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ORIGINAL ARTICLE

The magnitude and duration of post-exercise hypotension after land and water exercises

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Abstract The objective of the study was to determine and compare the magnitude and duration of post-exercise hypotension (PEH) during free-living conditions after an acute session of concurrent water and land exercise in individuals with prehypertension and hypertension. Twenty-one men and women (aged 52 ± 10 years) volunteered for the study. Participants completed a no exercise control session, a water exercise session and a land exercise session in random order. After all three sessions, participants underwent 24-h monitoring using an Ergoscan ambulatory BP monitoring device. Systolic blood pressure (SBP) and diastolic blood pressure (DBP) were monitored to determine changes from resting values after each session and to compare the PEH responses between land and water exercises. During daytime, both land and water exercises resulted in significantly lower SBP (12.7 and 11.3 mmHg) compared to the control session (2.3 mmHg). The PEH response lasted for 24 h after land exercise and 9 h after water exercise. There was no difference in the daytime DBP for the three treatments ($P > 0.05$). Although all three groups showed significant reductions during nighttime, both exercise treatments showed greater nocturnal falls in BP than the control treatment. This is the first study to show that the magnitude of the PEH response is similar for land and water exercises, although the duration of PEH may be longer for land exercise. These results suggest that water exercise is a safe alternative exercise modality for individuals with suspected and known hypertension.

Keywords Concurrent exercise · Water aerobics · Blood pressure · Ambulatory

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Introduction

The beneficial effects of regular exercise for special populations such as those with hypertension are undisputable (Fagard 2006; Pescatello et al. 2004). Many studies have shown that an acute bout of aerobic or resistance exercise leads to an immediate drop in both clinical and ambulatory blood pressure in normotensive and hypertensive individuals (Bermudes et al. 2004; Melo et al. 2006; Pescatello et al. 2004; Pescatello and Kulikowich 2001; Quinn 2000; Wallace et al. 1997). This phenomenon is termed post-exercise hypotension (PEH). The magnitude and duration of the drop in BP vary depending on the type and intensity of exercise (Quinn 2000; Wallace et al. 1997) and the hypotensive response is more pronounced and longer lasting in those with higher resting blood pressure values (Cardoso et al. 2010). Furthermore, the PEH response is usually observed during daytime hours (Blanchard et al. 2006; Brandão Rondon et al. 2002; Park et al. 2006; Pescatello and Kulikowich 2001; Wallace et al. 1997) when higher blood pressure levels may be expected.

One mode of exercise that has gained popularity over recent years is aquatic exercise. The buoyancy of the water reduces weight bearing by about 90 %, which reduces the mechanical stress on the limbs, thus making this a safe exercise for individuals with low levels of fitness and weaknesses or injuries of the lower extremities (Barbosa et al. 2007). The hydrostatic pressure causes redistribution of the blood to the thoracic cavities which leads to an increase in stroke volume and cardiac output (Cider et al. 2005; Park et al. 1999), while movement against the resistance of the water increases the workload. Water exercise can thus be classified as concurrent exercise as both cardiovascular fitness and muscle strength are improved. There is also greater heat exchange between the body and the water (Barbosa et al. 2007), which may enhance temperature regulation during exercise.

There is, however, no certainty regarding the acute BP responses during and especially after water exercise in normotensive or hypertensive persons. BP has been shown to increase (Park et al. 1999), decrease (Darby and Yaekle 2000) or remain unchanged (Cider et al. 2005) when the subject is immersed in thermo-neutral water. However, it has been reported that water immersion is associated with decreased plasma concentrations of renin, angiotensin II, aldosterone, norepinephrine and epinephrine, all of which regulate and affect BP (Cider et al. 2005). Importantly, there is no compelling evidence that exercise in any temperature or depth of water results in adverse cardiovascular or BP responses in individuals with or without hypertension. For instance, Darby and Yaekle (2000) found no significant differences in the blood pressure responses between similar land and water exercises, completed at comparable training heart rates. In fact, the individuals' systolic and diastolic blood pressures were slightly lower in the water.

