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Research Article

Ambulatory blood pressure reduction following high-intensity interval exercise performed in water or dryland condition

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Abstract

We aimed to compare blood pressure (BP) responses following moderate-intensity continuous exercise (MICE), high-intensity interval exercise (HIIE) in dry land or HIIE in immersed condition, using 24-hour ambulatory BP monitoring. Forty-two individuals (65 ± 7 years, 52% men) with a baseline BP ≥ 130/85 mm Hg (systolic/diastolic blood pressures [SBP/DBP]) were randomly assigned to perform one of the three following exercises on a stationary cycle: MICE (24 minutes at 50% peak power output) or HIIE in dry land (two sets of 10 minutes with phases of 15 seconds 100% peak power output interspersed by 15 seconds of passive recovery) or HIIE in up-to-the-chest immersed condition. While MICE modified none of the 24-hour average hemodynamic variables, dryland HIIE induced a 24-hour BP decrease (SBP: −3.6 ± 5.7/DBP: −2.8 ± 3.0 mm Hg, $P < .05$) and, to a much greater extent, immersed HIIE (SBP: −6.8 ± 9.5/DBP: −3.0 ± 4.5 mm Hg, $P < .05$). The one condition that modified 24-hour pulse-wave velocity was immersed HIIE (−0.21 ± 0.30 m/s, $P < .05$). J Am Soc Hypertens 2016;■(■):1–9. © 2016 American Society of Hypertension. All rights reserved.

Keywords: Ambulatory blood pressure monitoring; arterial stiffness; high-intensity interval exercise; water exercise.

Introduction

Hypertension is a worldwide epidemic involved in many stroke and ischemic heart diseases and responsible for millions of deaths and cases of disability. With the goal of improving both prevention and treatment of hypertension, physical activity is a cornerstone part of the nondrug measures highlighted in overall guidelines.[1–3] The mechanisms of the hypotensive benefit of regular physical exercise are complex and not completely understood but seem to be linked with the prolonged hypotensive response following exercise.[4,5] Indeed, this "postexercise hypotension" (PEH) can reach 14/9 mm Hg (systolic/diastolic blood pressures [SBP/DBP]) in individuals with prehypertension and 10/7 mm Hg in individuals with treated hypertension[4] and can persist up to 24-hour when assessed with ambulatory BP monitoring (ABPM).[6]

Conflict of interest: None.

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Regarding the guidelines involved in hypertension management, the recommended modalities of exercise are most often uniform consisting in moderate intensity and continuous exercises (MICE; 45%–65% of maximal oxygen consumption [VO_2max] in a continuous way).[7] Beyond those classic modalities, other methods such as high-intensity interval exercises (HIIE; repeated 15- to 300-second phases of aerobic exercise at an intensity ranging from 95% to 100% of VO_2max, interspersed by recovery periods of equal, shorter, or longer duration) are now recommended in patients suffering from cardiovascular diseases[8] but not specifically for management of hypertension. However, in individuals suffering from hypertension or prehypertension, HIIE induced also a significant PEH, whether exercises performed on treadmill[9,10] or on cycle ergometer.[11–13]

In a complementary manner, the environment where exercise is practiced, such as water immersion, could have additional antihypertensive effects because of physiological adaptations: higher stroke volume and cardiac output, greater reduction in sympathetic drive, in catecholamine release, reduction of peripheral vascular resistance, vasopressin and reninangiotensin systems, and stimulation of the atrial natriuretic peptide factor by venous return flows due to density difference.[14–16] These physiological adaptations are explanations for the specific hypotensive response of water-based exercises whether in healthy[17] or hypertensive individuals.[18] Also in water, only continuous modalities have been used and no further comparisons with HIIE have been made, despite the successful development of water-based exercises in swimming pools and fitness centers.

We consequently aimed to compare, in individuals with a baseline office BP ≥ 130/85 mm Hg, BP response using 24-hour ABPM at baseline and following 3 modalities of exercises: MICE (as reference), HIIE performed in dry land or HIIE performed in up-to-the-chest immersed condition. We put forward two hypotheses: (1) that HIIE would be more effective than MICE in improving postexercise 24-hour BP load; and (2) that an immersed condition would have additional favorable effect on postexercise BP level.

