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Effect of cycloergometry on blood flow and peripheral vascular conductance and resistance in young people

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Abstract
Introduction. Evaluate hemodynamic changes in peripheral blood flow, vascular conductance (VC) and peripheral vascular resistance (PVR) in healthy individuals undergoing passive and active lower limb cycle ergometry.
Methods. This is a prospective, controlled, randomized study and a crossover design, in which 14 normotensive volunteers were allocated to receive: (1) control group, assessment without intervention, (2) passive lower limb cycle group and (3) active cycle ergometry of lower limbs. In the physical exercise session of the active and passive lower limbs cycle ergometer protocol, the volunteers were placed in the supine position and then performed 20 minutes of aerobic exercise. Forearm blood flow was measured by venous occlusion plethysmograph, blood pressure was monitored by oscillometric and automatic equipment and heart rate was monitored continuously through lead II of electrocardiogram.
Results. Active cycle ergometry was able to promote hypotension after physical exercise due to a reduction in mean blood pressure ($p = 0.000$), with an improvement in vascular function observed by a reduction in PVR ($p = 0.000$) and an increase in VC ($p = 0.000$). Although the reduction in mean blood pressure in the passive cycle ergometry group was not significant, it was sufficient to promote an increase in VC ($p = 0.049$) and a reduction in PVR ($p = 0.008$) in this group.
Conclusions. A single session of 20 minutes physical exercise with passive and active cycle ergometry of the lower limbs was sufficient to promote hemodynamic changes in normotensive individuals.
Key words: physical exercise, cycloergometry, vascular resistance, vascular conductance, blood pressure

Introduction

Depending the physical exercise performed, we will have different metabolic responses and hemodynamic changes. Thus, post-exercise hypotension (PEH) has been observed after performing an aerobic exercise session of different types, such as walking [1], running [2], lower limb [3] and upper limb ergometer [4].

However, there are few studies that sought to directly compare the effect of different types of aerobic exercise on the behavior of PEH. Lizardo et al. [4], compared the responses of 30 minutes of physical exercise in an ergometer of lower and upper limbs in borderline hypertensive individuals, concluded that the muscle mass involved in the exercise does not directly affect the magnitude of the PEH, but they can lead to the duration of the response, with greater hypotension after physical exercise for lower limbs [4].

Although, few studies indicate that lower limb cycle ergometry, both active and passive, has been used as an adjunct in the control of the hemodynamic and biochemical functions of the human body, being the passive mode used mainly in patients intubated in intensive care units [5, 6]. Besides the greatest results from the use of the passive cycle ergometer are related to arthrokinematics, due to joint mobilization, positively significant changes in the variables of systolic blood pressure (SBP), mean blood pressure (MBP) and heart rate (HR) in critically ill patients were observed and justified by the greater activation of the cardiovascular system of individuals submitted to exercise, considering the resulted physiological changes [7].

Knowing some of the beneficial effects of an active and passive cycle ergometric session on cardiovascular function, the present study aims to clarify the hemodynamic changes in peripheral blood flow, conductance and vascular resistance in healthy individuals undergoing passive and active lower limb cycle ergometry.

Subjects and methods

This is a prospective, controlled, randomized study with crossover design. Using the website www.randomizer.org volunteers were randomly allocated: control group, they did only the evaluation process; passive cycle ergometer group (Flex Motor with sensor; Cajumoro; Bragança Paulista; São Paulo, Brazil) and active cycle ergometer group (WCT Fitness 608; Porto Alegre, Rio Grande do Sul; Brazil), with a minimum interval of 48 hours to participate in one of the groups. The randomization was to choose the order of administration of treatments.

The study was approved by the Research Ethics Committee of University Hospital Lauro Wanderley, as an integral part of the project under protocol number 2.656.106 and Clinical Registry (RBR-89QMHC). All participants were previously informed about the procedures and were asked to sign the Free and Informed Consent Form in accordance with resolution 466/12 of the National Health Council and Helsinki declaration.

The study was done at Federal University of Paraíba – UFPB, the Health Sciences Center and the Department of Physiotherapy. Young adult university students, of both sexes, aged between 18 and 35 years were included in the study. Adopted as eligibility criteria the absence of chronic degenerative diseases, not showing changes in the electrocardiogram (ECG) at rest and/or during exercise, not being a smoker or ex-smoker, not consuming more than 2 doses/day of alcohol, not using medications (cardiovascular, psychotropic and vasoactive agents) and body mass index (BMI) $\leq$ 30 kg/m^2. The exclusion criteria adopted was ingestion of sympathomimetics (coffee or stimulants) or alcohol in the last 24 hours preceding each evaluation and absence one of the experimental sessions.

