2±1 vs. 40%: Δ0±2mmHg, p=0.28) were similar between sessions. HR increases were higher in the 40% IME session than in the sham session (sham: Δ9±2 vs. 40%: Δ3±2bpm, p=0.001). SV only decreased during the sham session but responses were similar between sessions (sham: Δ−2±2 vs. IME 40%: Δ−6±2ml, p=0.13). Both sessions did not change SBP, DBP, MBP, CO, and TPR, but we observed a greater increase in HR in the IME 40% session. Only the Sham session decreased SV.
Keywords | Breathing Exercises; Hemodynamics; Young Adult.

RESUMO |A literatura carece de um consenso sobre respostas hemodinâmicas durante o exercício muscular inspiratório (EMI). Este estudo buscou avaliar e comparar as respostas hemodinâmicas durante uma sessão de EMI com e sem carga resistiva. Para tanto, 15 homens sedentários foram submetidos a duas sessões randomizadas de EMI: 40% da pressão inspiratória máxima (EMI 40%) e sem carga resistiva (*sham*), realizadas por dois minutos em oito séries e com intervalos de um minuto. A pressão arterial sistólica (PAS), pressão arterial diastólica (PAD), pressão arterial média (PAM), resistência periférica total (RPT), volume sistólico (VS), débito cardíaco (DC) e frequência cardíaca

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(FC) foram medidos por fotopletismografia infravermelha digital por cinco minutos basais e durante as sessões de EMI. Anova de uma via e o teste t de Student para dados pareados foram usados para analisar a resposta hemodinâmica e os valores delta entre as sessões, respectivamente. O tamanho do efeito foi avaliado pelo d de Cohen. Adotou-se nível de significância de 5%. As respostas de PAS (*sham*: Δ−1±2 vs. 40%: Δ−4±2mmHg, p=0,27), PAD (*sham*: Δ2±1 vs. 40%: Δ1±2mmHg, p=0,60) e PAM (*sham*: Δ2±1 vs. 40%: Δ0±2mmHg, p=0,28) foram semelhantes entre as sessões. Os aumentos da FC foram maiores na sessão de EMI 40% do que nas sessões *sham* (*sham*: Δ9±2 vs. 40%: Δ3±2bpm, p=0,001). O VS diminuiu exclusivamente durante a sessão *sham* mas a resposta foi semelhante entre as sessões (*sham*: Δ−2±2 vs. EMI 40%: Δ−6±2ml, p=0,13). Ambas as sessões não causaram alteração nas variáveis PAS, PAD, PAM, DC e RPT, mas notamos um aumento maior da FC na sessão EMI 40%. Apenas a sessão *sham* reduziu o VS.

Descritores | Exercícios Respiratórios; Hemodinâmica; Adulto Jovem.

RESUMEN | No hay consenso en la literatura sobre las respuestas hemodinámicas durante el ejercicio muscular inspiratorio (EMI). El objetivo de este estudio fue evaluar y comparar las respuestas hemodinámicas durante una sesión de EMI con y sin carga resistiva. Para ello, quince hombres sedentarios recibieron dos sesiones aleatorias de EMI: el 40% de la presión inspiratoria máxima (EMI 40%) y sin carga resistiva (*sham)*, realizadas durante dos minutos, ocho sesiones y a intervalos de un minuto. La presión arterial sistólica (PAS), la presión arterial diastólica (PAD), la presión arterial media (PAM), la resistencia periférica total (RPT), el volumen sistólico (VS), el gasto cardíaco (GC) y la frecuencia cardíaca (FC) se midieron mediante fotopletismografía infrarroja digital durante cinco minutos al inicio y durante las sesiones de EMI. Se utilizaron ANOVA unidireccional y la prueba t de Student a datos emparejados para analizar la respuesta hemodinámica y los valores delta entre las sesiones. El tamaño del efecto se evaluó por el d de Cohen. El nivel de significancia adoptado fue de 5%. Las respuestas de PAS (*sham*: Δ−1±2 vs. 40%: Δ−4±2mmHg, p=0,27), PAD (*sham*: Δ2±1 vs. 40%: Δ1±2mmHg, p=0,60) y PAM (*sham*: Δ2±1 vs. 40%: Δ0±2mmHg, p=0,28) fueron similares entre las sesiones. El incremento de la FC fue mayor en la sesión de EMI 40% comparada con la sesión *sham* (*sham*: Δ9±2 vs. 40%: Δ3±2bpm, p=0,001). El VS tuvo una disminución exclusiva durante la sesión *sham*, pero la respuesta fue similar entre las sesiones (*sham*: Δ−2±2 vs. EMI 40%: Δ−6±2ml, p=0,13). Ambas sesiones no tuvieron cambios en las variables PAS, PAD, PAM, DC y RPT, pero se observó un mayor incremento de la FC en la sesión EMI 40%. Solamente en la sesión *sham* hubo una reducción del VS.

