Accepted for publication in Journal of Strength and Conditioning Research

Title Page

Continuous and accumulated bouts of cycling matched by intensity and energy expenditure elicit similar acute blood pressure reductions in prehypertensive men

Running head: Postexercise hypotension and aerobic exercise

Guilherme F. Fonseca[1], Paulo T.V. Farinatti[2,3,4], Adrian W. Midgley[5], Arthur Ferreira[1], Tainah de Paula[3,6], Walace D. Monteiro[3,4], and Felipe A. Cunha[1,2,3]

1) Post-Graduate Program in Rehabilitation Sciences, Augusto Motta University Center (UNISUAM), Rio de Janeiro, Brazil. 2) Post-Graduate Program in Exercise Science and Sports, University of Rio de Janeiro State, Rio de Janeiro, Brazil. 3) Laboratory of Physical Activity and Health Promotion, University of Rio de Janeiro State, Rio de Janeiro, Brazil. 4) Post-Graduate Program in Physical Activity Sciences, Salgado de Oliveira University, Niterói, Rio de Janeiro, Brazil. 5) Department of Sport and Physical Activity, Edge Hill University, Ormskirk, Lancashire, England. 6) Post-Graduate Program in Medical Sciences, Faculty of Medical Sciences, University of Rio de Janeiro State, Rio de Janeiro, Brazil.

Address for correspondence:

Felipe A. Cunha, PhD. Rehabilitation Sciences, Augusto Motta University Center, UNISUAM. Praça das Nações 34, 3º andar, Bonsucesso, Rio de Janeiro, RJ, Brazil. CEP 21041-010; Phone: +55 (21) 3882-9797 ramal 2012. E-mail: felipeac@globo.com

Acknowledgements: This research was partially supported by grants from the Carlos Chagas Filho Foundation for the Research Support in Rio de Janeiro State and Brazilian Council for the Technological and Scientific Development.

Abstract

The present study investigated differences in postexercise hypotension (PEH) after continuous versus accumulated isocaloric bouts of cycling. Ten pre-hypertensive men, aged 23 to 34 yrs, performed two bouts of cycling at 75% oxygen uptake reserve, with total energy expenditures of 400 kcal per bout. One exercise bout was performed continuously (CONTIN) and the other as two smaller bouts each expending 200 kcal (INTER1 and INTER2). Systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial pressure (MAP), and cardiac autonomic control were monitored in a supine position for 10 min before and 60 min after each exercise bout, and during a control session. Compared to control, blood pressure was significantly reduced after CONTIN (SBP: Δ-3.4 mmHg, $P < 0.001$; MAP: Δ-2.5 mmHg, $P = 0.001$), INTER1 (SBP: Δ-2.2 mmHg, $P = 0.045$) and INTER2 (SBP: Δ-4.4 mmHg, $P < 0.001$; DBP: Δ-2.7 mmHg, $P = 0.045$; MAP: Δ-3.3 mmHg, $P = 0.001$). The PEH was similar in CONTIN and INTER2, while INTER2 elicited greater PEH than INTER1 (SBP and MAP: Δ-2.0 and Δ-1.8 mmHg, respectively, $P < 0.05$). Increases in sympathovagal balance from baseline were inversely related to changes in SBP and DBP after CONTIN and INTER2 (r = -0.64 to -0.71; $P = 0.021$ to $P = 0.047$). These findings indicate similar amounts of PEH are observed when exercise is performed as a single 400 kcal exercise bout or 2 x 200 kcal bouts and that the exercise recovery pattern of cardiac autonomic activity may be important in eliciting PEH.

Keywords: postexercise hypotension, cardiovascular physiology, heart rate variability, caloric expenditure, fractionation of exercise.

INTRODUCTION

Hypertension is a serious public health problem associated with increased risk of developing other cardiovascular diseases (CVDs) (30), and the observation that one in five people with prehypertension tend to progress to hypertension within an average time frame of 4 years (44) is of particular concern. Physical activity level also has been shown to be strongly associated with the development of CVD (6). Paffenbarger et al. (31), for example, showed that among 14,998 Harvard male alumni that initially presented without hypertension in 1962 or 1966, 681 (5%) developed hypertension by 1972, with those not engaging in vigorous sporting activities at 35% greater risk of developing hypertension than those who did. Regular physical exercise, especially aerobic exercise, has therefore often been recommended for the prevention, treatment, and control of hypertension (36, 41). Indeed, current evidence suggests that chronic reductions in blood pressure from engaging in long-term aerobic exercise programs are due largely to the summative effects of the blunted blood pressure response observed after single acute bouts of aerobic exercise (23). These blunted responses occur for several hours after exercise compared to the immediate pre-exercise period, or a non-exercise control day, and is a phenomenon known as postexercise hypotension (PEH) (37).

Although the optimal exercise prescription to maximize PEH remains unknown, research has established that the magnitude of PEH, and whether it occurs, largely depends on several basic components of exercise prescription such as intensity, duration, and mode (see 35 for a review). Another component that has received less attention is whether the exercise is performed continuously or cumulatively. Some studies support the idea that accumulated bouts may be a better strategy for prescribing aerobic exercise, by providing greater PEH than continuous bouts (2, 5, 22, 32, 33), while others suggested continuous and accumulated acute exercise bouts elicit similar blood pressure reductions (13, 27). A question therefore arises as to what could explain these conflicting findings? Cunha et al. (14) investigated PEH after short-duration cycling (105 ± 29 kcal), walking (113 ± 19 kcal), and running (141 ± 42 kcal) maximal exercise tests. Only running, which was the exercise mode associated with the greatest energy expenditure, elicited a significant reduction in blood pressure compared to a control session. From a practical perspective, the magnitude of PEH seems to be dependent on exercise volume, as reflected by energy expenditure. Notably, among seven previous studies that directly compared the effects of continuous versus accumulated exercises on PEH, five equated total work from the external work completed (2, 5, 22, 32,

33), while two studies employed isocaloric conditions, and concluded that accumulated exercise elicited similar reductions in blood pressure to continuous exercise (13, 27). How work is equated is an important methodological issue that confounds the interpretation of studies that compared the acute effects of continuous versus accumulated exercise on PEH. The studies that used cycle ergometry (2, 22) did not apply isocaloric bouts and therefore susceptible to such confounding. Considering that cycling is frequently used in aerobic training, knowledge about the impact of multiple short bouts of cycling on PEH could have clinically important implications and further research is warranted.