Methods

Participants

Forty-two participants (22 men and 20 women; age, 65 ± 7 years [43–80]) providing written informed consent were recruited at the Cardiovascular Prevention and Rehabilitation Centre (ÉPIC) of the Montreal Heart Institute. Inclusion criteria were men or women aged more than 18 years, an office SBP ≥130 mm Hg and/or DBP ≥85 mm Hg, whatever their use of hypotensive medical treatment. Exclusion criteria were an office SBP ≥180 mm Hg and/or DBP ≥110 mm Hg, any relative or absolute contraindications to high-intensity exercise, major cardiovascular event or procedure within the 12 months preceding enrollment, chronic atrial fibrillation, nighttime professional activity, pregnancy. Following the ethical guidelines of the Tri-Council Policy Statement, the research protocol was approved by the Research Ethics and New Technology Development Committee (CÉRDNT) of the Montreal Heart Institute (MHI#12-1367).

Experimental Design

On the first visit, participants underwent a complete medical evaluation, with a measurement of office BP and resting electrocardiogram (ECG). The office BP was assessed after 5 minutes of supine rest using an automated oscillometric BP device and a cuff adapted to arm circumference, in a quiet room, with an average of two consecutive measures. When inclusion criteria were fulfilled, they were allocated to one of the three groups (MICE, $HIIE_{dryland}$, or $HIIE_{immersed}$) using a stratified randomization. They underwent a baseline 24-hour ABPM, which was followed the day after by a maximal continuous graded exercise test. On the second visit (with a minimum delay of one week from the first visit), participants performed the exercise session of their specific group according to the procedure described in the next section, which was followed by a new 24-hour ABPM.

To ensure equal repartition, in each of the three study groups, of baseline characteristics that could influence our final results, we used a stratified random design in terms of both baseline office BP level (mean arterial pressure <107 or ≥107 mm Hg, corresponding to the mean arterial pressure for SBP/DBP of 140/90 mm Hg) and antihypertensive treatment (presence or absence). This stratified randomization in two levels was built by our statistical department, and results were placed inside individual sealed envelopes.

Maximal Continuous Graded Exercise Test

The maximal continuous graded exercise test was performed with an initial power output set at 30 W, and increased by 15 W every minute until exercise cessation. Electrocardiographic activity was monitored continuously using a 12-lead ECG (GE Healthcare Case Marquette, Missouri), and BP was measured manually every 2 minutes using a sphygmomanometer. Criteria for exercise cessation were volitional exhaustion, significant ECG abnormalities, or abnormal BP response. Power of the last completed stage was considered as the peak power output (PPO, in W).

24-hour Ambulatory BP Monitoring

The 24-hour ABPM were performed with a brachial cuff-based oscillometric device Mobil-O-Graph PWA Monitor (I.E.M. GmbH, Stolberg, Germany). Arm circumferences were measured and recorded to allow the correct choice of cuff size (24–34 cm or 32–42 cm). The monitor was programmed to measure BP every 20 minutes during the overall 24 hours.[1] Daytime and nighttime periods were individually adjusted according to the time for bed and for wake-up that each participant notified. Data were analyzed as average 24 hours, daytime and nighttime periods, for SBP, DBP (in mm Hg). Patients were also asked to fill out a diary indicating their activities over the 24 hours.

Arterial Stiffness

Arterial stiffness was automatically assessed, using the same oscillometric device Mobil-O-Graph PWA Monitor (IE.M. GmbH, Stolberg, Germany), at rest with the patient in supine position in a quiet atmosphere for the first measurement, and every 20 minutes during the following 24 hours. For each BP measurement, captors in the cuff analyzed the pulse wave, and the ARCSolver software used in Mobil-O-Graph 24h PWA Monitor calculated aortic central BP and stiffness parameters such as aortic pulse-wave velocity (PWV).[19] This method was previously validated in comparison with tonometry.[19] Data were analyzed as resting, average 24-hour, daytime and nighttime periods, for central SBP/DBP in mm Hg and aortic PWV in m/s.