Palabras clave | Ejercicios Respiratorios; Hemodinámica; Adulto Joven.

INTRODUCTION

The functional and cardiovascular benefits of inspiratory muscle training described in the literature reinforce the physiological integration between the cardiovascular and respiratory systems. Breathing is processed by the integration of the lungs into the central and peripheral nervous system, accompanied by the rib cage and respiratory muscles[1]. As a result, the nervous system adjusts the intensity of ventilation to the demands of the body under different physiological conditions[2]. Thus, pulmonary ventilation modulates intrathoracic pressure and consequently changes venous return and ventricular ejection volume, which trigger changes in heart rate (HR) and blood pressure (BP)[3]. Accordingly, it is reasonable to infer that the intensity of the used resistive inspiratory load may influence the hemodynamic responses to inspiratory muscle exercise (IME).

In fact, studies have investigated the acute responses to IME in different populations using different intensities of resisted loads. Effects during IME with loads from 50% to 90% of maximal inspiratory pressure (MIP) have been investigated in trained rowers, showing that all studied exercise intensities increased HR. However, only the 60% MIP load sustainedly increased systolic blood pressure (SBP), diastolic blood pressure (DBP), and mean blood pressure (MBP)[4].

Additionally, a study investigated the acute effects of IME at 30% of MIP on the cardiac parameters of young smokers. The authors observed a reduction in SBP and improvement in heart rate variability, suggesting that a single session of IME may mediate changes in cardiovascular autonomic control by increasing cardiac parasympathetic modulation[5].

Although studies have shown that an IME session can change the cardiovascular system in different populations, to our knowledge, the literature is yet to establish a consensus on acute hemodynamic responses to IME resistive load. Therefore, this study aimed to evaluate and compare hemodynamic responses during an IME session with and without a resistive load in healthy young adults.

METHODOLOGY

All volunteers were informed and instructed about the study procedures and those who agreed to participate signed an informed consent form in duplicates, following Resolution No. 466 of 2002 of the National Health Council. This study is a crossover randomized controlled trial.

Volunteers were recruited by an active search at the university, in health campaigns, in the municipality of Juiz de Fora, and by printed and digital dissemination of the research project. All volunteers were informed and instructed about the procedures to be used and all experimental procedures were performed at the Cardiovascular Research and Exercise Physiology Unit (InCFEx) at HU/UFJF/EBSERH.

The sample was composed of 15 young males who self-reported being healthy, took no cardiovascular and respiratory medications, and had no diagnosis of cardiovascular and pulmonary diseases.

The Baecke's questionnaire was used to assess habitual physical activity levels. This questionnaire is composed of three scores: occupational physical activities (OPA), physical exercise in leisure (PEL), and leisure and locomotion activities (LLA). The PEL score was used in this study, referring to the practice of sports or physical exercise, and the sample should have avoided practicing regular physical exercise with mild energy expenditure[6] in the 12 months prior to this study. Moreover, volunteers had no history of smoking.

Subjects with blood pressure levels greater than 140/90mmHg and electrocardiographic alterations, such as ischemia and complex cardiac arrhythmias detected during baseline monitoring, and a body mass index (BMI) greater than or equal to 30kg/m^2 were excluded from the study.

