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Acute Post-Exercise Blood Pressure Responses in Middle-Aged Persons with Elevated Blood Pressure/Stage 1 Hypertension following Moderate and High-Intensity Isoenergetic Endurance Exercise

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ABSTRACT

International Journal of Exercise Science 13(3): 1532-1548, 2020. This study investigated the acute post-exercise hypotension (PEH) response in persons with elevated blood pressure or stage 1 hypertension following moderate and high-intensity isoenergetic endurance exercise. Twelve middle-aged persons (six females), with resting systolic and diastolic BP of 130±6 and 84±7 mmHg, participated in three bicycle ergometer bouts: 1) Testing of peak aerobic capacity (VO_{2peak}), 2) Moderate intensity exercise (MOD) at 66% of VO_{2peak}, 3) High-intensity exercise (INT) at 80% of VO_{2peak}. All variables were recorded pre-exercise, during exercise and 0, 5, 10, and 30 minutes post-exercise. The total duration of exercise was 26% longer during MOD than INT (p <0.001), while total energy expenditure (TEE) was similar between exercise conditions (359 ± 69 kcal). Oxygen consumption, heart rate, power output and ratings of perceived exertion was 21, 13, 21 and 26% higher during INT than MOD exercise, respectively ($0.05 \le p \le 0.001$). Compared to pre-exercise, systolic BP was significantly lower at 30 min post-exercise following both INT ($p < 0.05$) and MOD ($p < 0.01$) exercise, and there was no difference between INT and MOD conditions. Other variables were similar to pre-exercise values at 30 min post-exercise. Linear regression shows that the largest post-exercise reductions in systolic BP was found for the persons with the highest pre-exercise systolic BP ($r = 0.58$ $r^2 = 0.33$, $p < 0.003$). In conclusion, this study shows that endurance exercise with different intensities and durations, but similar TEE is equally effective in eliciting reductions in the post-exercise systolic BP. Furthermore, the magnitude of PEH response is partly dependent on the individuals' resting blood pressure.

KEY WORDS: Isocaloric exercise, hemodynamic response, physical activity, post exercise hypotension, systolic blood pressure, diastolic blood pressure, cardiac output, systemic vascular resistance

INTRODUCTION

A large number of observational studies have shown that cardiovascular disease and mortality has a continuous relationship with both systolic and diastolic blood pressures (25) and hypertension is a major risk factor for an array of cardiovascular diseases as well as for diseases leading to a marked increase in cardiovascular risk (27). According to recent estimates, approximately 170 million Americans have higher than normal blood pressures; hence, many persons need to lower their resting blood pressure (BP). Normally, BP lowering drugs are not the first choice of intervention when higher than normal BP is diagnosed (8), thus the need for a non-pharmacological, health-promoting lifestyle intervention to lower BP and prevent cardiovascular disease is evident. In this regard, aerobic endurance training is regarded as the cornerstone of primary prevention, treatment and control of higher than normal blood pressure (27) and current exercise prescriptions are daily bouts of 30 min. or more of moderate intensity aerobic exercise (32), and preferably in combination with dynamic resistance exercise 2 – 3 days per week (35).

Previous investigations have demonstrated that following a single endurance exercise session, there is a sustained depression of the arterial blood pressure to resting levels or lower (13) and this acute reduction in BP below resting levels has been termed the *post-exercise hypotension* (PEH) response (23). It is suggested that the chronic lowering of resting BP following repeated endurance exercise bouts may be due to recurring occurrences of the PEH response (7, 43).

Considering this, it is argued that in order for an exercise intervention to be an effective alternative to pharmaceutical drugs, it is necessary to clarify how the different components of an exercise prescription (i.e. the intensity, duration, frequency and mode of exercise) affect the PEH response (22). Pescatello et al. (35) recently reviewed existing prescriptions on exercise and hypertension, and the majority of guidelines advocate the use of moderate intensity endurance exercise for adults with hypertension. However, in a systematic review on the effects of exercise and post exercise hypotension in hypertensives, the authors noted that the PEH response occurred after both low, medium and high intensity endurance exercise (17), hence there is a lack of consistency regarding how exercise intensity relates to post-exercise blood pressure reductions in hypertensive individuals. It is argued that differences in the PEH response among individual studies probably are caused by differences in exercise prescription components (32).

