European Journal of Applied Physiology (2019) 119:1235–1243
https://doi.org/10.1007/s00421-019-04114-9

ORIGINAL ARTICLE

High-intensity interval exercise promotes post-exercise hypotension of greater magnitude compared to moderate-intensity continuous exercise

Flávia C. Pimenta[1] · Fábio Tanil Montrezol[1] · Victor Zuniga Dourado[2] · Luís Fernando Marcelino da Silva[1] · Gabriela Alves Borba[1] · Wesley de Oliveira Vieira[2] · Alessandra Medeiros[1]

Received: 15 August 2018 / Accepted: 26 February 2019 / Published online: 8 March 2019

Abstract

Purpose Physical exercise is associated with reduced blood pressure (BP). Moderate-intensity continuous exercise (MCE) promotes post-exercise hypotension (PEH), which is highly recommended to hypertensive patients. However, recent studies with high-intensity interval exercise (HIIE) have shown significant results in cardiovascular disease. Thus, this study aimed to analyze PEH in hypertensive subjects submitted to HIIE and compare it to post MCE hypotension.

Methods 20 hypertensive adults (51 ± 8 years), treated with antihypertensive medications, were submitted to two different exercise protocols and a control session. The MCE was performed at 60–70% of VO_2 reserve, while HIIE was composed of five bouts of 3 min at 85–95% VO_2 reserve with 2 min at 50% of VO_2 reserve. The following variables were evaluated during exercise, pre- and post-session: clinical BP, heart rate (HR), double product, perception of effort, body mass, height and body mass index.

Results Systolic BP decreased after exercise in both sessions, showing greater decrease after HIIE (-7 ± 10 and -11 ± 12 mmHg, after MCE and HIIE, respectively, $p \leq 0.01$). Diastolic BP also decreased after both sessions, but there were no significant differences between the two sessions (-4 ± 8 and -7 ± 8 mmHg, after MCE and HIIE, respectively).

Conclusion Both exercise sessions produced PEH, but HIIE generated a greater magnitude of hypotension. The HIIE protocol performed in this study caused a greater cardiovascular stress during exercise; however, it was safe for the studied population and efficient for reducing BP after exercise.

Keywords Hypertension · Post-exercise hypotension · Aerobic exercise · Moderate-intensity continuous exercise · High-intensity interval exercise

Abbreviations

ANOVA	Analysis of variance
BMI	Body mass index
BP	Blood pressure
CVD	Cardiovascular disease
DBP	Diastolic blood pressure
DP	Double product
EPIMOV	Epidemiology and human movement
HIIE	High-intensity interval exercise
HR	Heart rate
MAP	Mean arterial pressure
MCE	Moderated-intensity continuous exercise
PHE	Post-exercise hypotension
PSE	Perception-subjective effort
SBP	Systolic blood pressure
SD	Standard deviation
SEM	Standard error of the mean
VO_{2peak}	Maximal oxygen uptake

Communicated by Massimo Pagani.

✉ Alessandra Medeiros
a.medeiros@unifesp.br

[1] Department of Biosciences, Federal University of São Paulo, Rua Silva Jardim, 136, Santos, SP 11015-020, Brazil

[2] Department of Human Movement Sciences, Federal University of São Paulo, Rua Silva Jardim, 136, Santos 11015-020, Brazil

Introduction

Hypertension is one of the principal risk factors for cardiovascular disease (CVD). Approximately 45% of heart disease deaths and 51% of deaths due strokes can be attributed to hypertension (WHO 2013). Thereby, its treatment aims to minimize cardiovascular morbidity and mortality, in addition to reduced blood pressure (BP) and maintain it at controlled levels (Kannel 1996).

It is essential for hypertensive patients to adopt lifestyle modification strategies in association with drug treatment. Thus, physical exercise is an important tool for reducing BP in hypertensive individuals, since a single session of acute exercise can cause a sustained reduction in BP compared to pre-exercise values. This phenomenon has been called post-exercise hypotension (PEH) and it was observed in normotensive and more sharply in hypertensive subjects (Halliwill et al. 2013; Kenney and Seals 1993; Hagberg et al. 1987; Headley et al. 1996; MacDonald 2002; Pescatello et al. 1991). Pescatello et al. (2015) define the aerobic PEH as a reduction in BP of 5–7 mmHg in hypertensive individuals. In fact, some studies have shown BP reduction after moderated-intensity continuous exercise (MCE) and such reduction has a prolonged effect, presenting reductions up to 24 h after exercise (MacDonald et al. 2001; Pescatello et al. 2004; Quinn 2000; Taylor-Tolbert et al. 2000; Wallace et al. 1999).

Prescription of aerobic exercise is an important factor for reducing cardiovascular diseases and mortality (Wen and Wang 2017), and its prescription is underpinned in the fact that this type of exercise is a gold standard method to increase cardiorespiratory fitness, and several studies have shown that cardiorespiratory fitness is a hallmark of risk mortality independent of age (Harber et al. 2017; Laukkanen et al. 2016). Beyond that point, aerobic exercise causes several adaptations in the human body. Some of these beneficial adaptations are cardiac structural changes, better balance in autonomic nervous system and better endothelial function in the arteries (Wen and Wang 2017).

Thus, based on broad scientific literature about the beneficial effects of MCE for hypertensive, this modality of exercise is highly recommended (James et al. 2014; Khan et al. 2009; Pescatello et al. 2004). However, new studies on cardiovascular disease and exercise training have been emerging and high-intensity interval exercise (HIIE) became theme of research. Meta analyzes and summary of clinical studies comparing high-intensity and moderate-intensity exercise training programs have already shown that this type of training is superior to continuous training, in several indicative of cardiovascular health and gains in functional capacity (Kemi and Wisløff 2010; Milanović et al. 2015). However, regardless of the number of articles that have evaluated the responses after periods of training (i.e., chronic effects of exercise), it is still not clear in the literature whether the chronic response is an adaptation itself or a sum of responses from single bouts of exercise in any type of exercise.