Anthropometry

A Leader® scale with a 0.1-kg precision and a coupled staggered stadiometer with a 0.5-cm precision were used to measure body mass and height, respectively. For BMI calculations, the body weight equation was used in kilograms divided by height in meters squared. Waist, abdomen, and hip circumference were measured with a Cardiomed measuring tape® with a 0.1-cm precision. For this measurement, volunteers were in orthostatism with their feet together, head in a neutral position, and arms next to their body[7].

Hemodynamic measures

In the first visit, BP measurements were performed by oscillometry following the recommendations of the Brazilian Guidelines on Arterial Hypertension[8,9]. Moreover, volunteers were subjected to anamnesis for information on life habits and health status.

In the second and third visits, HR and BP data were collected in the basal and IME conditions using Finometer Pro equipment (Finapress Medical System, Amsterdam, Netherlands) and digital infrared photoplethysmography, in which a cuff was positioned around the volunteers' right-hand middle finger as they rested their right arm at the height of their left ventricle. Accordingly, the BP pulse wave signal was captured for stroke volume derivation (SV) and cardiac output (CO) using the Modelflow method (BeatScope, Finapress Medical System, Amsterdam, Netherlands). Biological signals were collected using a data acquisition system and an analog/digital converter with a 16-bit resolution and sampling frequency of 1,000Hz (Biopac Systems Inc., Goleta, CA, USA) and recorded on the AcqKnowledge 4.2.0 program (Biopac Systems Inc., Goleta, CA, USA). Total peripheral resistance (TPR) was calculated by dividing MBP by CO[10].

Evaluation of respiratory muscle strength

Inspiratory muscle strength was measured by MIP, using a digital manovacuometer (GlobalMed). Expiratory muscle strength was measured using maximal expiratory pressure (MEP) with the same equipment. MEP was obtained from a maximal expiratory effort after complete inspiration. MEP was considered the highest value of a maximum of three attempts with a variation of less than 10%[11,12]. These values are shown in absolute numbers and percentage of predicted age and gender[13].

Inspiratory Muscle Exercise (IME)

The two IME sessions were performed with the following intensities: sham (without load) and at 40% MIP. The sham and IME 40% sessions were performed with eight sets of two minutes with a one-minute interval between series. Volunteers were instructed to perform diaphragmatic breathing and maintain a respiratory rate in the range from 12 to 15 incursions per minute (controlled by feedback from the evaluator). The entire IME protocol was performed with participants seated with their feet resting on the floor and wearing a common nasal clip to avoid air leaks. Session order was randomized using a website (volunteers were not previously informed as to which session they would be subjected).

Experimental protocol

The entire experiment was conducted at the Cardiovascular Research and Exercise Physiology Unit (InCEFx) at the Physical Evaluation Laboratory of the University Hospital of UFJF by the same researchers who were previously trained in the application of the protocol. The stages of this experiment were divided into three afternoon visits on nonconsecutive days with a 72-hour interval.

Experimental Protocol (Initial Evaluation): 1st Visit

The following procedures were performed: anamnesis, anthropometric measurements, electrocardiographic monitoring, BP measurement via oscillometry, respiratory rate measurement, respiratory muscle strength assessment, and familiarization with IME.

Experimental Protocol: 2nd and 3rd Visits

For the basal condition, volunteers were initially placed in a supine position for 10 minutes to stabilize and evaluate their hemodynamic variables. HR and BP were recorded simultaneously. Subsequently, volunteers were positioned in a chair with their feet resting on the floor to perform IME in eight series of two minutes with one-minute intervals, totaling 23 minutes. During the entire exercise session, volunteers were continuously monitored by ECG signal, respiratory brace, and hemodynamic variables, beat by beat, using Finometer Pro equipment.