Only a few studies attempted to determine the duration of PEH using ambulatory BP monitoring for up to 24 h after dynamic exercise (Brandão Rondon et al. 2002; Ciolac et al. 2008; Guidry et al. 2006; Rueckert et al. 1996; Quinn 2000). Although significant reductions in BP under free-living conditions have been reported for up to 22 h in hypertensive individuals, the results of most studies on the duration and magnitude of PEH during activities of daily living report disparate results (Darby and Yaekle 2000; Rueckert et al. 1996).

Hence the aim of this study was to quantify the magnitude and duration of the PEH response during free-living conditions after concurrent water and land exercise in individuals with prehypertension and hypertension.

Methods

Subjects

Twenty-one men ($n = 11$) and women ($n = 10$) aged between 33 and 69 years (mean 52 ± 10 years) volunteered to participate in the study. Subjects were excluded if they had a BMI greater than 40 kg m^{-2}, resting BP greater than 180/130 mmHg or had more than three risk factors according to the ACSM guidelines for exercise testing and prescription (American College of Sports Medicine 2010). Those participants ($n = 7$), who were taking anti-hypertensive drugs (3 calcium channel blockers, 3 ACE inhibitors, 1 diuretics) and obtained permission from their primary physicians, discontinued their medication for 2 weeks prior to the study. The rest of the group ($n = 14$) either never used anti-hypertensive drugs or had discontinued use at least 12 months prior to the study. Based on the ACSM's classification of hypertension (SBP >140 mmHg and/or DBP >90), 19 individuals were classified as hypertensive and two as prehypertensive during the baseline session and after the 2 weeks washout period. The study protocol was approved by the Ethics Committee of Research Subcommittee A at Stellenbosch University (Reference number 126/2008).

Procedures

Resting BP and heart rate (HR) were measured after a 5-min rest period and the average of three measurements was taken. All BP measures were taken with an automated ambulatory air bladder-containing cuff (Ergoline Ergoscan 2008, Germany) that met the validation criteria of the International Protocol for Validation of Blood Pressure Measuring Devices in adults issued by the European Society of Hypertension (Langewitz and Tanner 2009).

Waist and hip circumferences were measured according to the International Standards for Anthropometric Assessment (ISAA) protocol (Marfell-Jones et al. 2006) using a spring-loaded, non-extensible anthropometric tape measure (Rosscraft, Canada). Body composition was determined via bio-electrical impedance analysis (BIA) using the Bodystat 4.05® (Quadscan 2007, Isle of Man) and methods as previously described (Stahn et al. 2008).

Each participant's VO_{2peak} was determined on the h/p/cosmos Saturn treadmill (Nussdorf-Traunstein, Germany) using a Bruce protocol, while a 12-lead ECG (Mortara Instrument 2006, Milwaukee, USA) was monitored throughout the test. The participants were fitted on the treadmill with an adjustable safety harness. Breath-by-breath expired gas was sampled and analyzed using the Cosmed Quark b^2 (Rome, Italy) metabolic system. Heart rate was measured through telemetry (POLAR®, Polar Electro Oy, Finland) and interfaced with the metabolic system. The exercise test was terminated if any of the ACSM test termination criteria were visible (American College of Sports Medicine 2010), or the subject requested to end the test. At the termination of the exercise test, BP was recorded with the automated device.

Two 10 repetition maximum tests (10 RM test), one for the upper body (bench press) and one for the lower body (incline leg press), were performed to determine the maximal muscle strength for each individual and to quantify the intensity of the resistance exercise training sessions. The tests were performed according to the standard procedures (Baechle and Earle 2008) and BP was continuously monitored during and directly after the strength testing with the automated BP device.

Participants performed, in random order, one land and one water exercise session, as well as a control session with no exercise. The duration of each session was 55 min, while the intensity of the exercise sessions was between 60 and 80 % VO_{2peak} (RPE 12–16). HR was continuously recorded throughout each session with a Polar heart rate monitor (POLAR®, Polar Electro Oy, Finland). The water exercise was performed in an indoor pool and presented by a qualified and experienced instructor. The water temperature was regulated at 27 °C and the depth at the shallowest point of the pool was 2.1 m. Exercises included 30 min of endurance type activities, i.e. water treading, walking and jogging with and without rhythmic arm movements below and slightly above the water level. These activities were alternated with resistance type exercise, i.e. arm and leg movements against the resistance of the water with the body in the vertical position for a total of 25 min.