The basic components of cardiorespiratory exercise prescription are the relative *intensity* (e.g. % of VO_{2max} / $VO_{2reserve}$ / HR_{max} / $HR_{reserve}$), the *duration* (time), the *frequency* (no. of bouts $week^{-1}$), and the *mode* (type) of exercise (45). The specifics on how these prescription components are combined and relate to each other in an exercise bout, define the acute exercise *dose* and the subsequent physiological exercise and post-exercise *responses*. Evidently, many combinations of prescription components are possible and elucidating the *separate* effect of e.g. exercise intensity on the PEH response, is a challenging task. Recent studies suggest, however, that the change in blood pressure following endurance exercise is linearly associated with the exercise intensity (12). In this study, hypertensive men performed bicycle ergometer exercise (similar mode as present study) with three different intensities (low, moderate and vigorous), and the greatest BP reductions were observed after the most vigorous exercise bout (12). However, all the exercise bouts lasted 30 minutes, thus the exercise *dose* (exercise intensity x duration), differed between the three exercise bouts. Since energy expenditure per unit time increases with exercise intensity (41), the total amount of energy expended will be different between the exercise bouts. Hence, in the Eicher study (12), it is difficult to conclude if the PEH response is due to differences in exercise intensity or to differences in total energy expenditure. Consequently, to investigate the effect of intensity *per se* on the acute PEH responses, it is necessary that the different exercise sessions are *isocaloric*, meaning that the total energy expenditure is similar between the different exercise bouts. A few previous studies have investigated the effect of different bouts of isocaloric endurance exercise on the PEH response: Comparing moderate and intensive endurance exercise, Ramirez-Jimenez et al. (2017) observed that the ambulatory blood pressure 14 hours post exercise was lower following intensive exercise. Their conclusion was that the magnitude of PEH responses was determined by the exercise intensity (39), while others have concluded that the total volume (energy expenditure) seems to be a major determinant of the PEH response in pre-hypertensive men (14). However, there are marked differences between the two latter studies, as Ramirez-Jiminez et al. (39) included both hypertensive and normotensive persons with metabolic syndrome, while Fonseca et al. (14) included pre-hypertensive men without metabolic syndrome.

Consequently, results from previous studies are ambiguous and there is a need for additional research to clarify the importance of exercise intensity on PEH responses, especially in persons with stage 1 hypertension. The primary objective of the present study is to investigate the acute PEH response of middle-aged persons with elevated blood pressure/hypertension stage 1 following endurance exercise bouts with different intensities, but similar total energy expenditure. Furthermore, we will examine how cardiac output and systemic vascular resistance affects the PEH response and finally, investigate relations of resting blood pressure with magnitude of post-exercise blood pressure changes.

METHODS

Participants

Adult men and women over 40 years of age with elevated blood pressure (systolic BP 120-129 mmHg and diastolic BP < 80 mmHg) or stage 1 hypertension (130-139 or 80-89 mmHg) following the classifications of the American Heart Association (AHA) (47), but otherwise healthy, and with no history of cardiovascular disease were invited to participate in this project. Twenty persons responded to the invitation. Two participants withdrew of personal reasons, and six persons were disqualified due to the exclusion criteria. The physical characteristics of the remaining 12 persons (6 males and 6 females) that completed the study is reported in Table 1. Ethical approval for the study was given by The Regional Committee for Medical and Health Research Ethics in Norway and the study has been performed in accordance with the 1964 Declaration of Helsinki and its later amendments regarding ethical standards. Furthermore, this research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (30).Written consent was obtained by all participants' prior to inclusion in the study. Exclusion criteria were smoking, participation in strenuous exercise more than once a week, systolic/ diastolic blood BP lower than 120/80 mmHg, secondary hypertension, use of medication that could affect the outcome variables (including BP lowering drugs), or orthopedic disorders that would make it difficult to perform bicycling exercise.

Protocol

Overall design of the project: The overall aim of the study was to compare the acute post-exercise hemodynamic and cardiovascular responses of high intensity endurance exercise (INT) to the responses of moderate intensity endurance exercise (MOD). To study this objective, the participants conducted a test of their peak aerobic capacity (VO_2peak) and two endurance exercise bouts with different intensities on separate days. On day one of the experiments, resting systolic and diastolic blood pressure were recorded prior to the VO_2peak test (Table 1). The peak heart rate (HR_{peak}) values obtained during the VO_2peak test were later used for calculation of target intensity zones during the INT and MOD exercise bouts. The intensity zones were set to about 90% and 75% of HR_{peak} for the INT and MOD sessions, respectively. During both exercise session, the bike resistance (W) was continuously adjusted to keep the participants HR close to their target HR for the specific exercise session.

A primary goal of the study was to keep the total energy expenditure (TEE; kcal min^{-1}) similar between the INT and MOD exercise sessions (isoenergetic exercise). Hence, of practical reasons it was necessary that all participants completed the INT session before the MOD session since high intensity exercise expend more energy per unit time compared to moderate intensity exercise. The individual TEE obtained during the INT session was then the target TEE the participants had to achieve during MOD exercise. Consequently, in order to equate the TEE between the two bouts, the total duration of the INT and MOD sessions had to be different (Table 2). The INT and MOD exercise sessions were conducted on day two and three of the experiments at the same time of the day, but with a minimum of 48 hours between each session. For both exercise sessions, pre-exercise values (PRE-EXC) of systolic and diastolic blood pressures (SBP and DBP), heart rate (HR) and cardiac output (CO) were measured after the participants were fully instrumented and had been sitting quietly on the ergometer bike for five minutes. During INT and MOD exercise, the all the above variables were recorded at fixed intervals during exercise. The energy expenditure (kcal min^{-1}) was monitored continuously during the exercise sessions and reported by the ergo spirometry software each third minute. The exercise bouts were terminated once the predetermined target for total energy expenditure (TEE) was achieved, and the immediate post-exercise values (PE-0 min) SBP, DBP, HR and CO were recorded while the participants were still sitting on the ergometer bike. Following these registrations, the ergo spirometry measurements were stopped, the ergo spirometry facemask removed, and the participants moved to a comfortable chair where they sat quietly without sleeping for the next 30 minutes. Values of SBP, DBP, HR and CO were subsequently recorded 5, 10, and 30 minutes post-exercise (PE). The temperature in the laboratory was maintained at 21-22 °C during all sessions to keep the environment thermo-neutral (24). The participants were instructed to avoid exercise and alcohol 24 h before reporting to the laboratory for all testing and exercise sessions.