Statistical analysis

Data are displayed as a mean±standard error. All collected data were subjected to distribution analysis using the Shapiro–Wilk test. The hemodynamic responses of variables during the IME session of each protocol (Sham and IME 40%) were analyzed by one-way ANOVA. Sample power was calculated for the effect time (baseline and the eight series of IME) in relation to the SBP, DBP, MBP, HR, SV, CO, and TPR variables. To analyze the size of the effect of hemodynamic variables during IME (Sham and IME 40%), the partial eta squared was adopted with the following reference values: small (0.01 to 0.06), medium (0.06 to 0.14), and large (greater than 0.14)[14]. In the case of significant differences, a post hoc Bonferroni comparison was performed.

Variable responses (delta) for both sessions were obtained by subtracting the value of the last set of IME by the baseline value (Δ=last set – basal). The Student's t test for paired data was used to compare the delta of hemodynamic variables between the IME40% and sham sessions. To compare the size of the effect of hemodynamic responses, Cohen's D was used with the reference values: small (0.2 to 0.5), medium (0.5 to 0.8) and large (greater than 0.8). A significant difference of $p<0.05$ was accepted. Statistical analysis was performed in SPSS Statistics version 20.

RESULTS

This study included 18 volunteers, excluding three for the following reasons: (1) a baseline BP greater than 140/90mmHg; (2) being considered active based on the Baecke's questionnaire; and (3) failing to complete all the necessary research visits. Therefore, our sample consisted of 15 volunteers who participated in the entire protocol.

Table 1 shows the hemodynamic, anthropometric, demographic, and respiratory muscle strength characteristics of the studied sample.

Table 1. Volunteers' hemodynamic, anthropometric, demographic, respiratory muscle strength, and habitual physical activity

Characteristic	(n=15)
SBP (mmHg)	116±3
DBP (mmHg)	66±2
HR (bpm)	65±2
Age (years)	25±1
Body mass (kg)	69.5±2
Height (m)	1.72±0.01
BMI (kg/m^2)	23.5±1
Waist Circumference (cm)	80±2
Circumference of the abdomen (cm)	86±2
Hip circumference (cm)	96±1
MIP (cmH_2O)	−113±8
MIP (predicted %)	135±1
40% MIP (cmH_2O)	45±3
MPE (cmH_2O)	132±7
MPE (predicted %)	145±1
OPA (score)	2.7±0.1
PEL (score)	2.0±1.0
LLA (score)	2.2±0.1

SBP: systolic blood pressure; DBP: diastolic blood pressure; HR: heart rate; BMI: body mass index; MIP: maximal inspiratory pressure; MEP: maximal expiratory pressure; OPA: occupational physical activities; PEL: physical exercise in leisure; LLA: leisure and locomotion activities.
Results shown as mean±standard error.

SBP failed to significantly change during the two IME sessions. However, we observed an oscillatory pattern of reduction in BP values during the IME 40% series, followed by an increase during recovery between series (Figure 1). When we analyzed absolute delta values (Δ=last IME – basal series), we found no significant difference in SBP responses (Table 2). Similarly, the hemodynamic response of DBP during sham and IME 40% sessions showed no significant changes despite the oscillatory reduction pattern during the IME series and increase during the intervals (Figure 1). DBP and MBP showed similar responses in both sessions (Table 2).