Changes in autonomic cardiac control, as measured by heart rate variability (HRV) and reflecting beat-to-beat changes in HR and the sympathovagal interaction obtained by the variation of both instantaneous HR and R-R intervals within the cardiac cycle (42), seem to influence blood pressure after exercise (7, 43). It is known that blood pressure is determined by the relationship between cardiac output (Q) and systemic vascular resistance (SVR), cardiac (central) or vascular (peripheral) mechanisms that reflect changes in central regulation (8), leading to attenuation of the blood pressure response in the postexercise recovery. Evidence about the role of cardiac autonomic control in PEH is controversial, however. Some studies suggest decreased sympathetic activity and increased parasympathetic activity concomitant to PEH (33), while others suggest a compensatory increase in sympathetic activity would occur to offset the blood pressure reduction and baroreflex resetting (13, 14, 39, 43), or that no changes would occur (3, 32). The extent to which PEH accompanies a shift in cardiac autonomic balance therefore remains unclear and requires further investigation.

The main aim of the present study was to compare the effects of continuous and accumulated bouts of cycling, matched by intensity and energy expenditure, on PEH in prehypertensive men. A second aim was to investigate the relationships between changes in blood pressure *versus* changes in sympathovagal balance after each acute exercise bout.

METHODS

Experimental approach to the problem

Each participant visited the laboratory five times. During the first visit participants were familiarized with the equipment and experimental procedures, then they completed a pre-participation questionnaire for

assessment of cardiovascular risk, and then had their blood pressure measured to ensure they met the study inclusion criteria. On the second visit, anthropometric measurements were taken followed by resting oxygen uptake (VO_2), blood pressure and HRV assessments for 60 min ('control' condition). On the third visit, a maximal cardiopulmonary exercise test (CPET) on a cycle ergometer was performed to determine VO_{2max}. Approximately 72 h after the CPET, two isocaloric exercise bouts were performed at 75% of oxygen uptake reserve (VO_2R). During one of the visits the exercise bout was continuous and expended a total of 400 kcal. During the other visit the exercise bout was accumulated and consisted of 2 x 200 kcal bouts, separated by 1 h of passive rest, during which blood pressure and HRV were assessed. Allocation of test order for the continuous and accumulated exercise bouts was randomized and counter-balanced across participants. The exercise bouts were separated by 48 to 72 h. Before the exercise and control conditions, baseline assessments were performed during 10 min of bed rest in a quiet darkened environment with the final 5 min used for data collection. Within 5 sec of exercise (or control session) termination, participants were placed in the supine position, and data collection began 5 min after exercise for a period of 60 min in a quiet room kept at a relatively constant temperature and relative humidity (ranging from 21 to 23°C and 50 to 70%, respectively). The participants were instructed not to engage in any physical activity during the 48 h before and after each laboratory visit. All visits were conducted at approximately the same time of day (between 07:00 and 11:00 a.m.). Exercise bouts were performed on a cycle ergometer (Cateye EC-1600, Cateye™, Tokio, Japan), with the seat height individually set and standardized across all exercise bouts for a given participant.

Participants

Ten apparently healthy prehypertensive men, aged 23 to 34 yrs, participated in the study. Inclusion criteria consisted of a mean screening SBP of 120-139 mmHg and/or DBP of 80-89 mmHg (21). All participants were recreationally active, performing 20-60 min exercise per session on 2-5 days per week, for at least 6 months prior to the study. The exclusion criteria were: a) cardiovascular disease and diabetes; b) use of drugs that could affect the cardiovascular responses, or any ergogenic substances; c) smoking; and d) bone, joint, or muscle problems that could limit the performance of exercise. The study gained approval from the institutional ethics committee (reference 3082/2011) and participants were informed of the benefits and risks associated with the study prior to providing written informed consent to participate.

Blood pressure screening was performed by a single evaluator using a calibrated mercury column sphygmomanometer (Heidji, São Paulo, Brazil) and a stethoscope (Sprague Rappaport, Omron, USA), after participants remained seated for 10 min, in accordance with American Heart Association recommendations (34). Participants were instructed to remain relaxed and avoid talking during the measurements. The cuff was placed on the right arm so that the inferior extremity remained at a level within 2.5 cm of the antecubital fossa. The arm was supported at heart level and the bladder of the cuff encircled at least 80% of the arm circumference. The mercury column was deflated at 2-3 mmHg/s until Korotkoff sounds were heard that corresponded to systolic (first sound) and diastolic (fifth sound) values. The readings were registered to the nearest 2 mmHg. The blood pressure used for screening participants was calculated as the mean of three readings taken at 5 min intervals.

Experimental blood pressure assessment

Resting blood pressure determined before and after each exercise bout and the non-exercise control session was assessed by an oscillometric device (Spacelabs Medical™ model 90207; Spacelabs Inc., Redmond, WA, USA). Blood pressure monitoring followed standard procedures (38) using the criteria of the British Hypertension Society (29), including a calibration check before each experiment according to the manufacturer's instructions. Blood pressure recordings after exercise bouts and the non-exercise control session were obtained during 60 min at 20 min intervals in a quiet environment and in a supine position. The control session mimicked the exercise bouts in that participants remained seated at rest for 20 min and blood pressure was assessed using the same protocol as that used before and after the exercise bouts in a supine position.

Heart rate variability assessment

The HR and HRV were recorded concomitantly with blood pressure using a telemetric HR monitor (RS800cx, Polar™, Kempele, Finland). The R-R intervals were downloaded by Polar Precision Performance Software (Polar™, Kempele, Finland) and averaged for each 30-sec window using a sampling frequency of 1000 Hz. Before analysis, all R-R intervals were visually inspected for artifacts in order to make interpolation corrections on the sequences (42). This was necessary in less than 1% of the sequences for each participant. A Fast Fourier Transform (Welch's method) with a Hanning window and 50% overlap was used to estimate the power density spectrum of R-R interval variability using a

customized routine (Mathworks™, Natick, MA, USA). The beat-by-beat R–R interval series were then converted into equally spaced time series with 200 ms intervals using cubic spline interpolation (42).

The ratio between low frequency and high frequency bands (LF:HF) was used as an index of sympathovagal balance, with the LF band (0.04-0.15 Hz) being considered as a marker of sympathetic predominance, and the HF band (0.15-0.50 Hz) as a marker of parasympathetic predominance (10). The spectral values were expressed as normalized units (n.u.). To meet the stability requirement for performing spectral analysis, the first 5 min interval after each exercise bout was omitted from all HRV analyses. The HRV analyses for the control session and following exercise were then used to calculate HRV indices according to previously established guidelines (42).

Resting VO_2 assessment

Resting VO_2 was determined prior to calculation of $\%VO_2R$ using well-controlled procedures recommended by Compher et al. (9). These included abstentions from physical exercise, alcohol, soft drinks and caffeine in the 24 h preceding the assessment, and fasting at least 8 h prior to the assessment. In the laboratory, participants remained awake in a quiet environment for 10 min, after which the VO_2 was measured for 40 min in the supine position. The resting VO_2 was recorded as the average of the last 5 min of steady-state data assessed during 35 to 40 min (within-subject coefficient of variation ≤10%) (12). The resting VO_2 was always measured at the same time of the day between 07:00 and 11:00 a.m.