Measurements and procedures clinical

The clinical measurement was performed with the volunteer in a sitting position, after 5 minutes of rest. Blood pressure was monitored by oscillometric and automatic equipment (Dixtal®, DX 2020, Manaus, Brazil). Heart rate was monitored continuously through lead II of ECG and peripheral oxygen saturation was monitored by pulse oximeter (Oximeter, São Paulo, Brazil).

Forearm blood flow

Forearm blood flow (FBF) was measured, pre- and post-intervention, by venous occlusion plethysmography technique. The nondominant arm was elevated above heart level to ensure adequate venous drainage. A silastic tube filled with mercury, connected to a low-pressure transducer, fixed around the forearm, 5 cm distal to the elbow joint and connected to the plethysmograph (Hokanson/EC6). Sphygmomanometer cuff was placed around the wrist and upper arm. At 10-second intervals, the upper cuff was inflated above venous pressure for a period of 10 seconds, totaling 3 cycles/waves per minute. The increase in tension in the silastic tube reflected the increase in volume in the forearm and, consequently, vasodilation. When FBF was measured, flow to the hand was excluded by inflating the wrist cuff to suprasystolic pressure (250 mmHg). The signal of the blood flow wave was acquired "on-line" in a computer through the program WINDAQ DI-200, at the frequency of 500Hz.

The vascular conductance (VC) was calculated by the formula:

$$VC = FBF / \text{Mean blood pressure (MBP)} \times 100.$$

For the peripheral vascular resistance (PVR), the calculation was:

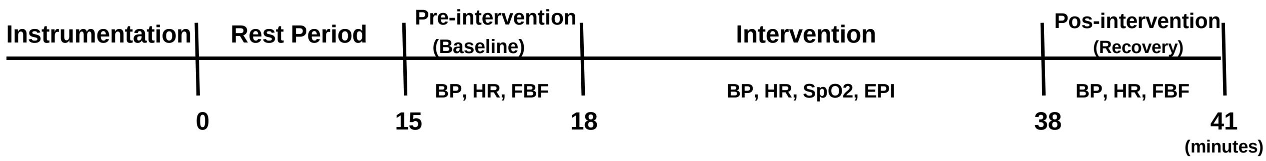
$$PVR = MBP / FBF \text{ (units)}.$$

Miscellaneous

Pre- and-post intervention blood pressure was monitored noninvasively by a finger photoplethysmography device (Finapres 2300, Ohmeda) on a beat-to-beat basis. HR was monitored continuously through lead II of ECG.

Intervention

In the physical exercise session of the active and passive lower limbs cycle ergometer protocol, the volunteers were placed in the supine position and then performed 20 minutes of aerobic exercise evaluated by the Borg's effort perception index (EPI) [8]. In passive cycle ergometry, the number of 30 revolutions per minute was adjusted and in active cycle the volunteer was instructed to maintain the same rotation speed of the ergometer at 30 revolutions per minute. The control session took place equally, but without the practice of any type of physical activity. The individuals remained in the supine position at rest for 20 min. Heart rate, arterial pressure, SpO_2 and EPI were recorded every 5 minutes during intervention.



BP – blood pressure, HR – heart rate, FBF – forearm blood flow,
SpO_2 – peripheral oxygen saturation; EPI = effort perception index
Figure 1. Timeline of experimental protocol (see experimental protocol for an explanation)

Experimental protocol

All of the studies were performed at ~14:00 AM, with the subjects lying in supine position in a quiet air-conditioned room (22°C to 24°C). ECG leads were placed on the chest, cuffs and silastic for FBF measurements were placed on the nondominant arm and finger photoplethysmography device were placed in medium finger on the dominant arm. After a 15-min rest period, baseline values for forearm blood flow, arterial pressure, and heart rate were recorded for 3 min. Than the volunteer performed 20 minutes of aerobic exercise on the lower limbs cycle ergometer or control session (remained in the supine position, at rest for 20 min). Immediately after the end of the intervention, hemodynamic measures were repeated (Figure 1).