However, to our knowledge, studies about HIIE are scarce when it comes to PEH, and due to lack of studies regarding their benefits and risks, this exercise modality is not yet included in the emerging recommendations to hypertensive patients (Pescatello et al. 2015; Piepoli et al. 2016). Therefore, our research seeks to contribute in this question, thus aiming to verify if the HIIE promotes a PEH similar to the MCE, and to compare the behavior of the BP after both modes of exercise.

Methods

Subjects and ethical aspects

The volunteers of the study were part of a convenience sample. They were recruited from the database of a research project entitled "The Epidemiology and Human Movement Study—The EPIMOV Study" approved by the Ethics Committee of the Federal University of São Paulo, SP, Brazil (#186796).

All subjects who fulfilled the inclusion criteria were invited to participate in the study. The inclusion criteria were: (1) hypertension, (2) age between 30 and 59 years old, (3) use of antihypertensive medication of any class, (4) cardiopulmonary test performed in the last 6 months as an evaluation in the EPIMOV study. The exclusion criteria were: (1) individuals with uncontrolled hypertension, (2) blood pressure $\geq$ 160/106 mmHg before exercise session (Medicine 2013), (3) not return to the next protocol, (4) subject with osteoarticular limitations, (5) other cardiovascular diseases, such as heart disease, arrhythmias, ischemia, heart failure, (6) individuals participating in a regular exercise program or training, and/or (7) individuals unable to perform HIIE protocol.

All volunteers were asked to maintain their daily routine as usual including the pharmacological treatment even for the VO_2 test.

All volunteers included in the study signed an informed consent form to participate in the study. They were clarified about the research before entering in the study, which was approved by the Ethics Committee of the Federal University of São Paulo, SP, Brazil (#0119/2016). The protocols of the study followed the ethical principles of Helsinki of 1975 (Carlson et al. 2004).

Study design

The volunteers underwent cardiopulmonary evaluation in treadmill before initiating training protocols. From this evaluation, the exercise intensity of each training protocol was prescribed for each volunteer. The highest value of the maximal oxygen uptake reached in the test was considered the VO_{2peak} and used to calculate VO_2 reserve, in which a percentage of this value was stipulated as the intensity of training for each volunteer. The intensity of the exercise corresponded to the speed associated to a percentage of VO_2 reserve.

All volunteers were submitted to three intervention protocols: control, MCE and HIIE. The protocols were performed for 3 weeks, in the morning period, always at the same time for each volunteer and with 1-week interval between each protocol. They were performed in random order and the exercise protocols were isocaloric, with their energy expenditure assessed through the cardiopulmonary test.

Intervention protocols and measures

An anamnesis of the volunteer was firstly carried out, as well as weight and height evaluation. We measured height (m) using an anthropometer (Professional Sanny®) and body weight (kg) using a calibrated precision scale (Welmy® W200/5 model). Body mass index (BMI) was calculated as weight (kg) divided by height in meters squared (m^2).

To predict the relative intensity of the exercise session a VO_{2peak} test was conducted with all volunteers as follows: the VO_{2peak} test was performed in an automated treadmill (ATL, Inbrasport, Curitiba, Brasil). We used the ramp protocol with initial velocity set at 3 km/h and 0% of inclination. The incremental load was set according to study published by Hansen et al. (1984) and the protocol test was based on the study published by Wasserman and Whipp (1975). VO_2 was measured breath-by-breath through a gas analyzer Quark PFT (COSMED, Pavona Albano, Italy).

The control protocol was performed without exercise practice, with the volunteer remaining at rest for 60 min at the same place where exercise sessions were executed. The other two protocols were performed on the treadmill with different exercise intensities.

Exercise intensity of the two experimental sessions was prescribed using the velocity: VO_2 relationship from the VO_{2peak}. Both exercise sessions contained 3 min of heating at velocity related to the 50% of VO_2 reserve (velocity: VO_2 reserve) and 2 min of cool down at 40% of velocity: VO_2 reserve, where VO_2 reserve = $VO_{2peak} - VO_2$ rest. The MCE protocol was performed at intensity corresponding to 60–70% of velocity: VO_2 reserve totaling a session of 35 min, and the HIIE was composed of five bouts of 3 min at a speed corresponding to 85–95% of velocity: VO_2 reserve, with 2 min of active rest at a speed of 50–60% velocity: VO_2 reserve, totaling 30 min of exercise. To calculate the VO_2 of the session (VO_2 exercise), we used the formula: VO_2 exercise = VO_2 rest + (% intensity × VO_2 reserve). As aforementioned, the exercise sessions had a slight difference in duration (i.e., HIEE was 5 min lower than MCE), and this fact makes the sessions to be isocaloric.

Exercise intensity was controlled by a frequency meter (Polar® FT4, Kenpale—Finland) and by the perception-subjective effort (PSE) (Borg and Noble 1974). BP was monitored by auscultatory method (sphygmomanometer and stethoscope Premium, Wenzhou Kangju Medical Instruments Co. Ltda.—China), and double product (DP) variable was estimated by multiplying systolic BP by heart rate (HR). Measures of BP were made according to technical recommendations of the VII Brazilian Guidelines on Hypertension (Cardiologia 2016).