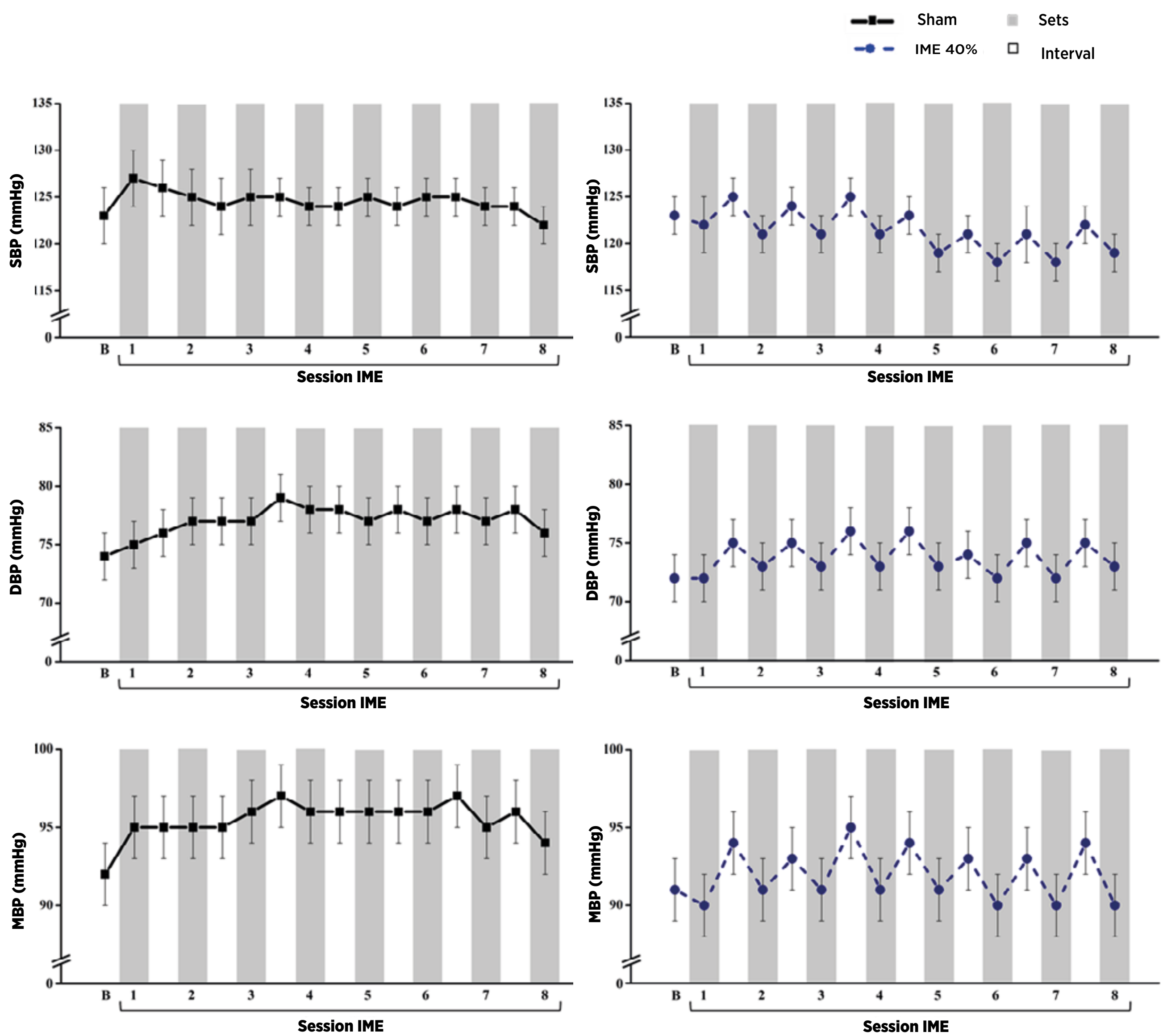

Figure 1. Hemodynamic responses of systolic blood pressure, diastolic blood pressure, and mean blood pressure during the control sessions (Sham) and inspiratory muscle exercise at 40% MIP

SBP: systolic blood pressure; DBP: diastolic blood pressure; MBP: mean blood pressure; IME: inspiratory muscle exercise.

Basal (B), 1st IME Series (1), 2nd IME Series (2), 3rd IME Series (3), 4th IME Series (4), 5th IME Series (5), 6th IME Series (6), 7th IME Series (7), and 8th IME Series (8). SBP showed a 0.67 sample power for the sham session and 0.99 for the IME 40%. DBP showed a sample power was 0.99 in both sessions. MBP showed a 0.93 and 0.93 sample power in the sham and IME 40% sessions, respectively.