Maximal and submaximal exercise tests

The ramp-incremented maximal CPET was performed as described elsewhere (11). The power output increment was individualized to elicit each participant's limit of tolerance in approximately 10 min. The criteria for test termination followed the recommendations of the ACSM (1). The test was considered to have elicited peak capacity when at least three of the following criteria were observed (18): a) maximum voluntary exhaustion defined by attaining a 10 on the Borg CR-10 scale; b) ≥ 90% predicted maximal heart rate (HR_{max}) [220 – age], or presence of a HR plateau (ΔHR between two consecutive power outputs ≤ 4 beats·min^{-1}); c) presence of a VO_2 plateau (ΔVO_2 between two consecutive power outputs < 2.1 mL·kg^{-1}·min^{-1}); and d) respiratory exchange ratio > 1.10.

Based upon the VO_{2max} achieved during the CPET and the resting VO_2, values corresponding to 75% VO_2R were calculated to determine the intensity of the two isocaloric exercise bouts. The absolute VO_2 values obtained from the $\%VO_2R$ equation were used to calculate the associated cycling power outputs [mean ± SD, 257 ± 55 W] by applying the ACSM metabolic equation (1). Each exercise bout was preceded by a 5-min warm-up at 30 W and 65-75 rev·min^{-1}. Expired gases were collected during exercise bouts via the metabolic cart. The exercise bouts were terminated when each participant had achieved a total energy expenditure of 400 or 200 kcal in continuous or accumulated acute exercise bouts, respectively, and followed by 60 min of recovery in the supine position to measure blood pressure and HRV.

Pulmonary gas exchanges were determined using breath-by-breath analyses with a VO2000 metabolic cart (Medical Graphics™, Saint Louis, MO, USA). Gas exchange data were calculated, averaged, and recorded every 30 sec, which provided a good compromise between removing noise in the data while maintaining underlying physiological trends (24). Prior to testing, gas analyzers were calibrated according to the manufacturer's instructions, using a certified standard mixture of oxygen (17.01%) and carbon dioxide (5.00%), balanced with nitrogen (AGA™, Rio de Janeiro, RJ, Brazil). Flows and volumes of the pneumotacograph were calibrated with a syringe graduated for 3 L capacity (Hans Rudolph™, Kansas, MO, USA).

Statistical Analyses

All statistical analyses were performed using IBM SPSS Statistics 22 software (SPSS™ Inc., Chicago, IL, USA). Descriptive statistics are presented as mean ± SD. The effect of Condition [control, continuous exercise (CONTIN), first intermittent exercise bout (INTER1), and second intermittent exercise bout (INTER2)] and Time [baseline and 60 min postexercise period (time-averaged at 20, 40, and 60 min)] on blood pressure and HRV indices were analyzed using marginal models using the SPSS MIXED procedure. The best fitting covariance structure was identified as that which minimized the Hurvich and Tsai's criterion value. Where there was a statistically significant main effect for Condition or a significant Condition x Time interaction effect, post hoc pairwise comparisons with Sidak-adjusted *P* values were obtained. Pearson correlations were used to determine the relationships between changes in SBP and DBP *versus* changes in the LF:HF ratio for the 60 min following the exercise bouts. Two-tailed statistical significance was accepted as $P \leq 0.05$.

RESULTS

Participant characteristics

Table 1 shows descriptive statistics for age, anthropometrical variables, resting physiological variables, maximal CPET responses, and HR, absolute VO_2, and time to achieve 400 kcal during CONTIN and accumulated (i.e. INTER1 and INTER2) isocaloric exercise bouts of cycling at 75% VO_2R. On average, participants were overweight, had prehypertension, and above average physical fitness for men of their age (1).

Acute blood pressure responses to cycling bouts

Figure 1 shows the average blood pressure responses during 60 min following the control session and each exercise bout. There were main effects for condition (SBP: F = 28.9, $P < 0.001$; DBP: F = 10.9, $P < 0.001$; MAP: F = 27.8, $P < 0.001$) and time (SBP: F = 229.2, $P < 0.001$; DBP: F = 7.9, $P = 0.009$; MAP: F = 110.3, $P < 0.001$). A significant condition x time interaction showed that the differences between control and the exercise conditions decreased over time for SBP (F = 4.1, $P < 0.001$), DBP (F = 4.0, $P = 0.001$), and MAP (F = 3.9, $P = 0.001$). For example, the largest reductions in blood pressure postexercise occurred during the first 20 min, with significant differences of 3.9-6.2, 2.8-3.6, and 3.5-4.4 mmHg observed between control and the postexercise periods for SBP, DBP, and MAP, respectively. Compared to control, on average, CONTIN, INTER1 and INTER2 elicited reductions in SBP of 3.4 ± 2.5 mmHg (95% CI = 1.7 to 5.1 mmHg, $P < 0.001$), and 2.2 ± 2.4 mmHg (95% CI = 0.6 to 4.0 mmHg, $P < 0.001$), and 4.4 ± 2.5 mmHg (95% CI = 2.5 to 6.0 mmHg, $P < 0.001$), respectively. No significant differences in SBP were observed between CONTIN and INTER2 (mean difference = 0.9 mmHg, 95% CI = -0.9 to 2.6 mmHg, $P = 0.934$), or between CONTIN and INTER1 (mean difference = -1.1 mmHg, 95% CI = -2.8 to 0.6 mmHg, $P = 0.652$); however, SBP was significantly lower after INTER2 than INTER1 (mean difference = 2.0 mmHg, 95% CI = 0.2 to 3.7 mmHg, $P = 0.015$). Unlike SBP, on average, there was no significant difference in DBP reduction after CONTIN [($P = 0.320$); except the mean difference of -2.8 mmHg between control and CONTIN at 20 min ($P < 0.05$)] and INTER1 compared to control ($P = 0.985$), while a significant difference was observed between INTER2 vs. control (mean difference = -2.7 mmHg, 95% CI = -0.3 to 5.2 mmHg, $P = 0.045$). There was no significant difference between DBP responses among the exercise conditions ($P = 0.771$ to $P = 0.999$). MAP was 2.5 ± 2.1 and 3.3 ± 2.1

mmHg lower after CONTIN (95% CI = 0.7 to 4.3, P = 0.001) and INTER2 (95% CI = 1.6 to 5.1, P < 0.001) compared to control, while there was a non-significant difference between INTER1 vs. control (P = 0.177) [except the mean difference of -2.2 mmHg between control and INTER1 at 20 min (P < 0.05)]. Comparing the exercise conditions, there was no significant difference between CONTIN vs. INTER1 (P = 0.832) or CONTIN vs. INTER2 (P = 0.968), except a significant reduction after INTER2 compared to INTER1 (MAP: mean difference = 1.8 mmHg, 95% CI = 0.3 to 3.6 mmHg, P = 0.043).