VO_2peak test procedure: Following measurements of baseline BP, the participants were instrumented with the proper equipment before they went to sit on the bicycle ergometer. Pre-exercise values of HR, lung ventilation (VE) and oxygen uptake (VO_2) were measured following quiet sitting for five minutes on the ergometer. The test then started with a warm-up sequence on the ergometer bike with a fixed load of 75 Watt (W) for 10 minutes. Cadence was self-selected, but the participants were instructed to keep the cadence > 70 rpm. Following the warmup, the load increased with 10 W every 30 seconds until volitional exhaustion. Expired gases were measured by ergo spirometry in breath-by-breath mode and averaged in 20 second intervals.

The highest VO_2 value (average of 20 sec.) observed in the last 60 sec of the test was recorded as the VO_2peak. Lactate (La^-) and ratings of perceived exertion (RPE; 0-10 scale) was measured prior to exercise and within one-minute following termination of the VO_2peak test.

INT exercise test procedure: Prior to start of INT exercise session, the participants were fitted with and a non-rebreathing facemask for ergo-spirometry and the appropriate equipment for HR, CO and BP measurements. The exercise session started with a warmup sequence for 10 minutes on a cycle ergometer with >70 rpm per minute, and with a load of 75 W. Following the warmup, the bike resistance was gradually increased to the target HR zone. Following four minutes at high intensity (about 90% of HR_{peak}), the participants then continued their exercise for four minutes at a medium intensity (about 75% of HR_{peak}). This protocol continued until the participant had completed a total of four high intensity intervals and three medium intensity intervals, hence, the total exercise time for the INT exercise session was 28 minutes. At the termination of INT exercise, the individual TEE (kcal min^{-1}) was logged, and the aim was then to reproduce this energy expenditure during MOD exercise.

MOD exercise procedure: The instrumentation, pre-exercise protocol and warm-up sequence during MOD exercise was similar to the INT exercise. Following the warm-up, the load of the ergometer bike was gradually increased to the predetermined exercise intensity, which was set to about 75% of HR_{peak}. The MOD exercise session was immediately stopped when the TEE was similar to the TEE during INT.

Instruments: VO_2peak testing and INT and MOD exercise sessions were performed on an electronically braked bicycle ergometer (Lode Excalibur Sport, Groningen, The Netherlands). Pulmonary gas exchange was measured by indirect calorimetry in breath-by-breath mode, using a Vyntus CPX ergo spirometry unit (Jaeger, BD/Carefusion, New Jersey, USA). The ergo spirometer was calibrated against ambient air and a commercial gas of known concentrations of O_2 (15 %) and CO_2 (5.8 %) according to the manufacturers' instructions. During testing and exercise, the participants breathed through a two-way, non-rebreathing facemask (model 7450 *V2*, Hans Rudolph Inc., Kansas, USA) connected to a turbine-type flow meter. The flow meter was calibrated using a 3 L precision calibration syringe (Calibration syringe 5530, Hans Rudolph Inc., Kansas, USA). The flow meter was changed and recalibrated before each test. Energy expenditure (kcal min^{-1}) was automatically reported by the software of the ergo spirometer based on stoichiometric equations involving oxygen uptake (VO_2 L min^{-1}), respiratory exchange ratio values and the corresponding caloric equivalents of oxygen during exercise (16). Protein oxidation during exercise was assumed to be insignificant (5). Cardiac output was measured noninvasively by impedance cardiography (PhysioFlow Enduro, Manatec, Folschviller, France), and are based on the assumption that changes in aorta blood volume induce opposing changes in electrical impedance (29). To investigate this, the participants were fitted with six EKG electrodes (Skintact FS-50, Innsbruck, Austria) that were attached to the upper body of the participants, carefully adhering to the manufacturer's instructions regarding skin preparation. A detailed description of the impedance cardiography methodology is found elsewhere (40). The reliability and accuracy of this system has been compared with the direct Fick method both at rest and during moderate and maximal endurance exercise. Mean difference in CO between the two methods was 0.04 L min^{-1} at rest and 0.29 L min^{-1} during moderate endurance exercise (6). During maximal incremental endurance exercise testing, the correlation coefficient of the two techniques was 0.946 ($P < 0.01$) with an average difference of 2.78% (40).

Pre-exercise, exercise and post-exercise SBP and DBPs were measured by an automated stress test monitor (Tango+, SunTech Medical, Morrisville, North Carolina, USA) using an Orbit-K exercise BP cuff (Suntech Medical, North Carolina, USA) placed on the left upper arm. The accuracy of the Tango+ instrument has been compared to beat-to-beat brachial intra-arterial measurements during exercise testing (4). During exercise, the combined mean difference (± SEM) between invasive and the automated Tango+ SBP and DBP measurements were 4.79 ± 0.14 mmHg and 6.33 ± 0.10 mmHg, respectively. Cameron et al. (4) concluded that the Tango+ instrument provided reliable BP assessments with absolute differences within an acceptable clinical range. La^- was measured in capillary whole blood by finger-prick samples (Lactate Pro2 LT-1730, Arkray Inc., Kyoto, Japan).