The land exercise session consisted of combined aerobic and resistance exercises. The aerobic exercises included 10 min each of treadmill walking, skiing on an elliptical trainer and cycling on a stationary bike. The resistance exercises followed the aerobic exercises and lasted 25 min. This included incline leg press, seated leg curl, leg extension, bench press, shoulder press, latissimus dorsi pull-down, seated row, triceps extension and biceps curl. Two sets of 10 repetitions were performed, with a rest period of 30 s between each set and 90 s between each exercise.

Directly after the exercise/control sessions, participants were fitted with the ambulatory BP monitor, and monitoring was started for the next 24 h. BP was measured every 20 min during daytime hours (between 06:00 and 22:00) and every 90 min during nighttime hours (between 22:00 and 06:00 the next morning). The longer measurement interval for nighttime was chosen to minimize discomfort levels and encourage compliance to the protocol. Day 2 comprised the waking hours of the next day taken from 06:00 until the BP monitor was removed at the laboratory.

During the 24-h recording, participants were required to follow their usual daily routine and diet, and abstain from any additional exercise. The 24-h monitoring was always performed on a typical workday and on the same day of the week for each participant. The three sessions were separated by 1 week and performed at the same time of day (between 6 and 9 a.m.).

Data analysis

Descriptive statistics are reported as mean ($\bar{x}$) and standard deviation (±SD) unless otherwise specified. Repeated measures analysis of variance (ANOVA) was performed with time (0–24 h) and treatment (land, water and control) as repeated factors. For each significant F ratio between baseline (point 0) and subsequent time points (1–24) (within-group differences), as well as between treatment groups at all the time points (between-group differences), post hoc comparisons were made using Fischer's least significant difference (LSD) tests. The statistical analysis was done on both the absolute measurements (as discussed in the text), as well as the change scores (differences between baseline and each time point (as depicted in the graphs). The level of significance was set at $P < 0.05$ for all analyses. Assuming a 5 mmHg reduction in BP as clinically important and statistical power of 80 %, it was estimated that a sample size of eight subjects would allow the detection of statistically significant PEH responses.

Results

The physical and physiological characteristics of the participants are summarized in Table 1. There were some expected statistically significant differences in anthropometric characteristics between men and women; however, there were no differences between the resting SBP or DBP of men and women and, therefore, the BP results were pooled. The average heart rates of the participants were 118 ± SD 11.3 bpm during the land exercise and 119 ± SD 17.4 bpm during water exercise.

In the graphs, time 0 h indicates the end of the exercise session and the start of the 24-h BP monitoring. Daytime is thus displayed up to 16 h after exercise and nighttime between 16 and 22 h post-exercise. Day 2 is indicated from 22 h until 24 h.

Systolic BP

There were no significant differences in SBP values at baseline for the three treatment groups (control: 145 ± SD 13.5, land: 150 ± SD 16.6, water: 152 ± SD 12.4 mmHg; $P > 0.05$). The average SBP over 24 h, including baseline, was 141 ± SD 6.6 mmHg (control), 137 ± SD 7.7 mmHg (land) and 139 ± SD 7.6 mmHg (water). There was a significant treatment effect ($P < 0.01$) in the average decrease in SBP from baseline (Fig. 1). The decrease over 24 h was greater following the land (14 ± SD 7.3 mmHg)

Table 1 The physical and physiological characteristics of the participants

Characteristic	Men ($n = 11$)	Women ($n = 10$)	Total ($n = 21$)
Age (years)	50 ± 12	54 ± 10	52 ± 10
Height (cm)	180 ± 5*	164 ± 6	172 ± 10
Weight (kg)	97 ± 11*	77 ± 15	87 ± 16
BMI (kg m^{-2})	29 ± 3	29 ± 6	29 ± 5
Body fat (%)	25 ± 4#	39 ± 7	32 ± 9
LBM (%)	75 ± 4*	61 ± 7	69 ± 9
Waist circumference (cm)	97 ± 7	87 ± 12	92 ± 11
Hip circumference (cm)	107 ± 5	108 ± 12	108 ± 9
WHR	0.9 ± 0.05*	0.8 ± 0.04	0.9 ± 0.07
Resting SBP (mmHg)	152 ± 14	145 ± 12	145 ± 13
Resting DBP (mmHg)	103 ± 12	94 ± 10	94 ± 12
HR_{max} (bpm)	158 ± 22	150 ± 18	154 ± 20
$VO_{2\ peak}$ (ml kg min^{-1})	33 ± 7*	24 ± 5	29 ± 8
1RM legs press (kg)	238 ± 58*	102 ± 62	173 ± 91
1RM bench press (kg)	45 ± 12*	14 ± 8	30 ± 19