Statistical analysis

The collected data were analyzed and treated statistically in quantitative form and presented as mean and standard deviation (SD), as appropriate. To test their assumption of normality of data, the Shapiro-Wilk test was applied. To evaluate and compare the measurements of hemodynamic parameters before, during and after the study protocol for the three-sessionstudied, the one-way ANOVA test was used and for repeated measures with Bonferroni post-hoc, performed according to the data distribution. using SPSS for Windows. All conclusions were taken at the 5% significance level, with a 95% confidence interval.

Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Research Ethics Committee of Lauro Wanderley University Hospital under CAAE number: 86468218.6.0000.5183 and was registered in the Brazilian Journal of Clinical Trials under the number RBR-89QMHC.

Informed consent

Informed consent has been obtained from all individuals included in this study.

Results

During the period from October 2018 to May 2019, 21 volunteers, young adults were recruited (Figure 2). Three were excluded from the study because their parents were hypertensive, 2 of them had ingested coffee or chocolate in the 24 hours prior to the evaluation, 1 had a BMI above the limit for the study, characterizing grade 1 obesity and 1 missed one of the evaluation steps without justification. Therefore, 14 volunteers concluded the study.

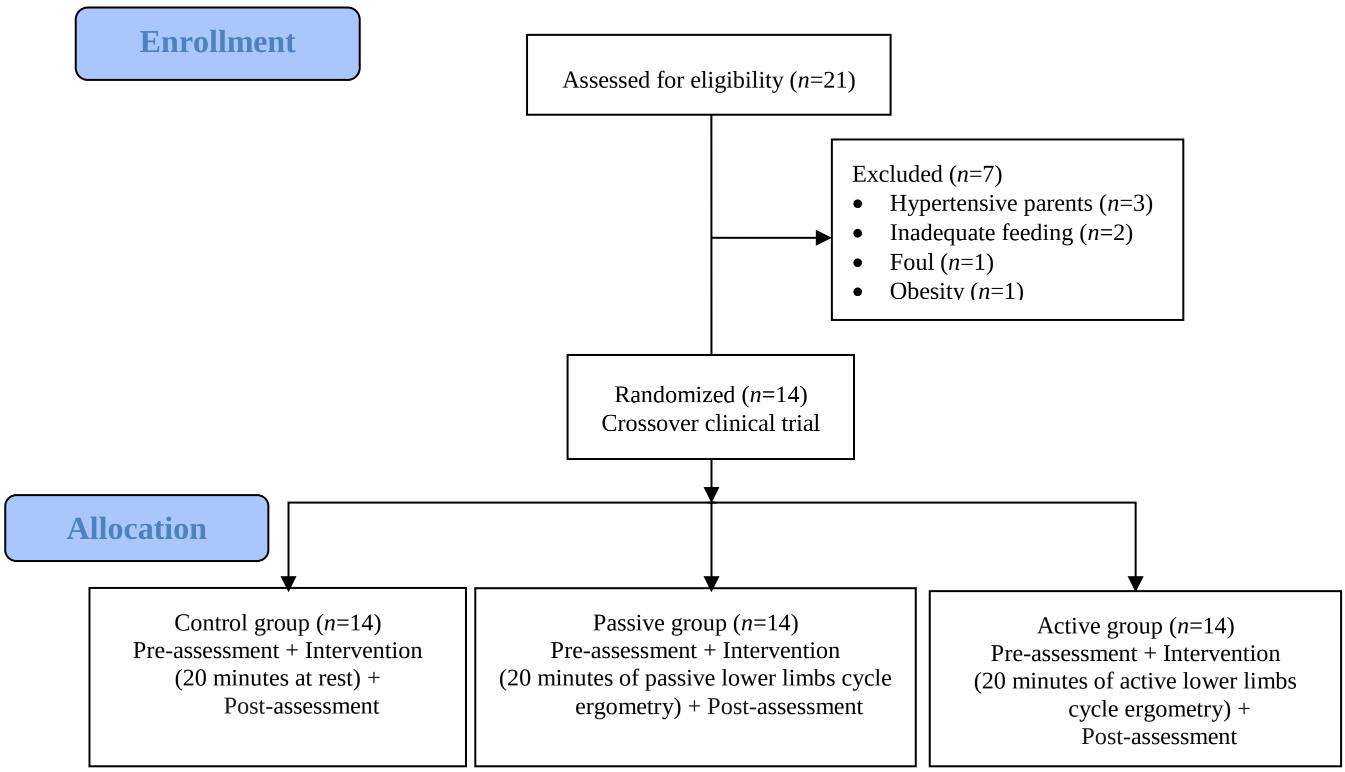


Figure 2. Study flowchart according to the CONSORT statement

Table 1 shows the demographic and hemodynamic characteristics of the 14 volunteers included in the study protocol. These volunteers had an average age of 22 years, with 6 male and 8 female all with a mean BMI of 23.6 kg/m^2. In this same table, the hemodynamic characteristics of the studied volunteers were presented, with mean and standard deviation of systolic blood pressure (SBP), diastolic blood pressure (DBP), HR and SpO_2.