HR, BP, and DP were evaluated after 10 min of seated rest and corresponded to the moment of rest or pre-exercise. The resting auscultatory BP was measured three times, taken at intervals of 1 min. During exercise, HR, BP, DP, and PSE were evaluated on 6°, 11°, 16°, 21°, and 26° minute of exercise, these moments corresponded to final intense period of HIIE. Following the exercise, HR and BP were monitored every 10 min for 1 h.

At the end of the interventions, the volunteers were asked about which protocol of exercise they preferred to practice.

Statistical analyses

We employed the model of repeated measures analysis of variance (ANOVA two-way), using post-hoc Bonferroni when necessary, to compare the protocols used in this study and in all times in relation to the variables BP, HR, and DP. To analyze the data, we used software R (R Foundation for Statistical Computing, Vienna, Austria) (Team 2016). For all analyses, $p \leq 0.05$ was adopted as significance.

Data are shown as mean ± standard deviation (SD) in the tables and in the figures.

To evaluate hypotension 1 h after exercise, we used the net effect calculation that consists in the formula: net effect = (post-exercise − pre-exercise) − (post-control − pre-control). From theses analyses, we observed the behavior of the BP in the different exercise sessions in relation to the control protocol. In addition to analyzing the gross values of BP during exercise, we also performed the BP delta (Δ) analysis during exercise, calculated through the formula: ΔBP = (BP exercise − BP pre-exercise). The value of BP utilized during exercise was the highest value reached by volunteers.

Lastly, we used *t* test for DP peak and PSE.

Results

Baseline characteristics of the study population

Initially, 88 individuals met the inclusion criteria and were invited to participate in the study, but only 26 accepted to participate. However, 23% of them were excluded for reasons cited in the exclusion criteria. The sample thus consisted of 20 hypertensive individuals.

Of all volunteers, 75% were female and 15% were male. Baseline characteristics are presented in Table 1. The average age was 51 ± 8 and the body mass index (BMI) was 30 ± 6 kg/m^2, characterizing them as individuals with obesity class I. In addition, 45% of the subjects used medication for hypercholesterolemia. Regarding the basal BP during the 3 intervention days, the mean was considered normal according to classification of the Eighth Joint National Committee (James et al. 2014), that is, individuals had controlled hypertension, meeting the inclusion criteria. Medication treatments are shown in Table 1.

In Table 2 is the main information regarding cardiopulmonary test and the average speed of exercise prescription in intervention protocols. The mean VO_{2peak} reached by the volunteers was 24.3 ± 6 ml/min/kg, meaning that the study sample had a low functional capacity and, although the HIIE protocol is very intense, the mean speed of this protocol was 6.4 ± 0.7 km/h at an inclination of 6%. This speed was very well tolerated by volunteers.

Table 1 Baseline characteristics of the study patients

Clinical data	
Sex (M/W)	5/15
Age (years)	51 ± 8
Body mass (kg)	79 ± 20
Height (cm)	161 ± 0.11
BMI (kg/m^2)	30 ± 6
Basal BP (mmHg)—CS	125/81
Basal BP (mmHg)—MCE	128/83
Basal BP (mmHg)—HIIE	127/84
Treatment	%
ARB	50
ACE inhibitor	25
Beta-blocker	25
Diuretic	15
CCB	10
Hypoglicemic	15
Statin	25
Antiplatelet	10

The results are presented as mean ± standard derivation of the mean

M men, *W* women, *BMI* body mass index, *BP* blood pressure, *CS* control session, *MCE* moderate-intensity continuous exercise session, *HIIE* high-intensity interval exercise session, *ARB* angiotensin II receptor blockers, *ACE inhibitor* angiotensin-converting enzyme inhibitors, *CCB* calcium channel blocker

Hemodynamic determinants during exercise

BP and hemodynamic determinants during exercise are shown in Table 3. We evaluated the behavior of BP and HR during exercise to compare the two sessions of exercise and analyze if the levels of BP that increased during exercise were safe in the studied sample. In comparison with control values, both sessions showed significant differences, as expected. At the same time, exercise sessions showed differences between them: HIIE increased SBP more than MCE (+26 ± 17 and +47 ± 26 mmHg, during MCE and HIIE, respectively, $p \leq 0.001$).

During MCE, the maximum mean value of SBP was 152 ± 23 mmHg, and during HIIE, 174 ± 29 mmHg. Regarding DBP, no significant differences were found between the intervention sessions nor between the moments measured during exercise. The HR comportment during exercise was observed to characterize both sessions of exercise, mainly to observe if HIIE was indeed more intense.

The results are presented in Table 3. There were significant differences in the three interventions sessions at all times during exercise ($p \leq 0.001$). The HR reached mean values of 119 ± 11 bpm in MCE and 148 ± 19 bpm in HIIE. In addition, PSE scale was used to characterize the participant's subjective intensity in both types of exercise (Table 3). The exercise sessions presented significant differences regarding rating media in PSE scale ($p \leq 0.001$): the volunteers presented an average perception of intensity of 12 (somewhat hard) on the PES scale in MCE, while in HIIE the average of perceived exertion was 15 (hard) on the PES scale.

The double product peak values reached by volunteers in the two exercise sessions are also presented in Table 3. As expected, the two exercise sessions showed different patterns of behavior, where HIIE resulted in greater cardiac effort in comparison to MCE. However, the volunteers did not present symptoms of dyspnea, chest pain, or excessive fatigue in any of the exercise sessions, and therefore both sessions were considered safe for the hypertensive volunteers of this study.

At the end of the last exercise protocol, volunteers were asked about which of the two exercise protocols they preferred to practice, and 75% of them answered that they felt more motivated after practicing HIIE, while 25% preferred MCE.