Exercise Sessions

For the exercise sessions, participants were asked to refrain from strenuous exercise the day before and to arrive fully hydrated to the laboratory, at least 3 hours after their last meal. No attempt was made to control meal size or content. Exercise sessions were performed on a stationary bicycle ergometer, either on dry land or in water, in small groups of participants, under the supervision of a kinesiologist blinded to the primary end point of the study. Training supervisor and assessor were different persons.

Dryland cycling was performed on an electromagnetically braked cycle ergometer (Ergometrics 800, Ergoline, Blitz, Germany) in a room at constant temperature (21°C) and humidity (45%). Saddle and handlebar height as well as forward placement were adjusted to determine optimal position. Each exercise session was preceded by a 5-minute warm-up consisting in pedaling at 60 W with a cadence of 80 rounds per minute (rpm), and followed by a 5-minute recovery period in a sitting position that began immediately after exercise cessation.

Immersed cycling (up-to-the-chest) was performed on a mechanically braked cycle ergometer (Hydrorider, DIE-SSE, San Lazzaro di Savena, Italia) in an indoor swimming pool at constant temperature (30°C). Saddle and handlebar height as well as forward placement were adjusted to determine optimal position. External power output was determined from pedaling cadence (in rpm).[20] Each exercise session was preceded by a 5-minute warm-up consisting in pedaling at 40 rpm, and followed by a 5-minute passive recovery period in a sitting position that began immediately after exercise cessation.

MICE Session

The MICE session was performed in the same center. We opted for an intensity of 50% of PPO which has consistently been shown to cause PEH[21] and was in line with the recommendation of exercise intensity lying between 50% and 80% of PPO.[22] Duration was 24 minutes, adjusted to match the 500–1000 METs.min.week^{-1} as recommended.[7]

High-Intensity Interval Exercise Sessions

The HIIE session was based on a previous study that compared tolerance of four different single sessions of HIIE in coronary patients.[23] The selected HIIE session represented the best compromise between safety, time spent at a high level of VO_2peak, and psychological adherence.[24] It consisted of a 6-minute warm-up at 50% of PPO, followed by two sets of 10 minutes composed of repeated phases of 15 seconds at 100% of PPO interspersed by 15 seconds of passive recovery. Four minutes of passive recovery were allowed between the two sets, and a 5-minute cool-down after the last 15-second exercise phase, immediately followed by a 5-minute period of passive recovery in a seated position.

Statistical Analysis

Standard statistical methods were used for the calculation of means and standard deviations. Normal Gaussian distribution of the data was verified by the Shapiro-Wilk test. A two-way analysis of variance was performed to test the null hypothesis that dependent variables will not be affected by exercise, whatever the group. Multiple comparisons were made with the Bonferroni post hoc test. The magnitude of the difference was assessed by the Hedges' g (g), and the scale proposed by Cohen was used for interpretation, as presented elsewhere.[25] The magnitude of the difference was considered either small ($0.2 < |g| \leq 0.5$), moderate ($0.5 < |g| \leq 0.8$), or large ($|g| > 0.8$). Statistical significance was set at $P < .05$.

Results

Baseline characteristics are presented in Table 1. Regarding the cardiovascular risk factors, 23 (55%) participants had an antihypertensive treatment (21 had an angiotensin-converting enzyme inhibitor or an angiotensin II receptor blocker, 10 had a thiazide diuretic, 7 had a beta-blocker, and 4 had a calcium channel blocker), 19 (45%) a treatment for dyslipidemia, 8 (19%) suffered from diabetes mellitus, 3 (7%) were current smokers, and 8 (19%) had a personal history of cardiovascular disease. The concordance rate between office and ambulatory BP classes of hypertension was 68%; white-coat effect