INSERT FIGURE 1

Acute cardiac autonomic responses to cycling bouts

Figure 2 shows the average cardiac autonomic responses at baseline and during 60 min following the control session and each exercise bout. There were significant main effects for condition (HR: F = 10.9, P < 0.001; LF: F = 46.4, P < 0.001; HF: F = 50.6, P < 0.001; LF:HF ratio: F = 23.1, P < 0.001), time (HR: F = 7.9, P = 0.009; LF: F = 4.0, P = 0.010; HF: F = 5.1, P = 0.008; LF:HF ratio: F = 4.4, P < 0.022), and a significant condition x time interaction only for HR (F = 4.0, P = 0.001). On average, HR was 12.8 ± 2.9 beats·min^{-1} (95% CI = 4.4 to 21.1 beats·min^{-1}, P < 0.001), 11.5 ± 4.2 beats·min^{-1} (95% CI = 3.2 to 19.8 beats·min^{-1}, P = 0.001), and 10.9 ± 4.1 beats·min^{-1} (95% CI = 2.6 to 19.2 beats·min^{-1}, P = 0.002), higher after CONTIN, INTER1, and INTER2 compared to control, respectively. Findings from time-frequency spectral analysis of HRV, for example, showed that CONTIN elicited a 25.3 ± 8.0-unit increase in LF compared to control (95% CI = 18.1 to 32.5 units, P < 0.001), whereas INTER1 and INTER2 elicited increases of 23.9 ± 8.9 units (95% CI = 17.1 to 30.7 units, P < 0.001) and 26.6 ± 3.5 units (95% CI = 19.8 to 32.8 units, P < 0.001), respectively. Unlike LF, HF was 26.2 ± 9.6 units (95% CI = 18.4 to 34.0 units, P < 0.001), 23.4 ± 11.0 units (95% CI = 16.2 to 30.5 units, P < 0.001), and 26.2 ± 5.9 units (95% CI = 20.1 to 32.3 units, P < 0.001) lower after CONTIN, INTER1 and INTER2 compared to control, respectively. Like HR and LF, the LF:HF ratio was significantly higher after CONTIN (P < 0.001), INTER1 (P < 0.001) and INTER2 (P < 0.001) compared to control. However, in all HRV indices, no significant differences were observed among exercise conditions (P > 0.05).

INSERT FIGURE 2

Relationships between changes in blood pressure and changes in LF:HF ratio

Figure 3 shows the relationships between ΔSBP and ΔDBP *vs.* ΔLF:HF ratio during the 60 min recovery period following exercise compared to control. Both ΔSBP and ΔDBP were negatively correlated to the ΔLF:HF ratio after CONTIN and INTER2, with Pearson correlation coefficients (r) ranging from -0.64 to -0.65 (P = 0.045 to P = 0.041, respectively) for SBP, and -0.26 to -0.71 (P = 0.467 to P = 0.021, respectively) for DBP. Only the relationships between ΔSBP and ΔDBP vs. ΔLF:HF ratio after INTER1 or between ΔDBP vs. ΔLF:HF ratio after CONTIN were not significant (P > 0.05).

INSERT FIGURE 3

DISCUSSION

To the best of our knowledge, the present study is the first to investigate the extent to which the magnitude of PEH is affected by cycling bouts performed continuously and cumulatively under isocaloric conditions (i.e. same energy expenditure) in prehypertensive men. Three important observations can be derived from the main findings of the present study with respect to optimizing exercise prescription for maximizing the magnitude of PEH: (a) there was a significant positive accumulative effect on PEH from accumulated exercise. Splitting the cycling exercise into two bouts of short-term exercise (i.e. 2 x 200 kcal) was shown to empower sub-acute effects on PEH, promoting similar decreases in blood pressure compared to a continuous cycling bout with an equivalent total energy expenditure of 400 kcal. Consequently, exercise prescription with either accumulated or continuous isocaloric exercise can be adopted; (b) these findings also suggest that the exercise volume determines the pattern of the hypotensive response to aerobic exercise, where INTER1 with the same relative intensity (i.e. 75% VO_2R), but lower volume (i.e. 200 kcal), promoted lower PEH than INTER2 with a greater exercise volume (i.e. 400 kcal); (c) lastly, sympathetic (LF component of HRV) and parasympathetic (HF component of HRV) activities remained significantly increased and decreased during the 60 min exercise recovery, resulting in a sympathetic overload (expressed by the LF:HF ratio) that was inversely correlated with the magnitude of PEH, regardless of CONTIN or INTER2 acute exercise. This finding indicates that the recovery pattern of cardiac autonomic activity may have an important role in eliciting PEH.

To date, findings from most previous studies support the idea that accumulated exercise bouts elicit a greater PEH than continuous exercise bouts using treadmill (5, 32, 33) and cycle ergometry (2, 22). Park et al. (33), for example, compared blood pressure responses after continuous (40 min) and accumulated (4 x 10 min with rest intervals of 50 min) bouts of treadmill walking, at an intensity of 50% VO_{2peak}, in twenty-one prehypertensive adults (SBP and DBP = 131.9 ± 1.1 and 82.5 ± 1.4 mmHg; and VO_{2max} = 34.5 ± 1.6 $ml \cdot kg^{-1} \cdot min^{-1}$). The continuous exercise bout resulted in lowered SBP and DBP for 7 h into recovery, whereas the accumulated bout provided greater PEH, with SBP and DBP significantly reduced for 11 and 10 h postexercise, respectively. However, the present study disagrees with this view, since the magnitude of PEH in relation to control was similar in both the CONTIN and INTER2 for cycling ($\Delta SBP_{60\text{-}min}$ = -3.4 and -4.3 mmHg; $\Delta DBP_{60\text{-}min}$ = -2.0 and -2.6 mmHg). On the other hand, similar to our findings, Cunha et al. (13) observed that accumulated (2 x 200 kcal with rest interval of 60 min) and continuous (400 kcal) treadmill running at 75% VO_2R elicited similar SBP and DBP reductions compared to a control session (ΔSBP = -6 and -7 mmHg, respectively; ΔDBP = -5 and -6 mmHg, respectively) among 10 hypertensive men. Beyond that, the authors provided further analysis showing that continuous and/or second accumulated bouts matched for total energy expenditure of 400 kcal induced greater blood pressure reduction compared to the first accumulated bout performed with equivalent intensity (i.e. 75% VO_2R) but a lower energy expenditure (200 kcal) (i.e. Δ SBP = 2.1 and 4.3 mmHg, respectively; DBP = 3.7 and 4.8 mmHg, respectively). In other words, it is feasible to think that the exercise volume involved, which seems to be a major determinant of PEH, is likely to be one of main reasons why the results of the present study differ from previous research reporting different blood pressure responses following continuous and accumulated acute aerobic bouts, since all these studies failed to match the exercise volume by energy expenditure.