Blood pressure after exercise protocols

Figure 1 shows the results of systolic blood pressure (SBP), diastolic blood pressure (DBP) and mean arterial pressure

Table 2 Data about cardiopulmonary exercise test and exercise sessions prescription

Variable	
VO_{2peak} (ml/min/kg)	24.3 ± 6
Speed and inclination associated to VO_{2peak} (km/h and %)	6.4 ± 0.8 and 7 ± 2
RQ maximum	1.11 ± 0.10
VE peak (l/min)	62 ± 20
Test duration (min)	9.5 ± 1.8
HR maximum (bpm)	156 ± 16
Speed and inclination associated to MCE (km/h and %)	5.3 ± 0.8 and 4 ± 1
Speed and inclination associated to HIIE in high intensity bout (km/h)	6.4 ± 0.7 and 6 ± 1
Speed and inclination associated to HIIE in active recuperation (km/h)	4.4 ± 0.9 and 3 ± 1

The results are presented as mean ± standard derivation of the mean

VO_{2peak} maximum oxygen uptake, *RQ* respiratory quotient, *VE peak* maximum ventilation, *HR* heart hate, *MCE* moderate-intensity continuous exercise, *HIIE* high-intensity interval exercise

Table 3 Hemodynamic determinants and perception-subjective effort during moderate-intensity continuous exercise and high-intensity interval exercise sessions

Variable	Baseline	6° min	16° min	26° min
Blood pressure during				
SBP (mmHg)—MCE	128 ± 15	150 ± 19	154 ± 20	151 ± 18
SBP (mmHg)—HIIE	127 ± 09	172 ± 34*	171 ± 28*	166 ± 32*
DBP (mmHg)—MCE	83 ± 10	83 ± 12	80 ± 11	77 ± 10
DBP (mmHg)—HIIE	83 ± 08	86 ± 12	80 ± 09	81 ± 09
MAP (mmHg)—MCE	98 ± 11	105 ± 11	105 ± 11	102 ± 10
MAP (mmHg)—HIIE	98 ± 08	115 ± 16*	111 ± 13	109 ± 14*
Heart hate during				
MCE (bpm)	79 ± 11	114 ± 10	119 ± 11	118 ± 12
HIIE (bpm)	80 ± 11	140 ± 18*	145 ± 18*	148 ± 19*
Double product during	Baseline			Peak
MCE (mmHg bpm)	10,117 ± 2189			18,841 ± 3817
HIIE (mmHg bpm)	10,176 ± 2030			26,792 ± 5837*
PSE				26° min
MCE				12 ± 3
HIIE				15 ± 3*

The results are presented as mean ± standard derivation of the mean

SBP systolic blood pressure, *DBP* diastolic blood pressure, *MAP* mean arterial pressure, *MCE* moderate-intensity continuous exercise, *HIIE* high-intensity interval exercise, *PSE* perception-subjective effort

*< 0.05 versus MCE

(MAP) 1 h after the physical exercise sessions and during the control session (Fig. 1d). These measures were clinically evaluated, such as the baseline measurement, with 10 min of interval between them. We used the net effect to calculate the hypotensive effect of the exercise.

SBP decreased 60 min after exercise in both sessions of exercise, showing greater decrease after HIIE protocol in all moments after exercise (− 7 ± 10 and − 11 ± 12 mmHg, after MCE and HIIE, respectively, $p \leq 0.01$). DBP also decreased after both exercise sessions; however, there were no significant differences between the two exercise sessions (− 4 ± 8 and − 7 ± 8 mmHg, after MCE and HIIE, respectively, $p = 0.141$). MAP significantly decreased after both exercise sessions, and HIIE caused greater MAP reductions in all moments after exercise (− 5 ± 8 and − 9 ± 8 mmHg, after MCE and HIIE, respectively, $p \leq 0.001$).

Discussion

Both types of physical exercise (MCE and HIIE) produced HPE in hypertensive individuals; however, when we quantify the magnitude of BP reduction 1 h after exercise sessions, we found a HPE of greater magnitude after HIIE for

SBP and MAP when compared to MCE. Note that this result was not consequence of a higher expenditure, since even with a slight difference in the duration between sessions (i.e., HIEE was 5 min lower than MCE), both were isocaloric.

The intensity used during HIIE raised some issues concerning the safety of this type of exercise, nevertheless, recently published articles endorse the participation in vigorous exercise protocols even for hypertensive patients. Among these publications we highlight a publication of a Work Group (Eckel et al. 2014) and the publication from American Heart Association (Brook et al. 2013).

In a recent research conducted by Crozier et al. (2018), the authors discuss that among individuals with coronary artery disease, myocardial infarction, and heart failure; there have been only two nonfatal cardiac arrests in more than 46,000 h of HIIE during cardiac rehabilitation, with occurrences similar to MCE. They suggest that an exercise testing with electrocardiography is recommended prior to initiating cardiovascular exercise.

Many studies have observed a decrease on BP after an acute session of moderate-intensity aerobic exercise (Forjaz et al. 2004; Kenney and Seals 1993; Taylor-Tolbert et al. 2000; Wallace et al. 1999). However, studies about hypotension after HIIE are scarce in the literature. Our results can be different from those found in the study of Lacombe et al. (2011), since the authors evaluated hypotension 1 h after exercise in a cycle-ergometer in pre-hypertensive elderly patients and our protocol was conducted with middle-aged participants and the exercise session was performed in a treadmill. Lacombe et al. demonstrated that both HIIE and MCE produced the same magnitude of SBP reduction, in the other hand, in our study HIIE showed a more pronounced reduction in SBP compared to MCE.