Table 1
Baseline characteristics

Parameters	Overall Population (n = 42)	MICE (n = 14)	$HIIE_{dryland}$ (n = 14)	$HIIE_{immersed}$ (n = 14)
Age (y)	65 ± 7	65 ± 6	65 ± 8	63 ± 9
Men, n (%)	22 (52.4)	8 (57.1)	9 (64.3)	5 (35.7)
Body mass index (kg/m^2)	29.7 ± 4.3	29.7 ± 4.5	30.7 ± 4.7	28.8 ± 3.9
Systolic BP (mm Hg)	143.1 ± 13.8	142.4 ± 11.4	144.2 ± 17.3	142.8 ± 12.9
Diastolic BP (mm Hg)	85.1 ± 9.2	81.9 ± 6.2	87.6 ± 11.6	85.9 ± 8.8
Heart rate (bpm)	71.7 ± 12.1	69.2 ± 11.3	73.6 ± 10.8	72.4 ± 14.3
Pulse-wave velocity (m/s)	9.59 ± 1.29	9.52 ± 1.26	9.86 ± 1.39	9.40 ± 1.26

BP, blood pressure; HIIE, high-intensity interval exercise; MICE, moderate-intensity continuous exercise.
Values are means ± SD or numbers of participants (%).

occurred in close to 21% of the participants and masked hypertension in around 12% (Table 2). The average ABPM results at baseline and after each condition of exercise are presented in Table 3. The number of valid BPs taken over the 24-hour period, with a minimum of one per hour, was 61 ± 9 (percentage of success, 85% ± 13) for baseline ABPM and 59 ± 11 (82% ± 16) for postexercise ABPM.

The magnitude of clinical PEH was similar between groups during the 4 hours immediately following exercise intervention (Figure 1). But thereafter for the 24-hour ABPM assessments, despite the absence of significant difference in between-group analysis of variance, we observed following differences between baseline and postexercise ABPM data. The MICE modified none of the average hemodynamic variables from baseline ABPM whatever the period (24 hours, daytime, or nighttime). Dryland HIIE induced a significant decrease in both systolic and diastolic measures during the 24-hour period (SBP: −3.6 ± 5.7 mm Hg, g = −0.24, *P* = .04; DBP: −2.8 ± 3.0 mm Hg, g = −0.27, *P* = .004) and the daytime period (SBP: −4.4 ± 7.5 mm Hg, g = −0.28, *P* = .046; DBP: −2.9 ± 4.0 mm Hg, g = −0.29, *P* = .02) but not during the nighttime period. Immersed HIIE resulted in a greater decrease from baseline in systolic measures during the 24-hour period (SBP: −6.8 ± 9.5 mm Hg, g = −0.57, *P* = .02) and the daytime period (SBP: −7.5 ± 11.2 mm Hg, g = −0.62, *P* = .03). We also found a significant decrease in diastolic measures during the 24-hour period (DBP: −3.0 ± 4.5 mm Hg, g = −0.32, *P* = .03) and the daytime period (DBP: −3.9 ± 4.5 mm Hg, g = −0.40, *P* = .006). The night and/or day SBP dipping was not modified after MICE and $HIIE_{immersed}$ but was altered after $HIIE_{dryland}$ (−2.8 ± 4.1%, g = −0.36, *P* = .02). We found no other significant changes during the nighttime period, and no interaction between $HIIE_{dryland}$ and $HIIE_{immersed}$. The magnitudes of these changes, as measured by Hedges' g and presented in Figure 2, reinforced the clinical differences we observed in pre-exercise and/or postexercise comparison. Regarding the proportion of participants that experienced reductions in BP, 26 participants (62%) decreased their 24-hour SBP after the exercise session: 7 (50%) in the MICE group, 8 (57%) in the $HIIE_{dryland}$, and 11 (79%) of those performing the $HIIE_{immersed}$ session.