BMI body mass index, *LBM* lean body mass, *WHR* waist to hip ratio, *HR* heart rate, VO_{2peak} maximum aerobic capacity, *RM* repetition maximum

* Significantly greater than women, $P < 0.05$

Significantly less than women, $P < 0.05$

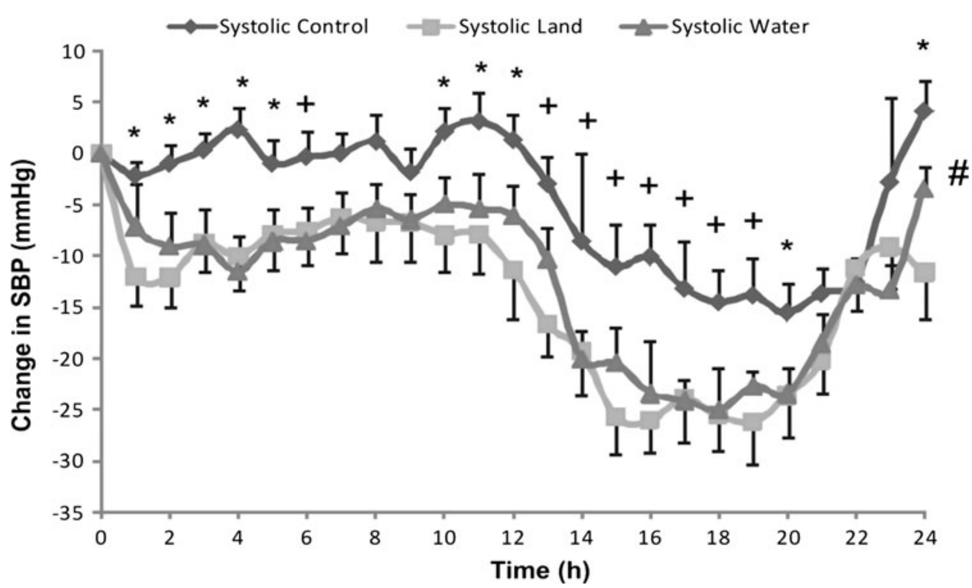

Fig. 1 Absolute changes in SBP from baseline over 24 h. Time point 0 indicates the baseline value (resting) followed by the differences between BP values every hour after exercise up to 24 h. *Asterisk* significantly different between land exercise and control, *plus symbol* significantly different between land exercise and control and between water exercise and control, *hash symbol* significant average decrease over 24 h, $P < 0.05$

and water (13 ± SD 7.3 mmHg) exercise sessions compared to the control session (5 ± SD 6.7 mmHg; $P < 0.01$ and $P < 0.01$, respectively). There was no significant difference in the average decrease between the land and water exercise treatments. However, the drop in SBP after land exercise was pronounced within the first hour after the exercise, while there was a slightly delayed response (up to 4 h) after the water exercise.

A significant interaction effect ($P = 0.01$) was observed for the daytime and nighttime responses (Fig. 2).There was an increase of 1.4 ± SD 7.7 mmHg during the daytime after the control session ($P > 0.05$), while the two exercise groups responded with significantly lower values during daytime (land: 7 ± SD 13.1 mmHg, $P = 0.02$; water: 7 ± SD 11.6 mmHg, $P = 0.02$). There were significant decreases during nighttime hours compared to baseline, with the greatest effect after the water exercise (control: 11 ± SD 12.2 mmHg, $P < 0.01$; land: 19 ± SD 15.2 mmHg, $P < 0.01$; water: 20 ± SD 16.8 mmHg, $P < 0.01$). Compared to baseline, the SBP in the morning on day 2 was 5 ± SD 12.2 mmHg lower for the control session ($P > 0.05$), 13 ± SD 17.2 mmHg ($P < 0.01$) lower for the land exercise session and 4 ± SD 15.5 mmHg ($P > 0.05$) lower for the water exercise session.