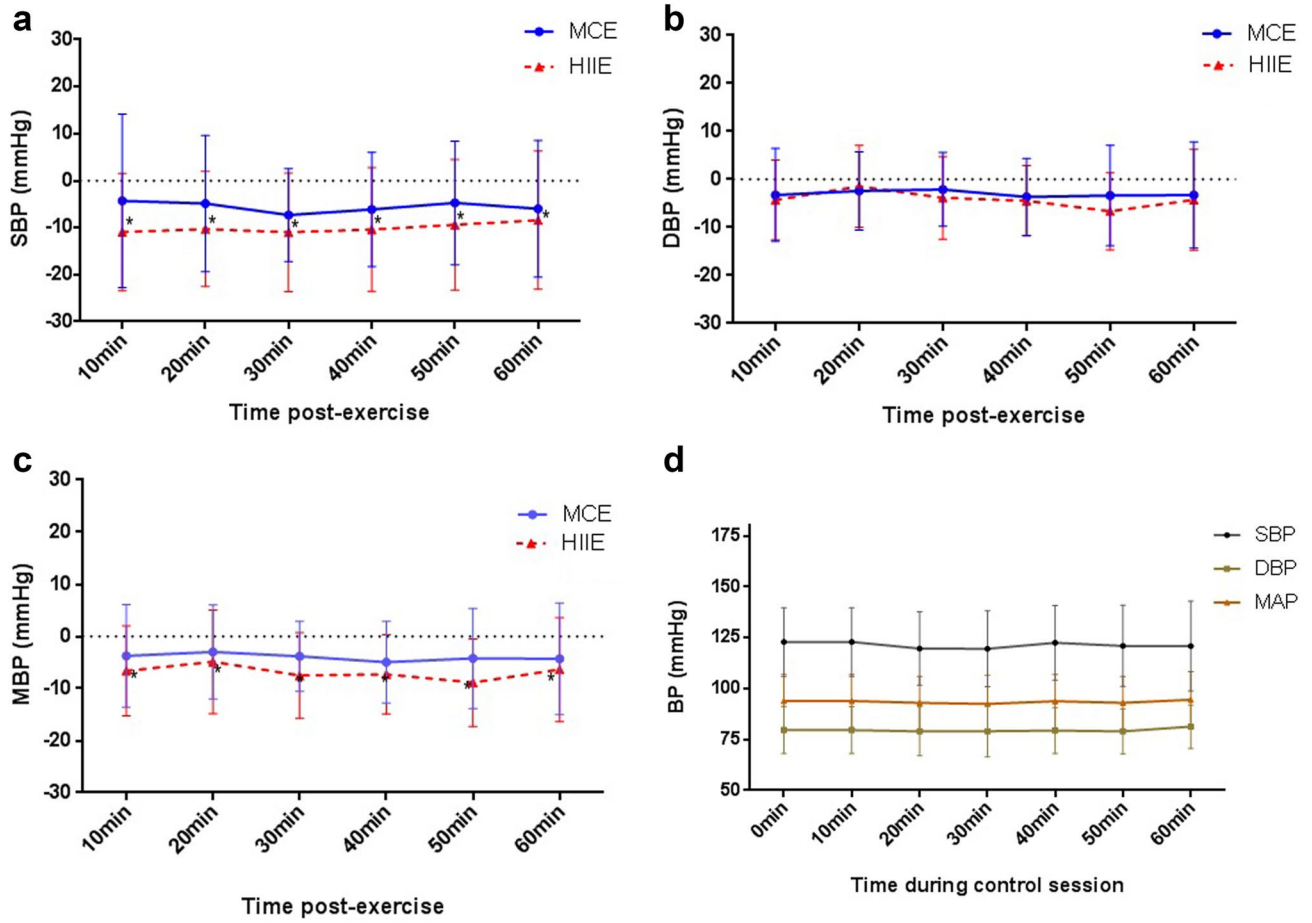

Fig. 1 Data of systolic (**a**), diastolic (**b**) and mean (**c**) blood pressure after moderate-intensity continuous exercise and high-intensity interval exercise sessions and during control session (**d**). The data were analyzed based on blood pressure net effect. Net effect = (post-exercise − pre-exercise) − (post-control − pre-control). The results are presented as mean ± standard deviation. *< 0.05 versus MCE. *MCE* moderate-intensity continuous exercise, *HIIE* high-intensity interval exercise, *SBP* systolic blood pressure, *DBP* diastolic blood pressure, *MAP* mean arterial pressure

Cunha et al. (2006) carried out a study comparing the HPE of moderate intensity and of varied intensities. They concluded that both sessions resulted in a similar hypotension for SBP; however, only the continuous exercise promoted a relevant hypotension for DBP. We highlight that the interval exercise protocol used in this referred study is not characteristic of an intense protocol, since it consisted of intervals of 1 min to 75% of HR reserve and 2 min to 55% of HR reserve. Then, we believe that the effects of HIIE depend on the intensity used in the protocol. In fact, it has been suggested that high-intensity exercise protocols promote a more effective stimulus for enhancing VO_{2max}, when the intensity is greater than 90% of VO_{2max} (Buchheit and Laursen 2013).

Although a common definition does not exist, Gibala and McGee (2008) characterize HIIE as repeated sessions of relatively brief intermittent exercise in effort intensity "all out" or close to VO_{2peak} (i.e., 90% of VO_{2peak}); bouts of high-intensity may last from few seconds to several minutes, with the bouts of high-intensity separated by few minutes of rest or low-intensity exercise (Gibala and McGee 2008). The common protocols used on cardiovascular risk patients are generally long (Fu et al. 2013; Moholdt et al. 2012; Molmen-Hansen et al. 2012; Rocco et al. 2012).

Molmen-Hansen et al. (2012) conducted a study with hypertensive patients and the protocol of HIIE was 4 × 4 min at 90% of HR reserve and 4 × 3 min at 70% of HR reserve. Many researches on individuals with cardiovascular diseases used this protocol as a basis for prescribing HIIE; in our study, we adapted this protocol for our population.