Table 2
Concordance of office versus ambulatory blood pressure values

Blood Pressure Measurement	Ambulatory Diurnal SBP/DBP <135/85 mm Hg	Ambulatory Diurnal SBP/DBP ≥135/85 mm Hg	Subtotal
Office SBP/DBP <140/90 mm Hg	13 (31.0%)	5 (11.9%)	18 (42.9%)
Office SBP/DBP ≥140/90 mm Hg	9 (21.4%)	15 (35.7%)	24 (57.1%)
Subtotal	22 (52.4%)	20 (47.6%)	42 (100%)

DBP, diastolic blood pressure; SBP, systolic blood pressure.
Values are numbers of patients (%).

Central-BP changes followed peripheral BP improvement observed in HIIE groups (Table 3). Nevertheless, the conditions of exercise that modified PWV from baseline were both HIIE groups during the daytime period ($HIIE_{dryland}$: PWV: −0.13 ± 0.20 m/s, g = −0.11, *P* = .03; $HIIE_{immersed}$: PWV: −0.21 ± 0.35 m/s, g = −0.13, *P* = .04) and only $HIIE_{immersed}$ during the 24-hour period (PWV: −0.21 ± 0.30 m/s, g = −0.13, *P* = .02).

Discussion

Although all exercise modes reduced equally clinical BP during the first 4 hours following exercise session, we demonstrated that only HIIE modes decreased 24-hour and daytime BP load in comparison with baseline ABPM. We also demonstrated that immersed condition would have an additional favorable effect on BP level in comparison with dryland. In addition, both HIIE conditions induced, from baseline, an improvement in ambulatory PWV (marker of arterial stiffness) for daytime period, but only the $HIIE_{immersed}$ for the 24 hours.

Postexercise BP Responses Assessed by ABPM

Many studies have examined BP decrease after exercise, for seconds (ie, transient pressure undershoot) or minutes

Table 3
Ambulatory blood pressure measurements at baseline and percentage of change post-exercise