Diastolic BP

There were no significant differences between the baseline DBP values for the three treatments (control: 99 ± SD 13.5, land: 98 ± SD 12.9, and water: 102 ± SD

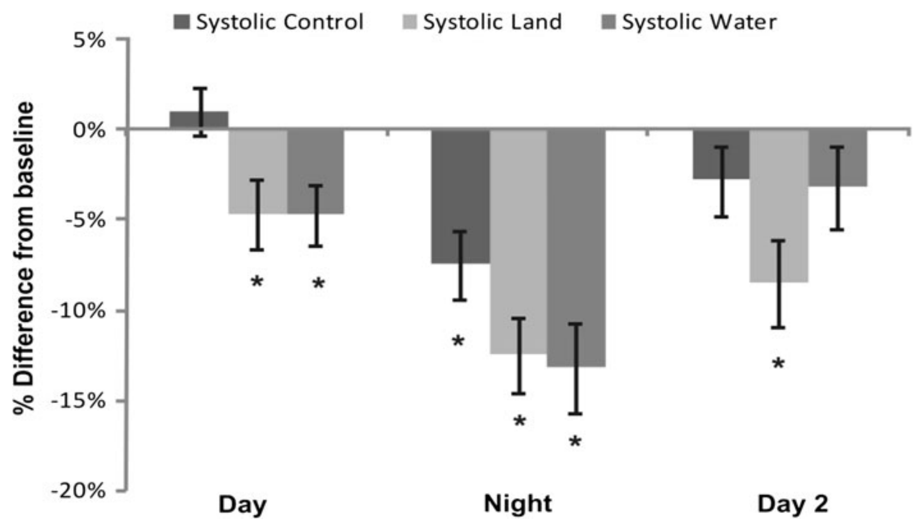

Fig. 2 Percentage change in SBP during daytime, nighttime and the next day after rest, land and water exercises. *Asterisk* significantly different from baseline, $P < 0.05$

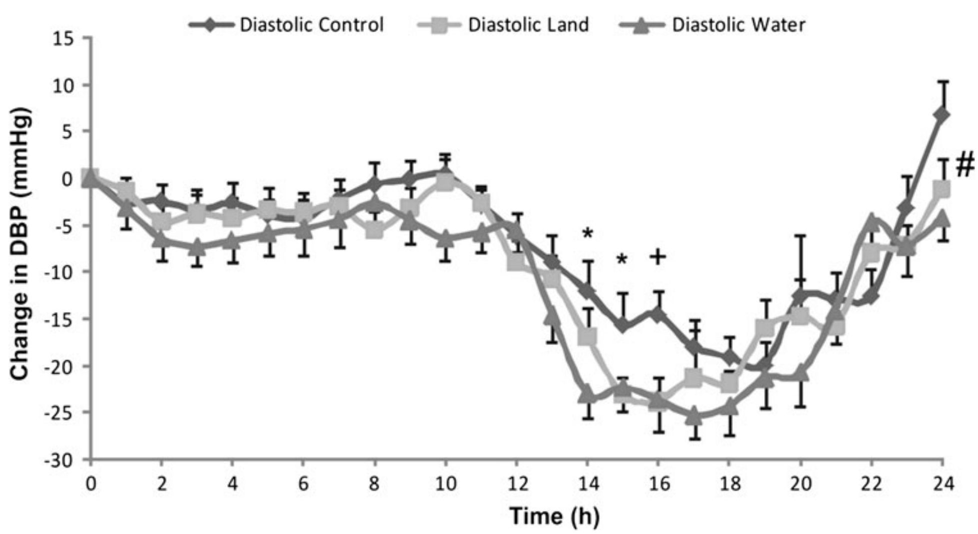

Fig. 3 Absolute changes in DBP from baseline over 24 h. Time point 0 indicates the baseline value (resting) followed by the differences between BP values every hour after exercise up to 24 h. *Asterisk* significantly different between water exercise and control; *plus symbol* significantly different between land exercise and control and between water exercise and control; *hash symbol* significant change over time, $P < 0.05$

11.9 mmHg, $P > 0.05$). The average DBP over 24 h, including baseline, was 92 ± SD 7.1 mmHg (control), 88 ± SD 7.8 mmHg (land) and 9 ± SD 8.3 mmHg (water), respectively. Figure 3 illustrates the difference between DBP and baseline at each time point over 24 h. Although there were reductions in DBP over 24 h after all three sessions compared to baseline (control: 7 ± SD 7 mmHg, land: 9 ± SD 7.7 mmHg and water: 10 ± SD 8.2 mmHg), there was no significant treatment effect for DBP ($P > 0.05$).