It is clear that accumulated exercise bouts can be a useful tool for prescribing aerobic exercise in different populations, since its acute effect on the magnitude of the PEH seems to be similar or equal to continuous exercise. Additionally, other advantages may make prescribing accumulated exercise more favorable, such as a better strategy to improve exercise adherence (20), since this strategy seems to be more palatable and easier to maintain (28). Sedentary individuals have low tolerance to prolonged efforts, such as continuous exercise lasting 30-60 min, and accumulated bouts also could minimize this issue. Accumulated bouts could even allow higher intensity exercise, which chronically, may result in greater benefits than continuous exercise with moderate intensity and long duration in improving

cardiorespiratory fitness, body composition, total cholesterol, low-density lipoprotein cholesterol, serum triglycerides, insulin sensitivity, and glucose control (41). All these favorable changes in health status from engaging in vigorous-intensity exercise (i.e. 60-85% VO_2R) have been identified as independent risk factors for hypertension (19, 40).

Regarding postexercise cardiac autonomic control, our findings agree with previous reports (13, 14, 39, 43), since the HRV spectral analysis indicated that during recovery from continuous and accumulated cycling bouts, sympathetic activity (LF band) increased while parasympathetic activity (HF band) decreased, resulting in higher sympathovagal balance (LF:HR ratio) concomitant with a reduction in blood pressure (see Figures 1 and 2). Moreover, the acute reductions in blood pressure following CONTIN and INTER2 were negatively correlated with changes in sympathovagal balance, meaning that the greater the magnitude of PEH, the greater the increase in relative sympathetic activity (see Figure 3). Nonetheless, the reason for this inverse relationship between changes in blood pressure and changes in the LF:HF ratio during exercise recovery remains unclear. Some studies have shown, for example, that the operating point of the arterial baroreflex seems to be at low values of blood pressure (7, 25), indicating that the elevated sympathetic activity and reduced vagal activity of HR may be associated with the hypotensive effect of exercise that reduces the discharge of pressoreceptors, causing less inhibition of sympathetic activation and lower parasympathetic activation mediated reflex arc dependent on arterial baroreceptors. This is a physiological response to offset the reduction in blood pressure and compensate for resetting of the baroreflex (17). If this is indeed the case, it is plausible that the hypotensive effect would somehow rely on the ability of peripheral vasodilation mechanisms to overcome such increases in sympathetical activity.

On the other hand, the absence of a correlation between blood pressure and sympathovagal balance in the present study occurred only after INTER1 (see Figure 3). Within a practical perspective, whether or not a correlation between blood pressure and sympathovagal balance is observed after exercise might be a result of exercise volume – in other words, the compensatory response related to acute blood pressure lowering and shift in cardiac autonomic balance might also be associated with exercise volume. It has been advocated that exacerbated hemodynamic responses after exercise may be influenced by the amount of muscle work, which would increase the exercise pressor reflex (ergoreflex) through afferent stimuli from muscle ergoreceptors (mechanoreceptors and metaboreceptors) (8, 16, 26). The increased muscle

afferent signaling would contribute to a higher sympathetic activity during exercise and to a consequent 'resetting' of the arterial baroreflex during the postexercise period, reducing sympathetic outflow and lowering blood pressure (15, 16). It is therefore plausible that at least to some extent, the magnitude of blood pressure reduction and the shift of sympathovagal balance following an aerobic exercise bout might rely on the amount of overall volume, as expressed by the energy expenditure. This could partially explain the total absence of correlation between blood pressure and sympathovagal balance only after INTER1 (i.e. the exercise bout with the lowest energy expenditure). Further research is certainly warranted to clarify these issues.

Another issue to be addressed is the effect of the recovery period between accumulated intermittent bouts on the acute blood pressure and cardiac autonomic control responses. Although there is no consensus in the literature on this issue, it is worth noting that previous studies have adopted 3 to 4 sets of 10 min of exercise interspaced by 10 min (22), 50 min (32, 33) or 4 h (2, 5) rest periods. From a practical perspective, it is feasible to think that this wide range observed for the recovery period between intermittent bouts (i.e. 10 min to 4 h) could directly affect the phenomenon of PEH, since the immediate postexercise hyperaemia - one of the mechanisms underlying hypotension - can last from several seconds up to 20 min (4, 16). Additional research is therefore needed to verify any changes in PEH in response to different recovery periods accumulated between intermittent bouts.

PRACTICAL APPLICATIONS

The PEH was favorably affected by the accumulation of cycling bouts. In practical terms, splitting the volume of exercise into two bouts of shorter-term exercise, with the same total energy expenditure, was as effective as the more traditional approach of using continuous exercise to promote the postexercise hypotensive effects of aerobic exercise. Additionally, exercise volume measured by energy expenditure markedly influences the PEH response, regardless of whether the exercise is performed continuously or cumulatively. In this context, aerobic exercise that involves a higher volume elicits greater PEH than that involving a smaller volume. Furthermore, the magnitude of PEH was associated with vagal inhibition and prolonged elevation in sympathetic activity during recovery from aerobic exercise involving greater volume in prehypertensive men. These findings may have important implications for prescribing aerobic exercise as a long-term intervention for lowering blood pressure.

REFERENCES

1. ACSM. *ACSM's guidelines for exercise testing and prescription.* 10th ed. Philadelphia : Wolters Kluwer, 2018.
2. Angadi SS, Weltman A, Watson-Winfield D, Weltman J, Frick K, Patrie J, and Gaesser GA. Effect of fractionized vs continuous, single-session exercise on blood pressure in adults. *J Hum Hypertens* 24: 300-302, 2010.
3. Anunciacao PG, Farinatti PT, Goessler KF, Casonatto J, and Polito MD. Blood pressure and autonomic responses following isolated and combined aerobic and resistance exercise in hypertensive older women. *Clin Exp Hypertens* 38: 710-714, 2016.
4. Bangsbo J and Hellsten Y. Muscle blood flow and oxygen uptake in recovery from exercise. *Acta Physiol Scand* 162: 305-312, 1998.
5. Bhammar DM, Angadi SS, and Gaesser GA. Effects of fractionized and continuous exercise on 24-h ambulatory blood pressure. *Med Sci Sports Exerc* 44: 2270-2276, 2012.
6. Blair SN, Kohl HW, 3rd, Barlow CE, Paffenbarger RS, Jr., Gibbons LW, and Macera CA. Changes in physical fitness and all-cause mortality. A prospective study of healthy and unhealthy men. *JAMA* 273: 1093-1098, 1995.
7. Chandler MP, Rodenbaugh DW, and DiCarlo SE. Arterial baroreflex resetting mediates postexercise reductions in arterial pressure and heart rate. *Am J Physiol* 275: H1627-1634, 1998.
8. Chen CY and Bonham AC. Postexercise hypotension: central mechanisms. *Exerc Sport Sci Rev* 38: 122-127, 2010.
9. Compher C, Frankenfield D, Keim N, and Roth-Yousey L. Best practice methods to apply to measurement of resting metabolic rate in adults: a systematic review. *J Am Diet Assoc* 106: 881-903, 2006.
10. Cooley RL, Montano N, Cogliati C, van de Borne P, Richenbacher W, Oren R, and Somers VK. Evidence for a central origin of the low-frequency oscillation in RR-interval variability. *Circulation* 98: 556-561, 1998.
11. Cunha FA, Midgley A, Montenegro R, Vasconcellos F, and Farinatti P. Utility of a non-exercise VO2max prediction model for designing ramp test protocols. *Int J Sports Med*, 2015.