Table 2. Hemodynamic response during the sham and inspiratory muscle exercise 40% MIP

Average hemodynamic response	Sham	IME 40%	p	Cohen's d
SBP (mmHg)	−1±2	−4±2	0.27	0.39
DBP (mmHg)	2±1	1±1	0.60	0.16
MBP (mmHg)	2±1	0±2	0.28	0.35
HR (bpm)	3±2	9±2	0.001	−0.85
SV (ml)	−2±2	−6±2	0.13	0.49
CO (L/minute)	0.04±0.2	0.26±0.1	0.27	−0.38
TPR (mmHg/l/minute)	0.01±0.0	−0.03±0.0	0.23	0.42

SBP: systolic blood pressure; DBP: diastolic blood pressure; MBP: mean blood pressure; HR: heart rate; SV: stroke volume; CO: cardiac output; TPR: total peripheral resistance.
Results shown as mean±standard error.

HR increased in both IME sessions but by a greater magnitude in the IME 40% sessions (Table 2). Again, we observed an oscillatory pattern of increases during the IME series and reductions during the intervals, finding significantly higher values than baseline ones (sham: Δ3±2 vs. IME: Δ9±2bpm, p=0.001) (Figure 2).

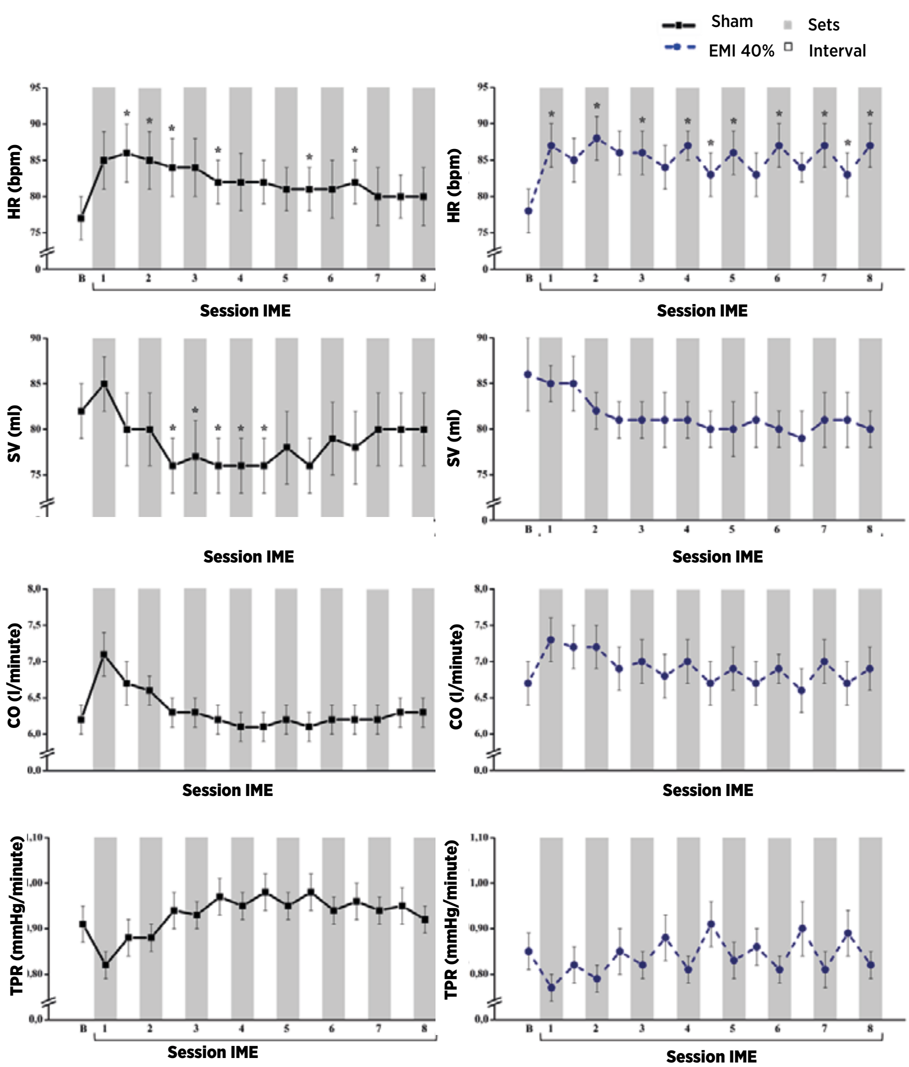

Figure 2. Hemodynamic responses of heart rate, systolic volume, cardiac output, and total peripheral resistance during the sham protocol and inspiratory muscle exercise 40% da PImáx.