Calculations: INT exercise responses of SBP, DBP, HR and CO were recorded during the third minute of each four-minute high intensity interval and reported as average values of the four high intensity work periods. Including the four minutes from the preceding medium intensity interval, this means that INT exercise responses were recorded each seventh minute. MOD exercise responses were recorded every seventh minute during exercise and are reported as average values of all these recordings. Systemic vascular resistance (SVR) was calculated according to the following formulae: SVR = MAP/CO x 80.

Table 1. Physical characteristics of the included participants, n = 12.

	Means ± SD
Age, years	54.1 ± 7.2
Height, cm	177 ± 11.0
Weight, kg	78.2 ± 7.2
Body mass index, kg/m^2	24.8 ± 3.7
Resting systolic BP, mmHg	130 ± 6.6
Resting diastolic BP, mmHg	84 ± 7.0

Resting arterial blood pressures (BP) were taken after five minutes of quiet resting in a chair. BPs were measured three times with one-minute intervals and the latter two measurements were averaged and then reported.

Statistical Analysis

The data was checked for normality with the Shapiro Wilks test. All variables satisfied the criteria of approximately normal distribution, except for SBP immediately after the INT exercise (PE-0 min., Shapiro-Wilk=0.799, p = 0.009). We identified one extreme score (male, SBP=199 mmHg) and, hence, excluded this subject from the analysis of SBP. Sample size was calculated for an F tests ANOVA with repeated measures and within-between interaction by use of the G*Power (version 3.0.10, Universität Kiel, Germany). Given an effect size of 0.38 for reductions in post-exercise systolic BP an alpha-level of 0.05 and desired power of 0.80 (4),(20), we calculated that we needed a total sample of minimum eight persons. Paired-sample t-tests were used to test for differences between participants' physiological responses, total duration of exercise, energy expenditure, bike resistance and self-reported level of exertion during the two different exercise sessions (MOD, INT), where only two means were involved in the analyses. A 2 (MOD vs. INT) × 6 (Pre-exercise, Exercise and Post-exercise 0, 5, 10, 30 min.) ANOVA with repeated measures on both variables and sex as between-subject factor was used to test for differences in SBP, DBP, HR, CO and SVR between the two exercise session from pre-excercise and throughout the post-exrcise recovery period. Post-hoc comparisons with Bonferroni corrections were conducted to detect the pair-wise differences in case of a significant ANOVA. All results are presented as means ± SD. In those instances where the sphericity assumption was violated, Greenhouse–Geisser adjustments of the P values were reported. The criterion level for significance was set at $p < 0.05$. The effect size was evaluated with pη2 (partial eta squared) where 0.01 < pη2 < 0.06 constitutes a small effect, 0.06 < pη2 < 0.14 constitutes a medium effect, and pη2 > 0.14 constitutes a large effect (11). To investigate the relationship between pre-exercise SBP values and post-exercise changes in SBP a linear regression analysis was performed with *delta* SBP as dependent variable and pre-exercise SBP as independent variable. *Delta* (Δ) SBP was calculated as SBP values 30 post-exercise minus SBP pre-exercise values. Statistical analysis was performed with IBM SPSS Statistics for Windows, version 24.0 (IBM Corp., Armonk, NY, USA).

RESULTS

VO_2peak test: Mean (± SD) peak oxygen uptake (VO_2peak) for the participants was 33.7 ± 5.8 mL min^{-1} kg^{-1} (2.63 ± 0.63 L min^{-1}). Peak values for VE, HR, RER, La^- and RPE were 109.5 ± 28.8 L min^{-1}, 174 ± 12.5 beats min^{-1}, 1.20 ± 0.06, 11.8 ± 2.3 mMol L^{-1}, 9.7 ± 0.5, respectively. The mean peak power generated was 252 ± 67 Watt.

Characteristics of INT and MOD exercise: Oxygen uptake, heart rate, power output and self-reported post-exercise RPE was higher during INT than MOD (Table 2). The total duration of exercise was longer during MOD than INT, while TEE was similar between the exercise sessions.

Table 2. Physiological responses, total energy expenditure (TEE), duration of exercise and bike resistance during high intensity (INT) and moderate intensity (MOD) exercise. Values are means ± SD, *n* = 12.

	MOD	INT
Duration of exercise, min	35.3 ± 4.5	28.0 ± 0***
VO_2 (% VO2peak)	66.2 ± 10	80.2 ± 8**
Heart rate (% HRpeak)	77.6 ± 17	87.6 ± 1.7***
Bike resistance, Watt	146 ± 32	176 ± 35*
TEE, kcal min^{-1}	359 ± 70	358 ±70

VO2, HR and Watt values are mean values of measurement recordings every 7th minute during INT and MOD exercise sessions (see method for details). * = Significant differences between MOD and INT exercise; $p < 0.05$; **p <0 .01; ***$p < 0.001$.