The study conducted by Molmen-Hansen et al. (2012) aimed to analyze the effect of aerobic interval training on BP and myocardial function in hypertensive patients, and they found that 12 weeks of high-intensity interval training was able to reduce BP of hypertensive patients more than moderate continuous training.

Although, we can see that there are studies with hypertensive individuals and high-intensity exercise showing positive effects; however, in a prescription update integrating existing recommendations with emerging researches about exercise for hypertension treatment, the authors recommend only MCE and suggest that recommendations of vigorous-intensity exercises may be included in the future when we had better comprehension about the benefits and risks of vigorous-intensity exercises for this population (Pescatello et al. 2015). European Guidelines on cardiovascular disease prevention in clinical practice also state that HIIE cannot be highly recommended until more efficacy and safety data are available (Piepoli et al. 2016).

Thereby, our study is further evidence that HIIE is an efficient alternative for hypertensive individuals as a non-pharmacological strategy for reducing BP. We observed a SBP reduction of up to 11 mmHg and DBP reduction of up to 7 mmHg after HIIE. This result can be considered clinically relevant, since an antihypertensive drug has the potential to reduce SBP up to 9.1 mmHg (when it is about 154 mmHg) and DBP up to 5.5 mmHg (when it is about 97 mmHg) (Law et al. 2009).

In addition, considering that 5 mmHg decrease in BP levels can reduce the risk of stroke in up to 40% and the risk of acute myocardial infarction in up to 15% in hypertensive (Kelley 1997), our results can be considered important.

Angadi et al. (2015) evaluated BP post-HIIE and compared it with a MCE protocol and a control session in normotensive individuals. HIIE protocol was 4 × 4 min at 90–95% HR_{max} and 3 min on active recovery. They observed that both HIIE and MCE promoted PEH, whose peak reached 1 h after exercise. However, HIIE promoted greater SBP reductions when compared to the other exercise protocols studied, also promoting a longer period of PEH. Therefore, these results resemble those found in our study, in which we found a greater magnitude of SBP reduction after HIIE; a key point of this study is that the PEH found after HIIE was seen in hypertensive individuals.

HIIE can be considered an effective exercise stimulus to improve aerobic metabolism and functional fitness in a short period of time (Gibala 2007). Six short high-intensity interval sessions with less than 20 min produce an increase in the maximal activity of mitochondrial enzymes in skeletal muscle, oxidative muscle capacity and peak oxygen uptake similar to a conventional training of moderate intensity with long duration. However, these gains are observed at 67% less time expended than moderate-intensity training (Gibala et al. 2012).

Regarding cardiovascular adaptations, HIIE has been shown to be more efficient than MCE in some cardiovascular health indicators. Some studies have indicated that HIIE promotes a greater increase in cardiorespiratory fitness due to increase in VO_{2max} when compared to MCE (Burgomaster et al. 2008; Helgerud et al. 2007; Moholdt et al. 2012; Tjønna et al. 2008). This marker is related to cardiovascular risk, since low VO_2 rate is correlated with mortality from cardiovascular diseases (Blair et al. 1996).

As studies have proved that HIIE is very effective for health gains of health individuals and individuals affected by cardiovascular diseases, it became a new option for the hypertensive patient. In our study, 75% of the volunteers felt more motivated after practicing HIIE, while only 25% preferred MCE. These results corroborate with other studies that also affirm that participants prefer to practice HIIE because they find it more motivating and challenging than moderate continuous training (Kemi and Wisløff 2010). In fact, Jung et al. evaluate the tolerability and the affective response after HIIE, MCE and continuous exercise of vigorous intensity; they observed that more than 50% of volunteers reported preferring HIIE as opposed to MCE and continuous vigorous-intensity exercise, suggesting that HIIE

is a viable alternative to the traditionally prescribed continuous modalities to promote self-efficacy and exercise pleasure in inactive individuals (Jung et al. 2014).

In addition to being efficient for PEH, HIIE was safe for hypertensive patients evaluated in this study, presenting no risk. SBP and DP had a normal elevation during both exercise modalities, showing greater increase in HIIE when compared to MCE, but this behavior was expected, since this type of exercise promotes higher demands of O_2.

Therefore, our study showed that HIIE is an efficient exercise option to produce PEH for hypertensive subjects, PEH being more pronounced when compared to MCE. The magnitude and duration of PEH may provide essential information on the efficacy of a training program to BP control (Liu et al. 2012). Finding an exercise that causes the greater answer of PEH is important to individualize the training prescription and provide better results for each hypertensive patient.

Study limitations

We consider that the sample could be larger. Besides that, the number of women was greater than men, so we believe it would be better to homogenize the sample. However, it is important to highlight that all subjects performed all sessions, which contributed to decrease the interference in the results.

Finally, we asked the volunteers about the preference of each modality of exercise, but we did not do any motivation questionnaire, impairing inferring about motivation and comparison of both exercise protocols.

Conclusion

The HIIE protocol performed in this study produced a PEH clinically and physiologically relevant in sedentary hypertensive individuals. One hour after exercise, we verified that both HIIE and MCE caused significant reductions in BP; however, the HIIE generated a greater magnitude of reduction of SBP and MAP than MCE. Thus, HIIE proved to be an effective and safe modality of exercise for hypertensive individuals, since no intercurrence occurred during the study, as well as, hemodynamic parameters during exercise sessions were in normality and safety standard. Therefore, HIIE can be considered as one more exercise option for hypertensive subjects, but it is important to emphasize that supervision of a physical education professional is important.