Table1. Demographic and hemodynamic characteristics of the studied volunteers at baseline

	Volunteers (n = 14)
Demographic characteristics	
Age (years)	22 ± 0
Sex (male/female)	6/8
BMI (kg/m^2)	23.6 ± 3
Hemodynamic parameters	
SBP (mm Hg)	115.7 ± 8.5
DBP (mm Hg)	75 ± 9.4
HR (bpm)	69.9 ± 2.7
SpO_2 (%)	98.1 ± 1.1

BMI – body mass index, SBP – systolic blood pressure, DBP – diastolic blood pressure, HR – heart rate, SpO_2 – peripheral oxygen saturation

Table 2 shows the mean and SD of hemodynamic parameters and EPI during the 20 minutes of the study protocol (at moments 0, 5, 10, 15 and 20 minutes) for the three groups studied. With the description of the analyzes, we can observe a significant increase in MBP and EPI for the group of active cycle ergometry when compared with the other groups.

Table 2. Hemodynamic parameters and effort perceiving index during the different intervention

Groups	MP (mm Hg)	HR (bpm)	SpO_2 (%)	EPI
Control	82.8 ± 8.1	70.2 ± 6.2	98 ± 1	0 ± 0
Passive	82.6 ± 6.7	68.6 ± 6.8	98 ± 1	0 ± 0
Active	90.2 ± 7.8*	69.5 ± 2.8	97.7 ± 1.1	1.4 ± 1.1*

MBP – mean blood pressure, HR – heart rate, SpO_2 – peripheral oxygen saturation,
EPI – effort perception index. One-way ANOVA with Bonferroni's post-hoc
* difference in MBP for the active vs. control group and control and active vs. passive group (p = 0.046 and p = 0.034 respectively), the same for the EPI with $p < 0.001$.

Table 3 describes the mean and *SD* measures of the MBP, FBF, VC and PVR values in the moments before and immediately after the study protocol for the three groups studied. We can observe an increase in FBF (p = 0.041) and a reduction in PVR (p = 0.046) in the control group; an increase in VC (p = 0.049) and a reduction in PVR (p = 0.008) in the passive cycle ergometry group; and a decrease in MAP (p = 0.000), an increase in VC (p = 0.000) and a reduction in PVR (p = 0.000) in the active lower limb cycle ergometry group.

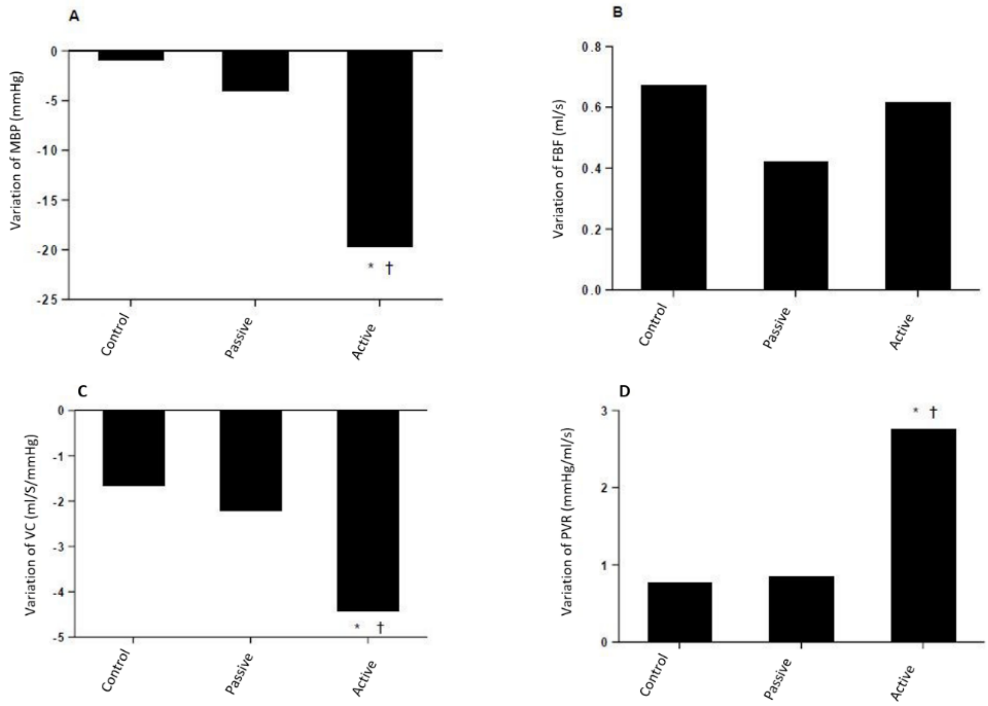
Table 3. Mean and standard deviation of the variables of blood pressure, forearm blood flow, vascular conductance and peripheral vascular resistance before and after the study protocol for the three groups studied