Blood pressure and hemodynamic responses during and after INT and MOD exercise: Table 3A and B shows Pre-exercise (PRE EXC), Exercise (EXC) and Post-exercise (PE) blood pressure and hemodynamic responses separately for male/females and exercise conditions (INT and MOD), as well as for all participants pooled (Total). Table 4 shows the related statistics from the repeated measures ANOVA. All measured blood pressure and hemodynamic variables showed a significant main effect of time and, thus, varied considerably between PRE EXC, EXC and PE (Table 4). For all participants pooled, the SBP was 12 – 13 % lower at PE-30 min. compared to PRE EXC. There also was a significant effect of sex and time by sex for SBP, due to males overall showing 8% higher values for SBP and about 14% higher SBP during exercise. There was no significant main effect of condition (INT and MOD exercise) upon the SBP-response. A main effect of time was found for DBP. At PE-0 min the DBP was overall 17% lower compared to PRE EXC. At PE-5 min and 10 min, the DBP was 11% and 13% higher than compared to immediately after termination of exercise (PE-0 min). No other main or interaction effects were found for DBP. Heart rate (HR) varied considerably as a function of exercise intensity (main effect of time). Overall, the HR was 7% higher for INT than for MOD. In particular, the HR was 12% higher for INT than for MOD during EXC and at PE 0 min. For CO and SVR there were only main effects of time and the response was due to the exercise intensity; CO increased during exercise and thereafter fell during rest, while SVR showed the opposite trait. At PE 30 min., DBP, HR, CO and SVR values were all similar to PRE EXC values.

Table 3. Blood pressure and hemodynamic responses at different times during high-intensity (3A) and moderate intensity (3B) isoenergetic endurance exercise. *n* =12, values are means ± SD

		High-intensity endurance exercise					
		PRE EXC	EXC	PE 0 MIN	PE 5 MIN	PE 10 MIN	PE 30 MIN
SBP, mmHg	Total	129.5±2.2	180.2±3.7 aaabb	145.4±5.1 bbb	122.0±2.4 ccc	117.5±2.8 cccd	114.3±2.4 acccdd
	Male	131.3±3.1	193.8±5.2 aaabb	154.5±7.2 bb	128.0±3.4 ccc	121.7±4.0 ccc	118.5±3.3 cccd
	Female	127.7±3.1	166.7±5.2 aaa	136.3±7.2 bb	116.0±3.4 ccc	113.3±4.0 ccc	110.0±3.3 ccc
DBP, mmHg	Total	84.3±1.5	77.1±3.5	70.7±2.0 aa	80.3±2.1	82.3±1.8 d	80.2±2.3
	Male	86.5±2.1	77.0±5.0	70.5±2.9	84.0±3.0	85.0±2.6	83.8±3.3
	Female	82.2±2.1	77.2±5.0	70.8±2.9	76.5±3.0	79.7±2.6	76.5±3.3
HR, beats^{-1}	Total	70.2±1.8	151.7±3.2 aaabbb	144.3±3.9 aaa	86.8±2.4 aaacccddd	83.0±3.0 acccddd	74.0±2.8 cccddd
	Male	69.8±2.6	152.1±4.5 aaabbb	144.8±5.5 aaa	86.0±3.4 aaacccddd	83.3±4.2 cccddd	75.2±3.9
	Female	70.5±2.6	151.3±4.5 aaabbb	143.7±5.5 aaa	87.7±3.4 aaacccddd	82.7±4.2 cccddd	72.8±3.9 ccddd
CO, L min^{-1}	Total	5.3±0.2	14.8±0.6 aaabb	14.0±0.8 aaa	7.4±0.3 aaacccddd	6.6±0.4 cccddd	5.6±0.4 cccddd
	Male	5.2±0.3	15.7±0.9 aaabb	14.9±1.1 aaa	7.3±0.4 acccddd	6.6±0.5 cccddd	5.8±0.5 cccddd
	Female	5.4±0.3	14.0±0.9 aaa	13.2±1.0 aaa	7.5±0.4 acccddd	6.6±0.5 cccddd	5.4±0.5 cccddd
SVR, dynes sec cm^{5}	Total	1510±46	656±39 aaabb	732±56 aaa	959±43 aaacccd	1134±53 aacccddd	1259±57 cccddd
	Male	1519±64	653±56 aaabbb	725±79 aaa	1001±62 aaccd	1172±74 cccdd	1254±80 cccddd
	Female	1501±64	660±56 aaa	740±79 aaa	917±62 aac	1097±74 acccd	1263±80 cccddd