Figure 4 shows that there was no significant decrease in the average daytime DBP when compared to baseline for the control or land treatments (control: 2 ± SD 8.6 mmHg, land: 2 ± SD 8.2 mmHg, $P > 0.05$). The water treatment, however, showed a trend towards a statistically significant decrease during daytime (5 ± SD 9.3 mmHg; $P > 0.05$). There were, however, significant reductions in DBP during nighttime hours compared to baseline (control: 16 ± SD 13.2 mmHg; land: 17 ± SD 10.3 mmHg; water: 20 ± SD 12.2 mmHg, $P < 0.01$). Furthermore, DBP remained significantly lower in the morning on day 2 for the land exercise group (8 ± SD 10.8 mmHg; $P = 0.01$). Although still reduced, these values were not statistically lower after the control and water exercise sessions.

Discussion

The present study is the first to our knowledge to examine the PEH phenomenon to an acute bout of water exercise. We observed a significant drop in BP in individuals with elevated resting BP which was similar in magnitude, but of shorter duration compared to land exercise. Secondly, our findings show that concurrent exercise, where aerobic and resistance exercises are combined, causes clinically meaningful reductions in BP under real-life conditions.

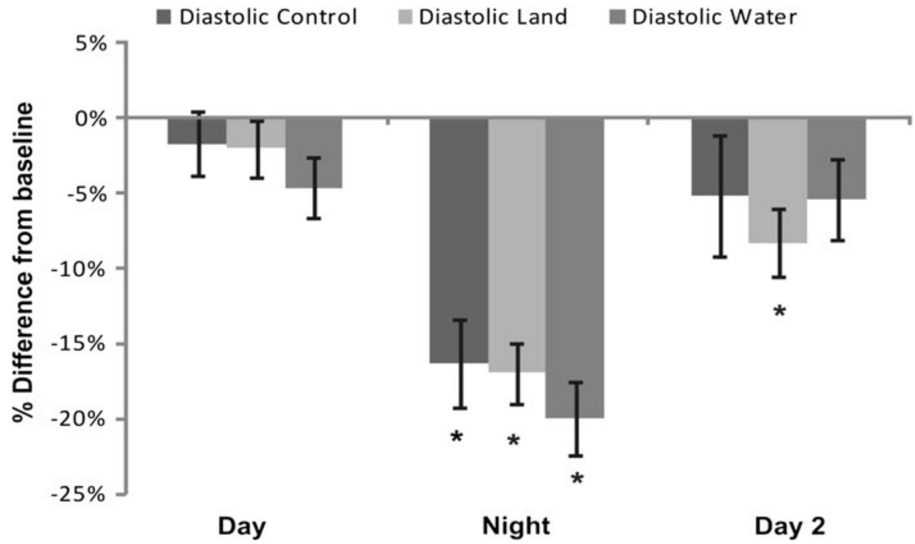

Fig. 4 Percentage changes in DBP during daytime, nighttime and the next day after rest, land and water exercises. *Asterisk* significantly different from baseline, $P < 0.05$

This is in accordance with the results of Teixeira et al. (2011) who found similar reductions in SBP and DBP after aerobic and concurrent exercise sessions (13 ± 1 and 11 ± 1 mmHg, respectively). These results, therefore, support the recommendation that aerobic and resistance exercise should be combined for its health and fitness benefits (Park et al. 2006).