Variables	Control			Passive			Active		
	before	after	*p*-value	before	after	*p*-value	before	after	*p*-value
MBP (mmHg)	93 ± 5.9	92.2 ± 4.7	0.684	89 ± 4.7	85 ± 6.1	0.064	92.5 ± 6.6	72.8 ± 6.4	0.000*
FBF (ml/min/100ml)	6.2 ± 0.7	6.9 ± 0.7	0.041*	5.8 ± 1.2	6.2 ± 0.4	0.192	6.3 ± 1	6.9 ± 0.7	0.060
VC (Units)	6.7 ± 0.9	7.5 ± 0.8	0.079	6.5 ± 1.4	7.3 ± 0.7	0.049*	6.8 ± 1.3	9.6 ± 1.4	0.000*
PVR (Units)	15 ± 2.3	13.4 ± 1.4	0.046*	15.8 ± 3	13.6 ± 1.3	0.008*	15 ± 2.9	10 ± 1.6	0.000*

MBP – mean blood pressure, FBF – forearm blood flow, VC – vascular conductance,
PVR – peripheral vascular resistance

ANOVA for repeated measures with Bonferroni post-hoc
* Intra-group difference before and after the intervention

Figure 3 shows the difference between the values before and after the study protocol, presented as delta value, for the means of MBP, FBF, VC and PVR between the control groups, passive and active cycle of lower limbs. We can observe a reduction in the MBP delta value (92.5 ± 6.6 to 72.8 ± 6.4, p = 0.000) in the active cycle ergometry group when compared to the passive cycle ergometry group and the control group. There was also an increase in the delta value of VC (6.8 ± 1.3 to 9.6 ± 1.4, p = 0.000) and a reduction in the delta value of PVR (15 ± 2.9 to 10 ± 1.6, p = 0.000) in the active cycle ergometry group compared to the group passive cycle ergometry and control group. We just did not observe any change in the FBF delta value when comparing the groups studied.



MBP – mean blood pressure, FBF – forearm blood flow, VC – vascular conductance,
PVR – peripheral vascular resistance
One-way ANOVA with Bonferroni's post-hoc test
* significant difference in the cycle ergometry active *vs.* control; † significant difference in the cycle ergometry active group *vs.* cycle ergometry passive group
Figure 3. Difference in the measurements of the delta value of MBP, FBF, VC and PVR between the studied groups

Discussion

The aerobic exercise session through active cycle ergometry in normotensive people promoted PEH, with an improvement in vascular function observed by an increase in VC and a decrease in local PVR. Although the non-significant reduction in blood pressure in the passive cycle ergometry group, it was sufficient to promote an increase in VC and a reduction in PVR in this group. PEH found in our study may have been influenced by hemodynamic factors such as vasodilation, humoral and neural, related by intensity, duration, type of exercise, clinical status, age group, ethnicity, gender and training status. This relaxation of the vessel wall favors a reduction in PVR and an improvement in VC.