		Moderate intensity endurance exercise					
		PRE EXC	EXC	PE 0 MIN	PE 5 MIN	PE 10 MIN	PE 30 MIN
SBP, mmHg	Total	130.6±3.0	174.2±5.2 aaa	136.3±5.7 bbb	119.1±3.1 ccc	117.5±2.9 ccc	113.1±2.9 aacccd
	Male	130.7±4.3	187.9±7.3 aaabb	148.2±8.1 bb	125.5±4.4 ccc	121.8±4.1 ccc	116.0±4.1 cccd
	Female	130.5±4.3	160.5±7.3 aa	124.3±8.1 b	112.7±4.4 ccc	113.2±4.1 cc	110.2±4.1 accc
DBP, mmHg	Total	87.8±1.7	72.3±3.6	75.4±3.4	81.7±2.2	82.8±2.4	79.7±3.0
	Male	89.5±2.4	72.5±5.1	77.8±4.9	87.5±3.2	88.0±3.4	80.2±4.3
	Female	86.0±2.4	73.3±5.1	73.0±4.9	75.8±3.2	77.5±3.4	79.2±4.3
HR, beats^{-1}	Total	68.6±2.2	134.6±4.2 aaabbb	128.6±3.4 aaa	82.3±2.0 aacccddd	77.4±1.8 cccddd	72.5±3.0 cccddd
	Male	69.3±3.1	134.6±4.2 aaabbb	131.2±4.8 aaa	79.5±2.8 cccddd	76.8±2.5 cccddd	71.8±4.3 cccddd
	Female	67.8±3.1	135.6±4.2 aaabbb	126.0±4.8 aaa	85.0±2.8 acccddd	78.0±2.5 cccddd	73.2±4.3 cccddd
CO, L min^{-1}	Total	5.2±0.2	13.9±0.7 aaabb	13.2±0.9 aaa	7.1±0.4 aacccddd	6.6±0.3 aacccddd	5.7±0.2 cccddd
	Male	5.2±0.3	13.9±0.9 aaabb	14.0±1.3 aaa	6.4±0.5 cccddd	6.3±0.4 cccddd	5.4±0.3 cccddd
	Female	5.3±0.3	13.9±0.9 aaa	12.3±1.3 aaa	7.8±0.5 accd	6.9±0.4 acccdd	6.1±0.3 cccdd
SVR, dynes sec cm^{5}	Total	1424±67	623±40 Aabb	686±43 aaa	938±42 aacccddd	1107±53 abcccddd	1242±70 ccddd
	Male	1461±95	644±56 aabb	714±61 aaa	1019±60 acccdd	1254±75* bcccddd	1370±99 cccddd
	Female	1387±95	602±56 aaa	659±61 aaa	856±60 aac	960±75 aacc	1124±99 cccdd

PRE EXC = Pre-Exercise, EXC = Exercise, PE = Post Exercise, SBP = Systolic blood pressure, DBP = diastolic blood pressure, HR = Heart rate, CO = Cardiac output, SVR = Systemic vascular resistance. The EXC values are mean values of measurement recordings every seventh minute during INT and MOD exercise sessions (see method for details). a = Significantly different from PRE EXC, $^{a}p < 0.05$, $^{aa}p < 0.01$,$^{aaa}p< 0.001$; b = Significant different from previous measurement, $^{b}p < 0.05$,$^{bb}p < 0.01$,$^{bbb}p < 0.001$; c = Significant difference from EXC, $^{c}p < 0.05$,$^{cc}p < 0.01$,$^{ccc}p< 0.001$; d = Significant different from PE 0 min, $^{d}p < 0.05$, $^{dd}p < 0.01$,$^{ddd}p< 0.001$.

Table 4. ANOVA-table for main effects of time, sex, condition (high- and moderate intensity) and their two-ways interactions upon blood pressure and hemodynamic responses.

	Time		Sex		Cond.		Time x Sex		Time x Cond.		Sex x Cond.	
	F-score	$p\eta^2$	F-score	$p\eta^2$	F-score	$p\eta^2$	F-score	$p\eta^2$	F-score	$p\eta^2$	F-score	$p\eta^2$
SBP	F(3/30) = 77.30***	0.89	F(1/10)= 5.21*	0.34	F(1/10) = 0.71	0.07	F(6/30)= 3.62**	0.27	F(2.2/22) = 1.46	0.13	F(1/10) = 0.12	0.01
DBP	F(2.3/23) = 5.76**	0.37	F(1/10)= 0.99	0.09	F(1/10) = 1.00	0.09	F(6/23)= 1.60	0.14	F(6/60) = 0.98	0.09	F(1/10) = 0.01	0.001
HR	F(6/60) = 218.37***	0.96	F(1/10)= 0.44	0.04	F(1/10) = 26.3***	0.72	F(6/60)= 3.23**	0.24	F(6/60)= 7.73***	0.44	F(1/10) = 0.01	0.000
CO	F(2.3/22.8) = 147.65***	0.94	F(1/10)= 0.01	0.001	F(1/10) = 1.00	0.09	F(6/22)= 2.65	0.21	F(6/60) = 1.03	0.09	F(1/10) = 0.76	0.07
SVR	F(3/29) = 96.78***	091	F(1/10)= 3.71	0.27	F(1/10) = 0.28	0.03	F(3/29)= 1.49	0.13	F(6/60) = 0.86	0.08	F(1/10) = 1.29	0.11

Cond. = Condition, SBP = Systolic blood pressure, DBP = Diastolic blood pressure, HR = Heart rate, CO = Cardiac output, SVR = Systemic vascular resistance, pη2 = Partial eta squared. * = Significant effect, *p < 0.05, **p < 0.01, ***p < 0.001.

Relationship between pre-exercise SBP values and changes in SBP 30 minutes post exercise: The linear regression analysis results showed a significant ($p < 0.003$) relationship between pre-exercise SBP values and the delta (Δ) SBP values 30 minutes post exercise (ΔSBP = PE 30 min SBP values minus PRE EXC SBP values) (Fig 1). The R^2 value was 0.334, so 33 % of the variation in post exercise Δ SBP values can be explained by the model containing only pre-exercise SBP. The scatterplot of standardized predicted values versus standardized residuals, showed that the data met the assumptions of homogeneity of variance and linearity and the residuals were approximately normally distributed.