12. Cunha FA, Midgley AW, Monteiro W, Freire R, Lima T, and Farinatti PT. How long does it take to achieve steady state for an accurate assessment of resting VO2 in healthy men? *Eur J Appl Physiol* 113: 1441-1447, 2013.

13. Cunha FA, Midgley AW, Pescatello L, Soares PP, and Farinatti P. Acute hypotensive response to continuous and accumulated isocaloric aerobic bouts. *Int J Sports Med* 37: 855-862, 2016.

14. Cunha FA, Midgley AW, Soares PP, and Farinatti PT. Postexercise hypotension after maximal short-term incremental exercise depends on exercise modality. *Appl Physiol Nutr Metab* 40: 605-614, 2015.

15. Fadel PJ. Arterial baroreflex control of the peripheral vasculature in humans: rest and exercise. *Med Sci Sports Exerc* 40: 2055-2062, 2008.

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

17. Halliwill JR, Taylor JA, and Eckberg DL. Impaired sympathetic vascular regulation in humans after acute dynamic exercise. *J Physiol* 495 (Pt 1): 279-288, 1996.

18. Howley ET, Bassett DR, Jr., and Welch HG. Criteria for maximal oxygen uptake: review and commentary. *Med Sci Sports Exerc* 27: 1292-1301, 1995.

19. Hubert HB, Feinleib M, McNamara PM, and Castelli WP. Obesity as an independent risk factor for cardiovascular disease: a 26-year follow-up of participants in the Framingham Heart Study. *Circulation* 67: 968-977, 1983.

20. Jakicic JM, Wing RR, Butler BA, and Robertson RJ. Prescribing exercise in multiple short bouts versus one continuous bout: effects on adherence, cardiorespiratory fitness, and weight loss in overweight women. *Int J Obes Relat Metab Disord* 19: 893-901, 1995.

21. James PA, Oparil S, Carter BL, and et al. 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, 2014.

22. Jones H, Taylor CE, Lewis NC, George K, and Atkinson G. Post-exercise blood pressure reduction is greater following intermittent than continuous exercise and is influenced less by diurnal variation. *Chronobiol Int* 26: 293-306, 2009.

23. Liu S, Goodman J, Nolan R, Lacombe S, and Thomas SG. Blood pressure responses to acute and chronic exercise are related in prehypertension. *Med Sci Sports Exerc* 44: 1644-1652, 2011.

24. Midgley AW, McNaughton LR, and Carroll S. Effect of the VO2 time-averaging interval on the reproducibility of VO2max in healthy athletic subjects. *Clin Physiol Funct Imaging* 27: 122-125, 2007.

25. Miki K, Yoshimoto M, and Tanimizu M. Acute shifts of baroreflex control of renal sympathetic nerve activity induced by treadmill exercise in rats. *J Physiol* 548: 313-322, 2003.

26. Mitchell JH, Kaufman MP, and Iwamoto GA. The exercise pressor reflex: its cardiovascular effects, afferent mechanisms, and central pathways. *Annu Rev Physiol* 45: 229-242, 1983.

27. Miyashita M, Burns SF, and Stensel DJ. Accumulating short bouts of brisk walking reduces postprandial plasma triacylglycerol concentrations and resting blood pressure in healthy young men. *Am J Clin Nutr* 88: 1225-1231, 2008.

28. Murphy MH, Blair SN, and Murtagh EM. Accumulated versus continuous exercise for health benefit: a review of empirical studies. *Sports Med* 39: 29-43, 2009.

29. O'Brien E, Coats A, Owens P, Petrie J, Padfield PL, Littler WA, de Swiet M, and Mee F. Use and interpretation of ambulatory blood pressure monitoring: recommendations of the British hypertension society. *BMJ* 320: 1128-1134, 2000.

30. Padwal R, Straus SE, and McAlister FA. Evidence based management of hypertension. Cardiovascular risk factors and their effects on the decision to treat hypertension: evidence based review. *BMJ* 322: 977-980, 2001.

31. Paffenbarger RS, Jr., Wing AL, Hyde RT, and Jung DL. Physical activity and incidence of hypertension in college alumni. *Am J Epidemiol* 117: 245-257, 1983.

32. Park S, Rink L, and Wallace J. Accumulation of physical activity: blood pressure reduction between 10-min walking sessions. *J Hum Hypertens* 22: 475-482, 2008.

33. Park S, Rink LD, and Wallace JP. Accumulation of physical activity leads to a greater blood pressure reduction than a single continuous session, in prehypertension. *J Hypertens* 24: 1761-1770, 2006.

34. Perloff D, Grim C, Flack J, Frohlich ED, Hill M, McDonald M, and Morgenstern BZ. Human blood pressure determination by sphygmomanometry. *Circulation* 88: 2460-2470, 1993.

35. Pescatello LS. *Effects of exercise on hypertension: from cells to physiological systems.* Springer International Publishing, 2015.

36. Pescatello LS, Franklin BA, Fagard R, Farquhar WB, Kelley GA, and Ray CA. American College of Sports Medicine position stand. Exercise and hypertension. *Med Sci Sports Exerc* 36: 533-553, 2004.

37. Pescatello LS, Guidry MA, Blanchard BE, Kerr A, Taylor AL, Johnson AN, Maresh CM, Rodriguez N, and Thompson PD. Exercise intensity alters postexercise hypotension. *J Hypertens* 22: 1881-1888, 2004.

38. Pickering TG, Hall JE, Appel LJ, Falkner BE, Graves J, Hill MN, Jones DW, Kurtz T, Sheps SG, and Roccella EJ. Recommendations for blood pressure measurement in humans and experimental animals: part 1: blood pressure measurement in humans: a statement for professionals from the Subcommittee of Professional and Public Education of the American Heart Association Council on High Blood Pressure Research. *Circulation* 111: 697-716, 2005.

39. Piepoli M, Coats AJ, Adamopoulos S, Bernardi L, Feng YH, Conway J, and Sleight P. Persistent peripheral vasodilation and sympathetic activity in hypotension after maximal exercise. *J Appl Physiol* 75: 1807-1814, 1993.