Over the 24 h after the acute land and water exercise bouts, we found significant and similar decreases in systolic (14 and 13 mmHg, respectively) and diastolic (9 and 10 mmHg, respectively) BP. These reductions over 24 h are at the higher end of the reported range of values for hypertensive individuals, namely −2 to −12 mmHg (Cardoso et al. 2010). A closer analysis of the data revealed that the overall decrease in BP over 24 h cannot only be attributed to the nocturnal fall in BP during nighttime, as both exercise treatments also lead to significant reductions in SBP (7 mmHg for land and water), while the control treatment resulted in an increase in SBP (1.4 mmHg). The reduction in DBP during daytime after the control and land exercise bout was minimal (2 and 2 mmHg, respectively), but it was substantial after water exercise (5 mmHg). Although this decrease failed to reach statistical significance, it is still clinically important. Touyz et al. (2004) reported that a 3 mmHg reduction in BP is associated with an 8 % reduction in the occurrence of stroke and a 5 % reduction in coronary artery disease. It is thought that this larger reduction in DBP after water exercise may be explained by augmented peripheral vasodilation to compensate for the increase in SV and CO (Park et al. 1999). Furthermore, the sequence of exercises in the concurrent land exercise session might have contributed to the slightly higher DBP after the land exercise. Resistance exercise causes mechanical compression of the vasculature, attenuating the vasodilation that occurred during the aerobic exercise. Therefore, the subjects may have ended the land exercise bout with a greater degree of TPR, whereas the two types of exercises were alternated during the water exercise bout.

It is known that the magnitude of PEH is dependent on a number of factors, of which resting BP is a significant predictor (Cardoso et al. 2010). Since obesity is one of the risk factors for the development of hypertension, one could also consider whether the magnitude of PEH is related to overweight and obesity. In this study, 11 individuals were classified as overweight and 7 as obese according to BMI. We found no differences in the BP responses of these individuals compared to those with normal weight. Hamer and Boutcher (2006) also reported that BMI is not a significant independent predictor of PEH, although the mechanism of PEH might be different in overweight compared to normal weight persons. They suggested that measures of central adiposity may actually show better correlations with PEH and this would, therefore, warrant further study.

Relatively few studies have measured ambulatory BP over 24 h following exercise, thus findings are mostly limited to short laboratory-based monitoring periods. The reported duration of the PEH response is highly variable and ranges from 1 to 24 h (Brandão Rondon et al. 2002; Ciolac et al. 2008; Forjaz et al. 2004). In the current study the PEH response was evident for 24 h after land exercise and for at least 9 h during daytime and the entire nighttime after water exercise. At 24 h, DBP was lower for both exercise treatments compared to baseline (8 and 5 mmHg after land and water exercises, respectively). These findings are in accordance with those of Brandão Rondon et al. (2002) who reported reductions for 22 h after exercise and Ciolac et al. (2008) who reported 24 h of sustained PEH. It is not apparent why the hypotensive response to land exercise lasted longer during daytime than for water exercise. Fagard (2001) concluded that exercise variables such as intensity, frequency and duration only explain 4.9 % of the variance in SBP and 1.1 % in DBP to exercise. Thus, it is unlikely that differences in the training characteristics of land and water exercises would explain the longer duration PEH response after the land exercise bout.

Our results show that both land and water exercises had a greater effect on the post-exercise SBP than DBP, which has important clinical significance. Firstly, evidence from epidemiological studies, such as the Framingham study, revealed that SBP more accurately predicts future coronary events than DBP in persons older than 50 years (Zanchetti and Waeber 2006). Secondly, clinical trials have shown that it is easier to control DBP through antihypertensive medication than SBP. It has been reported that DBP was controlled in 89.7 % of treated individuals, while SBP was only controlled in 49 % of cases (Lloyd-Jones et al. 2000). The current study, therefore, confirms previous studies that exercise is an essential adjunct in the treatment of hypertension, but also shows that water exercise can successfully be incorporated in the exercise regimes of hypertensive individuals.

It is a limitation of this study that the exercise intensities of the land and water sessions were not more closely controlled (i.e. intensities varied between moderate to severe levels). However, it was precisely the aim to investigate the BP responses under real-life conditions, i.e. during exercise sessions where workloads are varied and not artificially fixed at a certain level. This allows us to conclude that individuals will experience PEH when they perform regular land and water exercise classes in a gymnasium.

Conclusions

The novel finding of this study is that water exercise has clinically significant hypotensive effects in prehypertensive and hypertensive individuals and that the PEH response is similar in magnitude, albeit of slightly shorter duration, than land exercise under free-living conditions. To understand the mechanism of the PEH response to water exercise, future studies are needed where the hemodynamic changes following water exercise is monitored for up to 24 h.

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Conflict of interest The authors declare that they have no conflict of interest.

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