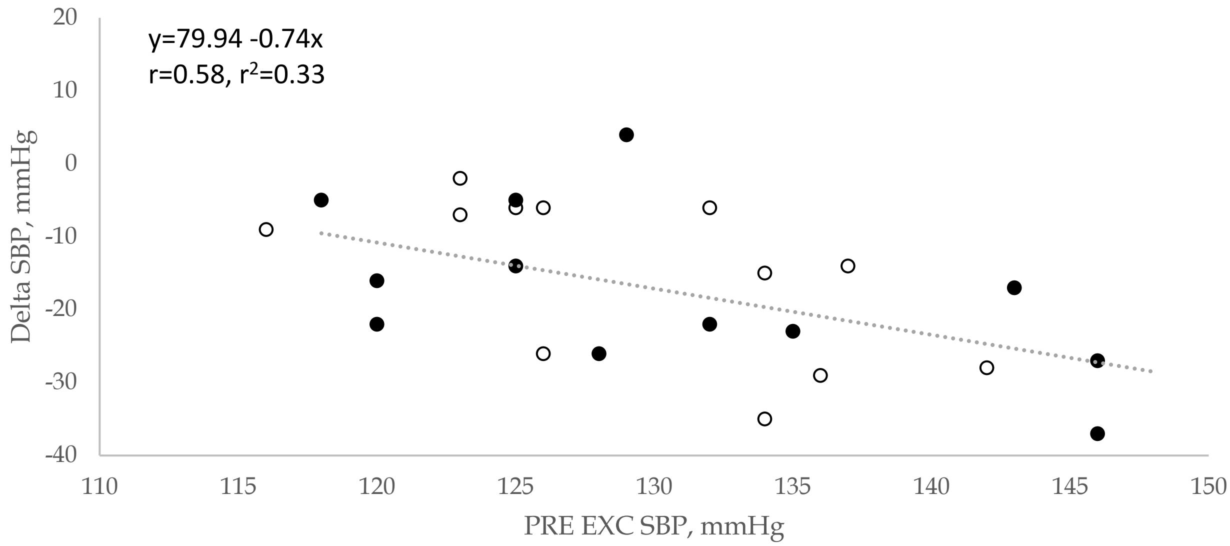

Figure 1. Relationship between pre-exercise systolic blood pressure (SBP) values and the magnitude of post-exercise SBP reductions. Delta SBP values are calculated as SBP values 30 min. post exercise minus SBP pre-exercise values. Open symbols = INT exercise; Closed symbols = MOD exercise.

DISCUSSION

The present study investigated the post-exercise hypotension (PEH) responses following moderate (MOD) and intensive (INT) isolcaloric endurance exercise. The major finding in our study was that endurance exercise with different intensities, but similar total energy expenditure elicited similar reductions in the post exercise systolic blood pressure (BP). Current exercise prescriptions for persons with high BP recommend moderate intensity endurance exercise, but our results show that intensive, intermittent exercise for less than 30 minutes per session is equally effective in reducing systolic BP as longer duration, moderate intensity exercise. It should be noted that e.g. AHA (2) in consideration of emerging evidence on exercise intensity and magnitude of BP reductions, also endorses vigorous intensity aerobic exercise for people with hypertension. We believe our results support this endorsement.

There is, however, a lack of consistency regarding the effect of exercise intensity on the PEH response. Prior investigations on this topic (12),(18),(31),(38),(33),(1),(42),(37),(9) have compared the effect of different exercise intensities on post exercise BP, but in these studies the different exercise sessions were of similar duration. Using exercise sessions with different intensities, but similar duration results in different total energy expenditures across sessions, thus from these studies it is difficult to conclude on how exercise intensity per se affects the PEH responses.

Few prior studies have used a research design similar to the present study, but e.g. Jones et al. (22) investigated the effect of exercise intensity on post-exercise BP responses while simultaneously controlling the total work performed (watt x time). In this study, seven normotensive males performed semi-recumbent cycling at 70% of VO_2peak for 30 min and cycling at 40% VO_2peak for a time that corresponded to the same total work as in the more intense exercise trial. The results show that the overall PEH response was similar following high intensity short duration exercise and moderate intensity longer duration exercise matched for total work done (22). In contrast to the present study and the study of Jones et al., Ramirez-Jiminez (39) showed that average systolic BP during 14 h of ambulatory post-exercise BP collection was about 6 mmHg lower in hypertensive individuals following intensive exercise (80% of VO_2peak), compared to moderate intensity isocaloric exercise (60 % of VO_2peak). The Ramirez-Jiminez study is quite similar to the present study with regard to use of bicycle ergometry, isocaloric exercise and choice of exercise intensities, but none the less, they observe an effect of exercise intensity on post-exercise systolic BP. The reason for this discrepancy is unclear, but we observe that the participants in the Ramirez-Jiminez study were overweight (BMI ~ 30), they all had metabolic syndrome, had 26% lower VO_2peak and about 5 mmHg higher resting BP than the participants in the present study. Hence, differences in participant baseline characteristics may affect the BP response following exercise. This argument is supported by the fact that Ramirez-Jiminez et al. observed no differences in ambulatory post-exercise BP in the normal-weight, normotensive participants in the above study (39). Taken together, the results of Jones et al., (22) and Ramirez-Jiminez et al., (39) suggest that the PEH response is independent of exercise intensity in healthy, normotensive adults, and this seems to be the case also for adults with elevated blood pressure/stage 1 hypertension without metabolic syndrome (present study). However, in hypertensive unfit individuals with metabolic syndrome, the PEH response may obviously be different (39).