	Overall Population	MICE (n = 14)		HIIE$_{dryland}$ (n = 14)		HIIE$_{immersed}$ (n = 14)	
	(n = 42) Baseline	Baseline	Postexercise	Baseline	Postexercise	Baseline	Postexercise
24-h period							
SBP (mm Hg)	128.4 ± 12.2	126.9 ± 12.9	125.2 ± 8.8	130.6 ± 12.2	127.0 ± 14.1*	127.6 ± 12.1	120.9 ± 9.6*
DBP (mm Hg)	77.4 ± 8.4	76.4 ± 7.5	75.3 ± 6.5	78.7 ± 9.7	75.9 ± 9.4*	76.9 ± 8.2	73.9 ± 9.0*
HR (bpm)	69.0 ± 9.7	67.3 ± 9.9	68.6 ± 10.1	72.6 ± 11.0	70.9 ± 10.5	67.1 ± 7.6	67.9 ± 7.7
cSBP (mm Hg)	117.5 ± 11.7	116.3 ± 10.6	114.2 ± 8.7	118.7 ± 12.2	115.9 ± 13.6*	117.5 ± 10.6	111.5 ± 9.5*
cDBP (mm Hg)	78.3 ± 8.5	76.7 ± 7.5	76.5 ± 5.5	80.1 ± 9.5	77.8 ± 9.1*	78.0 ± 8.7	75.1 ± 9.3*
PWV (m/s)	9.28 ± 1.27	9.24 ± 1.35	9.22 ± 1.28	9.48 ± 1.10	9.40 ± 1.12	9.11 ± 1.45	8.90 ± 1.33*
Daytime period							
SBP (mm Hg)	134.0 ± 12.4	133.1 ± 14.2	130.8 ± 10.5	135.1 ± 11.1	130.6 ± 14.7*	133.9 ± 12.7	126.4 ± 9.6*
DBP (mm Hg)	81.5 ± 8.7	80.8 ± 7.9	79.6 ± 7.4	81.8 ± 9.4	78.9 ± 9.2*	81.9 ± 9.2	78.0 ± 9.3*
HR (bpm)	73.7 ± 10.7	71.8 ± 11.9	73.3 ± 11.2	77.6 ± 11.0	75.5 ± 10.8	71.7 ± 8.8	74.0 ± 10.1
cSBP (mm Hg)	122.0 ± 12.0	121.8 ± 14.3	118.6 ± 10.8	122.1 ± 11.2	118.4 ± 12.9*	122.0 ± 11.3	115.9 ± 9.1*
cDBP (mm Hg)	83.2 ± 8.7	82.6 ± 7.7	81.1 ± 7.1	83.5 ± 9.4	80.9 ± 9.4*	83.5 ± 9.4	79.7 ± 9.3*
PWV (m/s)	9.45 ± 1.26	9.46 ± 1.31	9.37 ± 1.19	9.61 ± 1.07	9.49 ± 1.12*	9.26 ± 1.44	9.06 ± 1.30*
Nighttime period							
SBP (mm Hg)	119.2 ± 12.3	117.3 ± 10.5	115.7 ± 8.5	122.5 ± 14.2	122.1 ± 16.8	117.8 ± 12.1	112.4 ± 10.2
DBP (mm Hg)	70.8 ± 8.5	69.9 ± 6.9	68.7 ± 6.5	73.5 ± 10.4	72.7 ± 10.6	68.9 ± 7.7	67.4 ± 8.0
HR (bpm)	61.7 ± 8.9	60.9 ± 8.7	61.2 ± 8.7	64.4 ± 10.8	64.5 ± 10.7	59.9 ± 6.7	59.1 ± 8.2
cSBP (mm Hg)	110.9 ± 12.0	108.9 ± 10.4	106.9 ± 7.3	113.3 ± 14.4	112.9 ± 17.3	110.4 ± 11.2	105.0 ± 10.1
cDBP (mm Hg)	71.1 ± 8.4	68.9 ± 6.5	69.2 ± 6.4	74.6 ± 9.8	74.1 ± 10.4	69.6 ± 7.9	68.1 ± 7.9
PWV (m/s)	9.04 ± 1.28	9.00 ± 1.38	8.96 ± 1.37	9.26 ± 1.02	9.28 ± 1.15	8.85 ± 1.46	8.68 ± 1.41
Nighttime/daytime SBP drop (%)	11.0 ± 5.3	11.7 ± 5.0	11.1 ± 6.6	9.4 ± 5.7	6.6 ± 7.5*	11.9 ± 5.1	11.0 ± 4.0

cDBP, central diastolic blood pressure; cSBP, central systolic blood pressure; DBP, diastolic blood pressure; HIIE$_{dryland}$, high-intensity intermittent exercise in gymnasium; HIIE$_{immersed}$, high-intensity intermittent exercise in immersed condition; HR, heart rate; bpm, beats per minute; MICE, moderate-intensity continuous exercise; PWV, pulse-wave velocity; SBP, systolic blood pressure.

Values are mean ± SD.

* $P < .05$ in postexercise versus pre-exercise intragroup comparison.

(ie, PEH), and shown a greater PEH in hypertensive than in normotensive participants.[4] In our prehypertensive and hypertensive participants, we observed a similar PEH the 4 hours after session, whatever the exercise mode.

The use of ABPM gave additional information, in particular of a sustained BP effect during the 24-hour period after exercise, that we resumed by BP average under the term of BP load. Therefore, in studies using ABPM, BP decrease appeared significant for SBP/DBP in prehypertensive[26] and untreated hypertensive participants[27–29] but not for SBP in normotensives.[27,28] In hypertensives, only one study reported BP change for the 24-hour period[27]: 21 untreated hypertensive participants younger than ours (48 ± 12 years), performing a 50-minute MICE at 50% VO_2peak on a cycle ergometer, decreased their 24-hour SBP/DBP of 6.8/4.1 mm Hg. We found no 24-hour BP decrease after MICE but with a shorter duration of exercise in our study (24 minutes). Nevertheless, we observed this result in our best responder HIIE$_{immersed}$ group (6.8/3.0 mm Hg, respectively, for SBP/DBP). We are lacking of additional studies for further comparison before concluding that HIIE could spend less time than MICE for similar BP improvement.