The occurrence of the PEH phenomenon with the use of cycle ergometry was evident. PEH was found only in the use of active cycle ergometry, which is in agreement with the study by Endo et al. [9] who also observed PEH after 60 minutes of exercise with lower limb cycle ergometry [9]. It is important to highlight that the volunteers were normotensive and had no family history of hypertension and they also performed the exercise in the afternoon, as well as in the present study. Jones et al. [10] compared periods of the day and blood pressure responses after physical exercise and demonstrated in normotensive individuals the occurrence of PEH only in the afternoon [10]. Boutcher et al. [11] did not find PEH in normotensive patients, children of hypertensive parents, after 20 minutes of physical exercise on a cycle ergometer of lower limbs at 60% of VO_2max [11]. Perhaps these results are associated with the low intensity of load linked to this studied population.

In our study, the reduction in MBP with the use of passive cycle ergometry was not significant. Findings that corroborate the results of Freitas et al. [12], who, evaluating the effects of passive mobilization of legs on acute hemodynamic responses in patients on mechanical ventilation, also found no change in MBP [12]. These results can be explained by Coutinho et al. [13], who also evaluated the acute effect of passive cycle ergometry of lower limbs in critically ill patients and did not observe changes in HR and MBP, explained due to the small activity of hemodynamic activity in response to the lower recruitment of muscle activity in this type of exercise [13].

In our study, we could observe an increase in the FBF after the intervention only in the control group. As well, the groups of passive and active cycle ergometry had hypotensive responses after exercise associated with a significant increase in VC and a reduction in PVR observed in both therapies.

In a similar study to ours, Boutcher et al. [11] submitted normotensive individuals to a 20-minute session in lower limb cycle ergometry, with an intensity of 60% of VO_2max. After physical exercise, the peak blood flow in the forearm increased 22% and the PVR of the forearm decreased 17% when compared to pre-exercise values [11]. In this way, Koch et al. [14] observed that an exercise session in lower limb ergometry was able to increase the FBF and reduce the PVR in the active and non-active muscles [14]. Another study, carried out in hypertensive women, showed that a cycle ergometer session for 40 minutes decreased the PVR [15]. A possible mechanism is the shear stress that occurs during physical exercise in the arterial vessels. This mechanical stimulus performed by physical exercise induces the release of vasodilating factors by the vascular endothelium, triggering an endothelium-dependent vasodilator response, like nitric oxide, the hyperpolarizing factor derived from the endothelium [16], histamines [17] and endogenous opioids [9].

Our results show reduction in MBP and PVR and an increase in VC immediately after the use of active cycle ergometry compared to passive and control, when comparing the variation of hemodynamic measurements. The results can be related to a greater reduction in MBP after exercise found in this group, considering the greater cardiovascular stress compared to the other two studied groups, including reported in the volunteers' EPI. This finding associated with the reduction of sympathetic discharge presented a direct association with the reduction of PVR and with the remodeling of resistance vessels [18]. This response may have been caused by the influence of the chemoreceptors present in the muscles and which are sensitive to the accumulation of metabolites caused by physical exercise [19] or even to the dissipation of the heat produced [20].

We also found only in active cycle ergometry group the increase in MBP and EPI during the intervention period. Wielemborek-Musial et al. [21], using the ambulatory blood pressure measurement found an increase of 5 mmHg in the SBP during mean time of 12.7 hours, when compared to the resting value [21]. During this type of exercise there is an increase in cardiac output, redistribution in blood flow and an increase in circulatory perfusion to the muscles in activity. Tension levels rise during physical exercise predominantly static effort, having already been found, in young and healthy individuals, intra-arterial pressure levels above 400/250 mm Hg without damage to health [22–24].

Our study may favor a range of investigations of vascular changes with the use of passive and active cycle ergometers in patients with vascular disorders, critically ill patients or even elderly people who have some limitation to perform active exercise on a stationary bicycle, since, passive exercise with cycle ergometry was able to reduce PVR and increase VC.

Limitations

The main limitation of our study was the small size of the participants in the experiment.

Conclusions

These results indicate that an exercise session with passive and active lower limb cycle ergometry was sufficient to promote hemodynamic changes in normotensive individuals, such as the reduction of MBP in active cycle ergometry and a reduction in PVR and an increase in VC in active and passive cycle ergometry. It is possible to state that both forms of physical exercise were able to promote changes in hemodynamic parameters, being more significant in active cycle ergometry. Moreover, the hypothesis of variations in the protocols with passive and active cycle ergometry opens to this treatment as a protagonist or adjuvant to physical therapy interventions in elderly people with disabilities, critically ill patients and patients with vascular disorders.

Disclosure statement
No author has any financial interest or received any financial benefit from this research.

Conflict of interest
The authors declare no conflict of interest.

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