We also observed that the males in the present study had a significant higher systolic BP (SBP) during both MOD and INT exercise, compared to the females. Others have observed similar sex related differences in the blood pressure response during bicycle ergometry (21, 46) and Hedman et al. (21) argued that sex differences in exercise SBP test might be due to females having a greater systemic vascular resistance (SVR) compared to males. In the present study, however, there was no difference between males and females for exercise SVR. We observe, however, that overall, men tended to have a larger cardiac output (CO) during exercise than females (14.8 ± 0.6 vs. 13.9 ± 0.6 L min^{-1}, difference not significant). This is similar to the study of Wheatley et al. (46), demonstrating that males had a higher SBP and CO than females during moderate and vigorous bicycle ergometry. The study of Wheatley et al. (46) is relatively comparable to our study design, while the study of Hedman et al. (21) used a continuous ramp maximal exercise protocol. Hence, sex differences in the exercise BP response may possibly be related to differences in exercise protocols or e.g. a different balance between cardiac output and systemic vascular resistance in males and females, but this needs to be further investigated.

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The participants in the present study had a mean resting systolic/diastolic BP of 130/84 mmHg, and recently the effect of systolic blood pressure reductions on risk of cardiovascular disease and mortality has been reviewed (3). This systematic review and meta-analysis show that persons with an systolic BP of 120 – 124 mmHg had nearly 30 % lower risk (Hazard Ratio) of major cardiovascular disease compared to persons with systolic BP of 130 – 134 mmHg (Hazard Ratio 0.71, 95% CI 0.60 – 0.83). Hence, potentially large health benefits can be achieved with a reduction in resting systolic BP of 6 – 10 mmHg. In this respect, our data demonstrate that there was a negative association between resting systolic BP and post exercise reductions in systolic BP, i.e. the persons with the highest resting systolic BP had the largest reduction in post exercise systolic BP (Fig 1). Thus, the persons most in need of lowering their resting blood pressure obtain the greatest benefits of endurance exercise (34, 35). From pre exercise values, the reduction in systolic BP after 30 minutes of rest was about -16 ± 11 mmHg, but since we stopped our monitoring at 30 minutes post exercise, it is unclear if the BP reductions had reached its nadir at this time point. Other studies suggest that relative to resting values, the hypertensive response following one bout of exercise, may last at least for one hour (10), (26), (28) and possibly for several hours (31), (36).

Also, Pescatello et al. (35) suggests that the PEH response is a low threshold phenomenon with regards to the duration of exercise needed to produce the hypotension effect. Studies using ambulatory blood pressure recordings for extended periods of time, demonstrate that the blood pressure is lower on the days persons exercise compared to the days they do not exercise (1), (9), (44), i.e. the PEH response is obviously a transient phenomenon. This indicates that the exercise frequency (no. of bouts week^{-1}) is important in shaping the hypotension effect, and that patients should exercise regularly, if not most days of the week, if endurance exercise is to be an effective alternative to pharmacological treatment of elevated BP/hypertension. This topic needs, however, to be investigated more thoroughly.

Previous investigations have established that the hypotension response can be regulated by both neural and vascular components (18), but it was not possible to investigate potential neural components in the present study. We have, however, investigated how adjustments in cardiac output (CO) and systemic vascular resistance (SVR) affect the PEH response. The general view on this topic is that the vascular component of the PEH response is mediated by a sustained reduction in SVR which is not offset by an increase in CO (19). This seems to be the case also in the present study and similar to Forjaz et al. (15), we observed no differences in SVR and CO responses between MOD and INT exercise. Compared to pre-exercise values, SVR dropped approximately 50% during exercise, and while SVR started to increase following termination of exercise, measurements were still significantly lower than pre-exercise values 10 minutes post-exercise. As expected, CO values showed a reverse relationship to SVR during exercise and following exercise termination, there was a continuous decrease of CO towards pre-exercise, resting levels. Following 30 minutes of post-exercise recovery, CO and SVR were similar to pre-exercise values, and this underscore the importance of exercising regularly, in order for exercise is to be an effective substitute to pharmacological treatment of higher than normal BP.

Conclusion: The major finding in our study was that endurance exercise bouts with different intensities, but similar TEE elicited similar reductions in the post-exercise systolic BP, with no differing effects between men and women with elevated blood pressure/stage 1 hypertension. Hence, if one chooses to exercise at a higher intensity, the duration of the exercise bout may be shorter, without compromising the PEH response. Also, our findings point out that it is not necessary to perform intensive exercise to volitional exhaustion to obtain a substantial PEH response as we obtained a PEH response after only 28 minutes of exercise. Collectively, our findings generate more options for tailoring exercise prescriptions to the needs and preferences of individuals in need of a non-pharmacological way of lowering resting blood pressures.

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