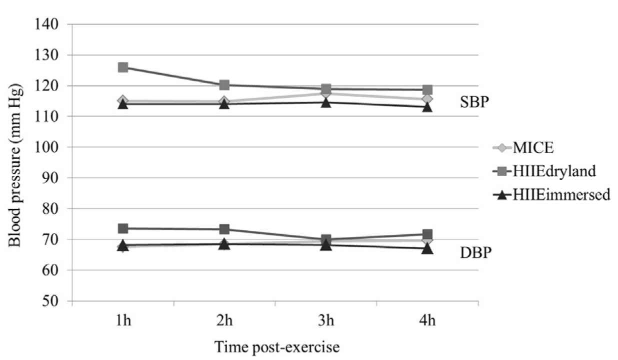

Figure 1. Hourly average blood pressure measurements during the acute phase following the exercise sessions. DBP, diastolic blood pressure; HIIE, high-intensity interval exercise; MICE, mild-intensity continuous exercise; SBP, systolic blood pressure.

Day and/or night dipping is an important point for cardiovascular outcomes,[1] and the higher intensity of aerobic exercise was previously associated with a higher BP drop during nighttime.[30] But in our study, the night and/or day SBP dipping was not modified after both MICE and HIIE$_{immersed}$ sessions and was altered after HIIE$_{dryland}$. We have no explanation for the alteration of the drop we observed after HIIE in dry land.