40. Schmieder RE and Messerli FH. Does obesity influence early target organ damage in hypertensive patients? *Circulation* 87: 1482-1488, 1993.

41. Swain DP and Franklin BA. Comparison of cardioprotective benefits of vigorous versus moderate intensity aerobic exercise. *Am J Cardiol* 97: 141-147, 2006.

42. Task-Force. Heart rate variability: standards of measurement, physiological interpretation and clinical use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. *Circulation* 93: 1043-1065, 1996.

43. Teixeira L, Ritti-Dias RM, Tinucci T, Mion Junior D, and Forjaz CL. Post-concurrent exercise hemodynamics and cardiac autonomic modulation. *Eur J Appl Physiol* 111: 2069-2078, 2011.

44. Wang Y and Wang QJ. The prevalence of prehypertension and hypertension among US adults according to the new joint national committee guidelines: new challenges of the old problem. *Arch Intern Med* 164: 2126-2134, 2004.

Table 1. Baseline participant characteristics (N = 10).

Moment	Variables	Mean ± SD
Anthropometric assessment	Age (yr)	27.6 ± 3.5
	Height (cm)	173.9 ± 8.7
	Body mass (kg)	78.0 ± 8.5
	BMI ($kg \cdot m^{-2}$)	25.7 ± 0.9
Resting assessment	SBP (mmHg)[a]	125.9 ±4.3
	DBP (mmHg)[a]	84.0 ± 3.2
	HR rest ($beats \cdot min^{-1}$)	68.3 ± 4.8
	LF power (n.u.)	42.0 ± 9.5
	HF power (n.u.)	49.6 ± 7.7
	LF:HF ratio (n.u.)	0.9 ± 0.3
	Resting VO_2 ($L \cdot min^{-1}$)	0.2 ± 0.1
Maximal cardiopulmonary exercise test	Maximal heart rate ($beats \cdot min^{-1}$)	181 ± 1
	Maximal oxygen uptake ($L \cdot min^{-1}$)	3.8 ± 0.6
	Minute ventilation ($L \cdot min^{-1}$)	118 ± 22
	Respiratory exchange ratio	1.17 ± 0.02
	Time to exhaustion (s)	575 ± 40
Continuous bout	Heart rate ($beats \cdot min^{-1}$)	159 ± 5
	Oxygen uptake ($L \cdot min^{-1}$)	2.5 ± 0.603
	Respiratory exchange ratio	1.02 ± 0.06
	Time to achieved 400 kcal (s)	2214 ± 452
Accumulated intermittent bouts	Heart rate ($beats \cdot min^{-1}$)	157 ± 10*
	Oxygen uptake ($L \cdot min^{-1}$)	2.5 ± 0.7*
	Respiratory exchange ratio	0.93 ± 0.06*
	Time to achieved 400 kcal (s)	2307 ± 438*

[a] Average of three screening BPs; BMI = body mass index; VO_2 = oxygen uptake; HR = heart rate; SBP = systolic blood pressure; DBP = diastolic blood pressure; HF = high frequency band; LF = low frequency band; LF:HF ratio = sympathovagal balance. *Average of two exercise bouts (first and second intermittent exercise bouts).

Figures

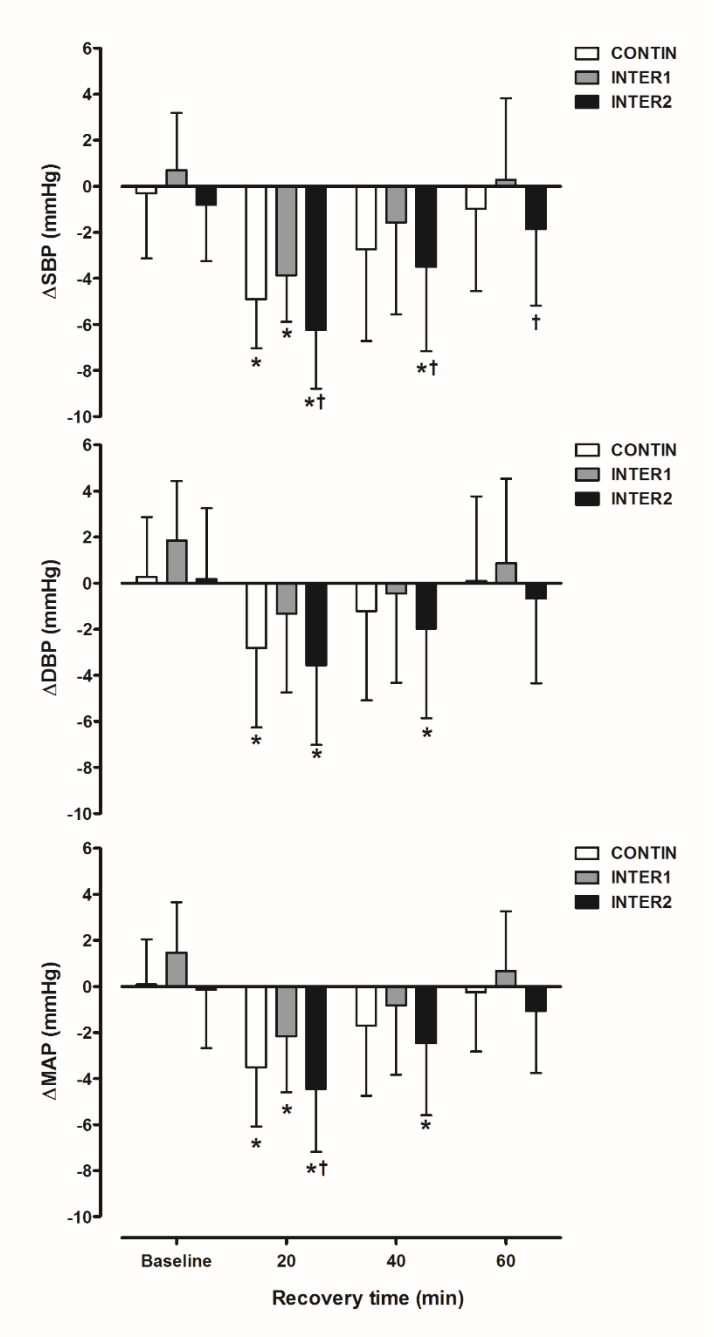

Figure 1. Mean ± SD change in SBP, DBP, and MAP (mean value for condition *minus* mean value for control) at baseline and postexercise recovery periods. * Significantly lower than control ($P < 0.05$ to $P < 0.001$). † Significantly lower than INTER1 ($P < 0.05$). CONTIN = continuous cycling bout; INTER1 = first intermittent cycling bout; INTER2 = second intermittent cycling bout; SBP = systolic blood pressure; DBP = diastolic blood pressure (DBP); MAP = mean arterial pressure.