HR: heart rate; SV: systolic volume; CO: cardiac output; TPR: total peripheral resistance. Basal (B), 1st IME Series (1), 2nd IME Series (2), IME 3rd Series (3), 4th IME Series (4), 5th IME Series (5), 6th IME Series (6), 7th IME Series (7), and 8th IME Series (8).

* p<0.05 vs. basal. The sample power of the variables HR, SV, CO, and TPR totaled 1.00 in both the sham and IME 40% sessions.

In contrast, SV significantly decreased during the sham session, unlike during the IME 40% session (Figure 2). However, we observed no difference in SV responses between sessions (sham: Δ−2±2 vs. IME: Δ−6±2ml, p=0.13 (Table 2). CO resembled baseline throughout the sham and IME 40% sessions (Figure 2). Thus, CO responses were similar in both protocols (Table 2).

TPR failed to change during the sham and IME 40% sessions. However, we observed an oscillatory pattern of reduction during the IME series and an increase during the intervals, but differences were statistically insignificant (Figure 1). TPR showed equivalent responses between the sham and IME 40% sessions (Table 2 and Figure 3).

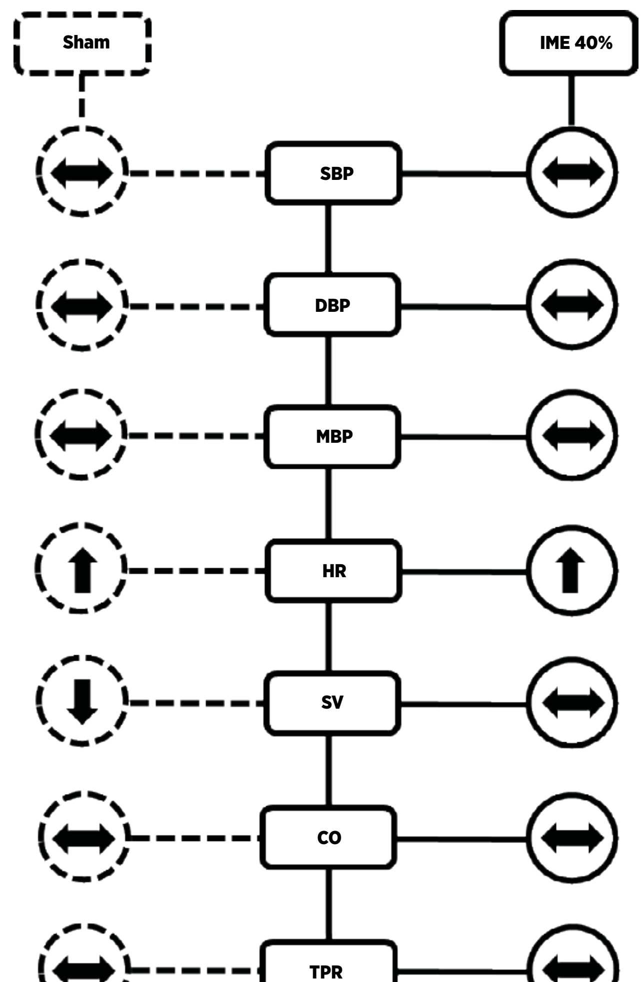

Figure 3. Hemodynamic responses of systolic blood pressure, diastolic blood pressure, mean blood pressure, heart rate, systolic volume, cardiac output, and total peripheral resistance during the sham and inspiratory muscle exercise 40% sessions

SBP: systolic blood pressure; DBP: diastolic blood pressure; MBP: mean blood pressure; HR: heart rate; SV: systolic volume; CO: cardiac output; TPR: total peripheral resistance.

⬌ Maintain; ⬆ Increase; ⬇ Decrease.

DISCUSSION

The main finding of this study refer to the increase in HR during the sham and IME 40% protocols, with the largest increase occurring in the IME 40% sessions. Moreover, we should highlight the oscillatory hemodynamic responses of variables during the series and intervals.