Acknowledgements This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior—Brasil (CAPES)—Finance Code 001.

Author contributions AM, FCP and VZD conceived and designed research. FCP, LFMS, GAB and WOV conducted experiments. AM, FCP and FTM analyzed data. AM, FCP, FTM and VZD wrote the manuscript. All authors read and approved the manuscript.

Compliance with ethical standards

Conflict of interest The authors report no relationships that could be construed as a conflict of interest.

References

Angadi SS, Bhammar DM, Gaesser GA (2015) Postexercise hypotension after continuous, aerobic interval, and sprint interval exercise. J Strength Cond Res 29:2888–2893

Blair SN, Kampert JB, Kohl HW, Barlow CE, Macera CA, Paffenbarger RS, Gibbons LW (1996) Influences of cardiorespiratory fitness and other precursors on cardiovascular disease and all-cause mortality in men and women. JAMA 276:205–210

Borg GA, Noble BJ (1974) Perceived exertion. Exerc Sport Sci Rev 2:131–154

Brook RD et al (2013) Beyond medications and diet: alternative approaches to lowering blood pressure: a scientific statement from the American heart association. Hypertension 61:1360–1383. https://doi.org/10.1161/HYP.0b013e318293645f

Buchheit M, Laursen PB (2013) High-intensity interval training solutions to the programming puzzle. Sports Med 43:313–338

Burgomaster KA, Howarth KR, Phillips SM, Rakobowchuk M, MacDonald MJ, McGee SL, Gibala MJ (2008) Similar metabolic adaptations during exercise after low volume sprint interval and traditional endurance training in humans. J Physiol 586:151–160

Cardiologia. SBd (2016) 7° Diretriz Brasileira de Hipertensão Arterial

Carlson RV, Boyd KM, Webb DJ (2004) The revision of the Declaration of Helsinki: past, present and future. Br J Clin Pharmacol 57:695–713

Crozier J et al (2018) High-intensity interval training after stroke: an opportunity to promote functional recovery. Cardiovasc Health Neuroplast Neurorehabil Neural Repair 32:543–556. https://doi.org/10.1177/1545968318766663

Cunha GA, Rios ACS, Moreno JR, Braga PL, Campbell CSG, Simões HG, Denadai MLDR (2006) Hipotensão pós-exercício em hipertensos submetidos ao exercício aeróbio de intensidades variadas e exercício de intensidade constante. Revista Brasileira de Medicina do Esporte 12:313–317

Eckel RH et al (2014) 2013 AHA/ACC guideline on lifestyle management to reduce cardiovascular risk: a report of the American College of Cardiology/American Heart Association Task Force on. Pract Guidel Circ 129:S76–S99. https://doi.org/10.1161/01.cir.0000437740.48606.d1

Forjaz CL, Cardoso CG Jr, Rezk CC, Santaella DF, Tinucci T (2004) Postexercise hypotension and hemodynamics: the role of exercise intensity. J Sports Med Phys Fit 44:54–62

Fu T-c et al (2013) Aerobic interval training improves oxygen uptake efficiency by enhancing cerebral and muscular hemodynamics in patients with heart failure. Int J Cardiol 167:41–50

Gibala MJ (2007) High-intensity interval training: a time-efficient strategy for health promotion? Curr Sports Med Rep 6:211–213

Gibala MJ, McGee SL (2008) Metabolic adaptations to short-term high-intensity interval training: a little pain for a lot of gain? Exerc Sport Sci Rev 36:58–63

Gibala MJ, Little JP, MacDonald MJ, Hawley JA (2012) Physiological adaptations to low-volume, high-intensity interval training in health and disease. J Physiol 590:1077–1084

Hagberg JM, Montain SJ, Martin Wr (1987) Blood pressure and hemodynamic responses after exercise in older hypertensives. J Appl Physiol 63:270–276

Halliwill JR, Buck TM, Lacewell AN, Romero SA (2013) Postexercise hypotension and sustained postexercise vasodilatation: what happens after we exercise? Exp Physiol 98:7–18

Hansen JE, Sue DY, Wasserman K (1984) Predicted values for clinical exercise testing. Am Rev Respir Dis 129:S49–S55. https://doi.org/10.1164/arrd.1984.129.2P2.S49

Harber MP, Kaminsky LA, Arena R, Blair SN, Franklin BA, Myers J, Ross R (2017) Impact of cardiorespiratory fitness on all-cause and disease-specific mortality: advances since 2009. Prog Cardiovasc Dis 60:11–20 https://doi.org/10.1016/j.pcad.2017.03.001

Headley SA, Claiborne JM, Lottes CR, Korba CG (1996) Hemodynamic responses associated with post-exercise hypotension in normotensive black males. Ethn Dis 6(1–2):190–201

Helgerud J et al (2007) Aerobic high-intensity intervals improve VO_{2max} more than moderate training. Med Sci Sports Exerc 39:665–671

James PA et al (2014) 2014 evidence-based guideline for the management of high blood pressure in adults: report from the panel members appointed to the Eighth Joint National Committee (JNC 8). JAMA 311:507–520

Jung ME, Bourne JE, Little JP (2014) Where does HIT fit? An examination of the affective response to high-intensity intervals in comparison to continuous moderate-and continuous vigorous-intensity exercise in the exercise intensity-affect continuum. PLoS One 9:e114541

Kannel WB (1996) Blood pressure as a cardiovascular risk factor: prevention and treatment. JAMA 275:1571–1576

Kelley G (1997) Dynamic resistance exercise and resting blood pressure in adults: a meta-analysis. J Appl Physiol 82:1559–1565

Kemi OJ, Wisløff U (2010) High-Intensity aerobic exercise training improves the heart in health and disease. J Cardiopulm Rehabil Prev 30:2–11