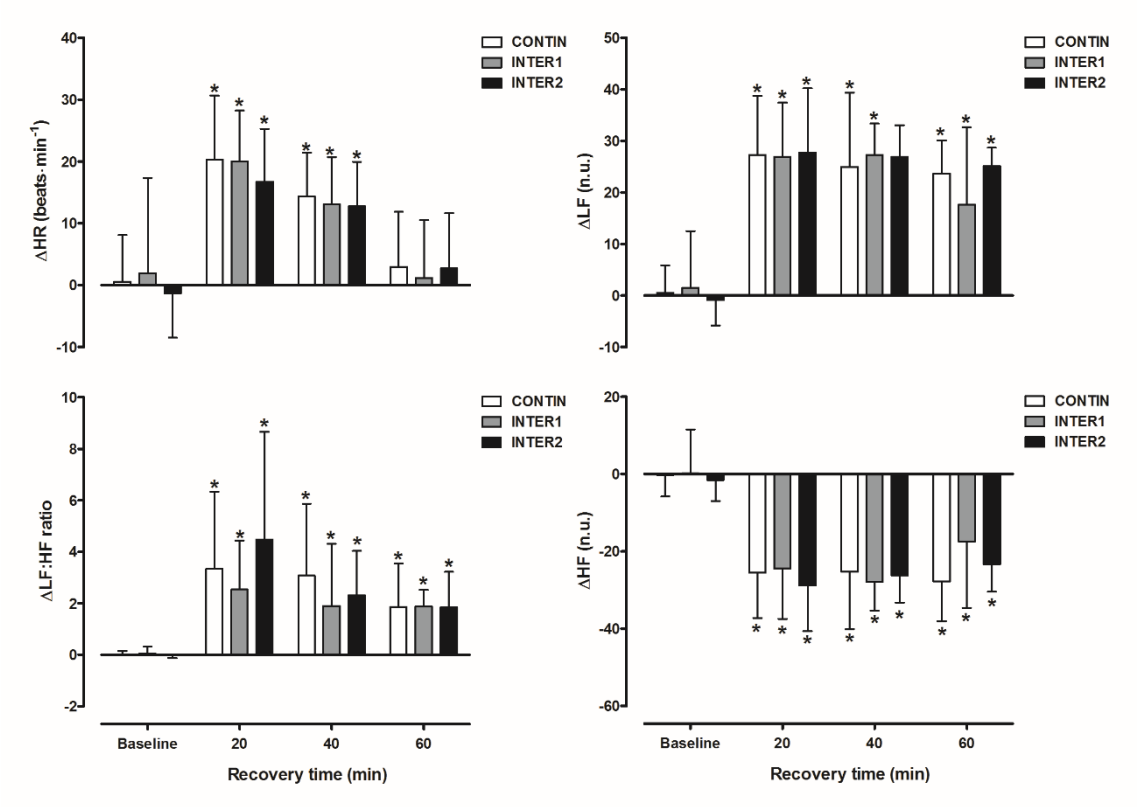

Figure 2. Mean ± SD change in HR, LF, HF and LF:HF ratio (mean value for condition *minus* mean value for control) at baseline and postexercise recovery periods. * Significantly lower than control ($P < 0.05$ to $P < 0.001$). CONTIN = continuous cycling bout; INTER1 = first intermittent cycling bout; INTER2 = second intermittent cycling bout; HR = heart rate; LF = low frequency band; HF = high frequency band; LF:HF ratio = sympatho-vagal balance.

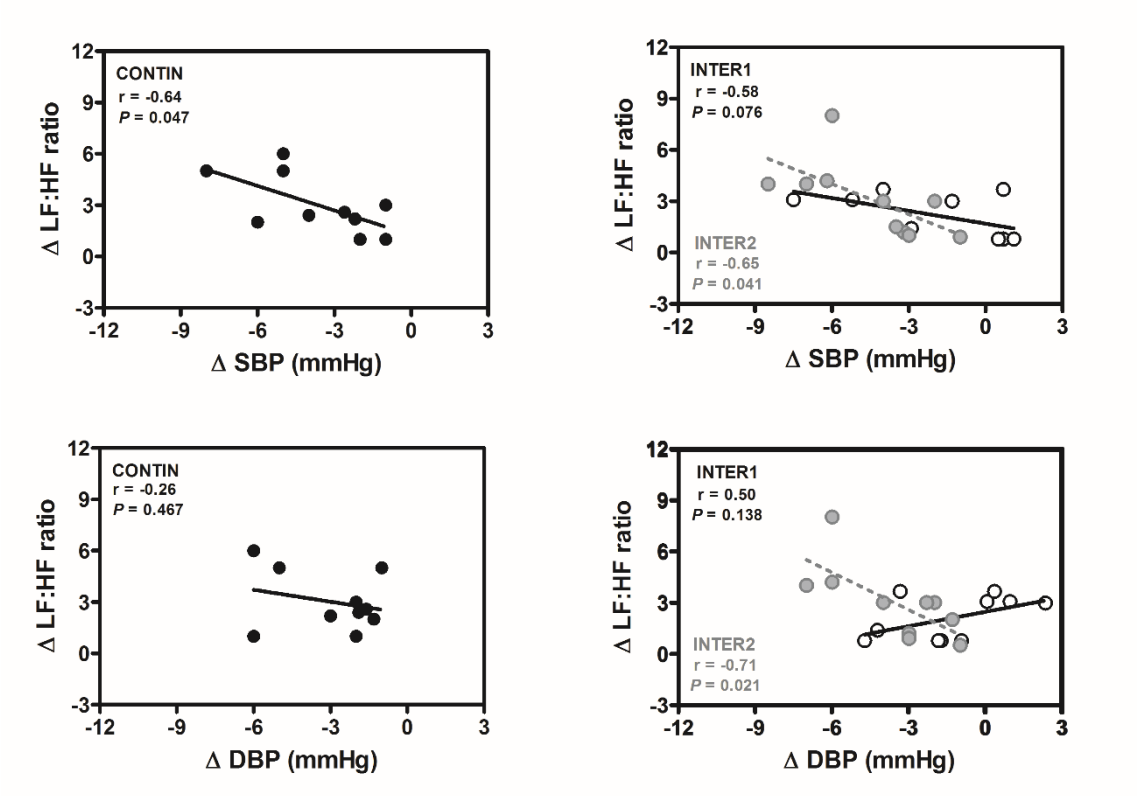

Figure 3. Relationships between average changes in blood pressure and the LF:HF ratio during the 60-min assessment after control and recovery period from CONTIN, INTER1 and INTER2. CONTIN = continuous cycling bout; INTER1 = first intermittent cycling bout; INTER2 = second intermittent cycling bout; SBP = systolic blood pressure; DBP = diastolic blood pressure; LF:HF ratio = sympathovagal balance.