Regarding the increase in BP levels in response to IME, results remain controversial. In young smokers, the acute effects of IME at 30% of MIP for 15 minutes reduced SBP and maintained DBP in the smoking group, but the control group's variables show no such effect[5]. On the other hand, in rowers, the different loads of IME from 50% to 90% of MIP for 15 minutes sustainedly increased HR for all intensities. However, the sustained increase in SBP, DBP, and MBP occurred only at a load of 60% of MIP[4].

Although our results showed no significant increase in BP, we highlight its oscillatory effect. This effect probably occurs because of the protocol we prescribed (eight sets of two minutes with one-minute intervals) and the load at 40% of MIP, which may be partially associated with modulation responses of the autonomic nervous system on the heart[3,15]. Thus, we can infer that resistive inspiratory loads and IME length can influence hemodynamic responses. We should mention the increase in HR in both sessions (at a greater magnitude in the IME 40% session). Corroborating these findings, restrictive loads of 30% and 60% of MIP increased HR in healthy young people[3].

Of note, the increase in HR in this study agrees with other studies[16-18]. The increase in HR during dynamic and isometric physical exercise occurs due to vagal withdrawal and the greater contribution of sympathetic nervous activity. Peripheral aferential information from muscle contraction, mechanoreflex, and metaboreflex, associated with stimuli from central control stimulate areas of cardiovascular control increase sympathetic nervous activity and reduce cardiac parasympathetic activity by efferent pathways, favoring increased HR[19]. As a result, in this study, the higher intensity of the IME 40% session (compared to the sham session) could have more greatly activated the central command and the exercise pressor reflex. This finding would at least partally explain the greater increase in the IME 40% session.

Another possible explanation for the increase in HR is the Bainbridge reflex, an acceleration of the heart rate due to increased BP in the sinus node or in the vena cavas. In this context, some atrial receptors, undergoing strain or the pressure of increased venous return, transmit aferentous signals to the bulb, which responds with reduced vagal activity and greater sympathetic activity, stimulating HR elevation[20].

We should highlight that SV only decreased in the sham protocol of this study. Although we avoided measuring tidal volume during the IME protocols, we can infer that the volunteers in the sham protocol had higher tidal volume with each inspiration due to the lack of resistance of inspiratory action. Thus, greater pulmonary volume would mechanically hinder ventricular filling during cardiac diastole, decreasing the final diastolic volume and, thus, SV[21,22]. However, we observed no difference between SV deltas in our comparison between sessions.

Moreover, during the process of inspiration, we found a reduction in intrathoracic pressure. This reduction increases venous return and, thus, SV in the right ventricle, resulting in increased flow to the pulmonary circulation. However, as the respiratory pump influences the two ventricles differently, the left ventricle suffers volume reduction in the inspiratory phase[23].

The increase in heart rate probably compensated for the reduction in SV given that CO failed to change during either IME session. Similarly, the non-alteration of CO and TPR may justify that of BP during the sham and IME 40% sessions.

As a possible limitation of the study, we mention the impossibility of measuring and controlling tidal volume during exercise sessions. However, in clinical practice, tidal volume control is normally ignored during IME, increasing the external validity of this study.

In conclusion, note that the understanding of hemodynamic responses during IME protocols with and without resistive load enables safer exercise prescription for different populations.

Clinical implications and intervention perspectives

Several studies with inspiratory muscle training show the efficacy of increasing inspiratory muscle strength with a load of 40% of MIP in varied populations[24,25]. Based on the data from an acute session of this study, we can infer that this increase in MIP can be obtained without significant hemodynamic changes in healthy young people. Thus, exercise and IME seem to be effective tools for increasing MIP, which is an important prognostic factor in several populations[4,24,26-28], without apparently causing significant hemodynamic changes, contributing to their safe prescription.

CONCLUSION

Both sessions, i.e., with and without resistive load, failed to alter SBP, DBP, MBP, CO or TPR. However, both sessions increased HR, with a greater increase in the IME 40% session. Only the sham session reduced SV.

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