Kenney MJ, Seals DR (1993) Postexercise hypotension. Key features, mechanisms and clinical significance. Hypertension 22:653–664

Khan NA et al (2009) The 2009 Canadian hypertension education program recommendations for the management of hypertension: part 2—therapy. Can J Cardiol 25:287–298

Lacombe SP, Goodman JM, Spragg CM, Liu S, Thomas SG (2011) Interval and continuous exercise elicit equivalent postexercise hypotension in prehypertensive men, despite differences in regulation. Appl Physiol Nutr Metab 36:881–891

Laukkanen JA, Zaccardi F, Khan H, Kurl S, Jae SY, Rauramaa R (2016) Long-term change in cardiorespiratory fitness and all-cause mortality: a population-based follow-up study. Mayo Clinic Proc 91:1183–1188. https://doi.org/10.1016/j.mayocp.2016.05.014

Law M, Morris J, Wald N (2009) Use of blood pressure lowering drugs in the prevention of cardiovascular disease: meta-analysis of 147 randomised trials in the context of expectations from prospective epidemiological studies. BMJ 338:b1665

Liu S, Goodman J, Nolan R, Lacombe S, Thomas SG (2012) Blood pressure responses to acute and chronic exercise are related in prehypertension. Med Sci Sports Exerc 44:1644–1652

MacDonald JR (2002) Potential causes, mechanisms, and implications of post exercise hypotension. J Hum Hypertens 16:225

MacDonald JR, Hogben CD, Tarnopolsky MA, MacDougall JD (2001) Post exercise hypotension is sustained during subsequent bouts of mild exercise and simulated activities of daily living. J Hum Hypertens 15:567–571. https://doi.org/10.1038/sj.jhh.1001223

Medicine ACoS (2013) ACSM's guidelines for exercise testing and prescription. Lippincott Williams & Wilkins, Philadelphia

Milanović Z, Sporiš G, Weston M (2015) Effectiveness of high-intensity interval training (HIT) 3 and continuous endurance training for VO_{2max} improvements: 4 a systematic review and meta-analysis of controlled trials. Sports Med. https://doi.org/10.1007/s40279-015-0365-0

Moholdt T et al (2012) Aerobic interval training increases peak oxygen uptake more than usual care exercise training in myocardial infarction patients: a randomized controlled study. Clin Rehabil 26:33–44. https://doi.org/10.1177/0269215511405229

Molmen-Hansen HE et al (2012) Aerobic interval training reduces blood pressure and improves myocardial function in hypertensive patients. Eur J Prev Cardiol 19:151–160

WHO (2013) A global brief on hypertension: silent killer, global public health crisis. https://www.who.int/cardiovascular_diseases/publications/global_brief_hypertension/en/

Pescatello LS, Fargo AE, Leach CN, Scherzer HH (1991) Short-term effect of dynamic exercise on arterial blood pressure. Circulation 83:1557–1561

Pescatello LS, Franklin BA, Fagard R, Farquhar WB, Kelley GA, Ray CA (2004) American College of Sports Medicine position stand. Med Sci Sports Exerc 36:533–553

Pescatello LS, MacDonald HV, Lamberti L, Johnson BT (2015) Exercise for hypertension: a prescription update integrating existing recommendations with emerging research. Curr Hypertens Rep 17:87

Piepoli MF, Hoes AW, Agewall S, Albus C, Brotons C, Catapano AL, Cooney MT, Corrà U, Cosyns B, Deaton C, Graham I, Hall MS, Hobbs FDR, Løchen ML, Löllgen H, Marques-Vidal P, Perk J, Prescott E, Redon J, Richter DJ, Sattar N, Smulders Y, Tiberi M, Bart van der Worp H, van Dis I, Verschuren WMM (2016) 2016 European Guidelines on cardiovascular disease prevention in clinical practice: The Sixth Joint Task Force of the European Society of Cardiology and Other Societies on Cardiovascular Disease Prevention in Clinical Practice (constituted by representatives of 10 societies and by invited experts) Developed with the special contribution of the European Association for Cardiovascular Prevention & Rehabilitation (EACPR). Atherosclerosis 252:207–274. https://doi.org/10.1016/j.atherosclerosis.2016.05.037

Quinn TJ (2000) Twenty-four hour, ambulatory blood pressure responses following acute exercise: impact of exercise intensity. J Hum Hypertens 14:547–553

Rocco EA et al (2012) Effect of continuous and interval exercise training on the $PETCO_2$ response during a graded exercise test in patients with coronary artery disease. Clinics 67:623–628

Taylor-Tolbert NS, Dengel DR, Brown MD, McCole SD, Pratley RE, Ferrell RE, Hagberg JM (2000) Ambulatory blood pressure after acute exercise in older men with essential hypertension. Am J Hypertens 13:44–51

Team RC (2016) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. 2015. http://www.R-project.org. Accessed 25 Jan 2017

Tjønna AE et al (2008) Aerobic interval training versus continuous moderate exercise as a treatment for the metabolic syndrome. Circulation 118:346–354

Wallace JP, Bogle PG, King BA, Krasnoff JB, Jastremski CA (1999) The magnitude and duration of ambulatory blood pressure reduction following acute exercise. J Hum Hypertens 13:361–366

Wasserman K, Whipp BJ (1975) Excercise physiology in health and disease. Am Rev Resp Dis 112:219–249. https://doi.org/10.1164/arrd.1975.112.2.219

Wen H, Wang L (2017) Reducing effect of aerobic exercise on blood pressure of essential hypertensive patients: a meta-analysis. Medicine 96:e6150. https://doi.org/10.1097/md.0000000000006150