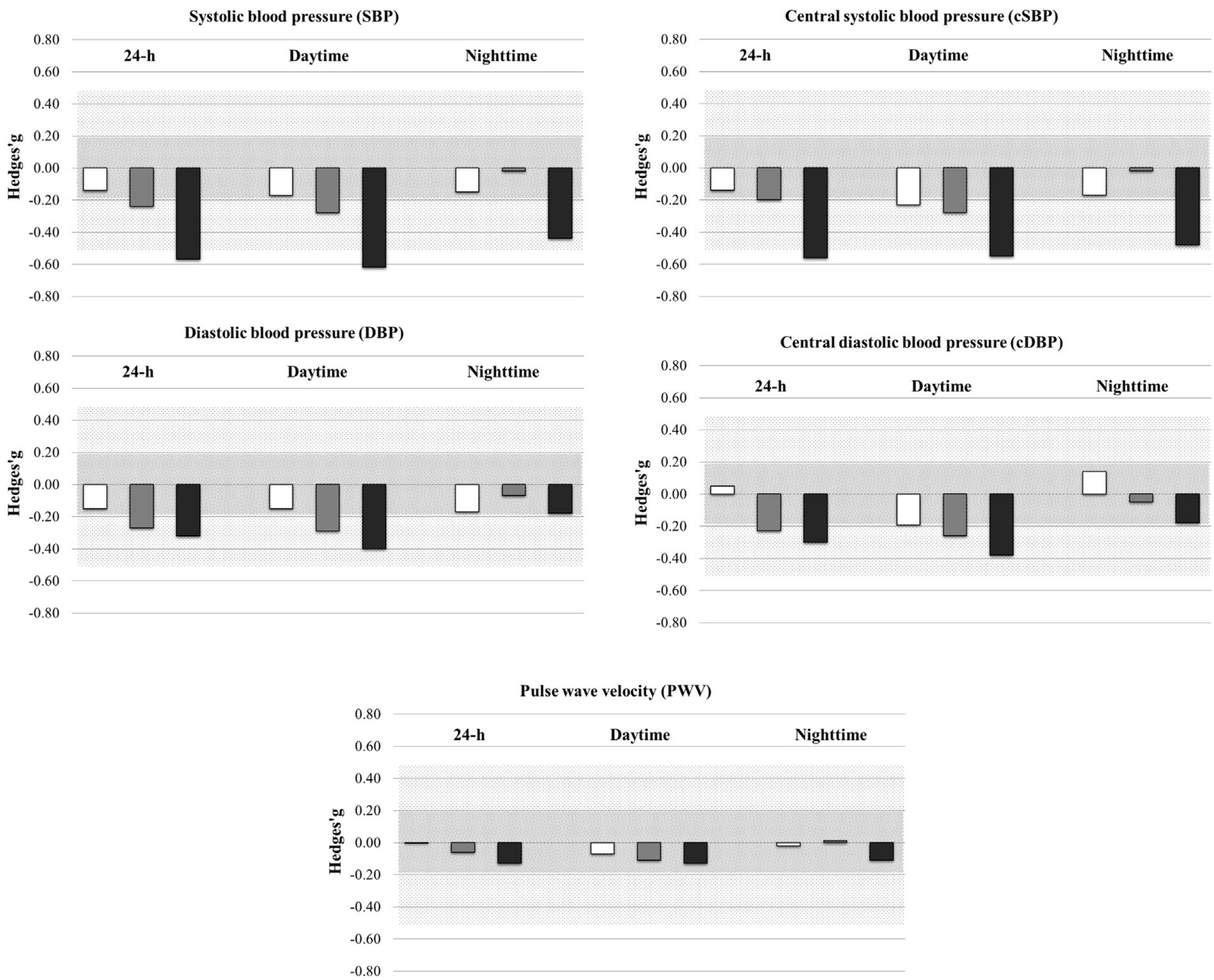

Figure 2. Effect size of exercise session on ambulatory hemodynamic parameters. White columns: mild-intensity continuous exercise (MICE); gray columns: high-intensity interval exercise on dry land ($HIIE_{dryland}$); and dark columns: high-intensity interval exercise in immersed condition ($HIIE_{immersed}$). The magnitude of the difference was considered either small ($0.2< |g| \leq 0.5$), moderate ($0.5< |g| \leq 0.8$), or large ($|g| >0.8$).

Exercise Modalities

Interestingly, by providing a clinical interpretation of the magnitude of BP change (measured by Hedge's g), our data showed a larger effect of HIIE performed in the swimming pool, that clearly underscored the relevance of this treatment, independently of the statistical analysis. Thereby, the HIIE demonstrated many benefits in patients suffering from cardiovascular diseases[8] but also in hypertensive patients with a greater PEH following vigorous intensity exercise (100% VO_2peak) than MICE (30-minute 60% VO_2peak) either low-intensity continuous exercise (30-minute 40% VO_2peak) illustrating a dose response of exercise intensity in PEH.[29] But, few studies have assessed the effect of the manipulation of exercise modalities (interval versus continuous exercise, dryland versus immersed condition) on 24-hour BP response.

Regarding comparison between continuous and intermittent modalities, most studies have reported little difference in PEH: whether for exercises performed on treadmill in hypertensive participants,[9] or on a cycle ergometer either in either healthy,[12,31] prehypertensive,[13] or hypertensive participants.[11] One recent study reported in 20 hypertensive elderly individuals (aged 60 years or older), a greater BP decrease assessed by ABPM (20-hour duration of monitoring) following intermittent rather than continuous exercises performed on treadmill: a BP response reaching −15.5/−12.5 mm Hg (20-hour SBP/DBP, respectively) for the continuous group (42 minutes at the ventilatory anaerobic threshold) versus −18.5/−14.5 mm Hg (20-hour SBP/DBP) in the intermittent group (42 minutes with alternation of 4 minutes at the respiratory compensation threshold and 2 minutes at 40% of VO_2max).[10] The explanation for their greater results in BP fall could be the longer duration of exercise than in our study, and the fact that, despite being uniformly on antihypertensive drugs, their patients were not well controlled for their hypertension and had a higher BP level before exercise than ours, level that was seen to be associated with a greater PEH.[32]

Regarding comparison of PEH between dryland and immersed conditions, we limited our discussion with studies assessing upright practice of water exercise (such as cycling or walking) and chose to not include swimming mode because of major differences in physiological blood flow response.[33] Thereby, we observed a similar PEH the fourth hour after exercise whatever the condition, dry land or water. Our result is in accord with a previous study comparing, in 23 normotensive healthy women, the effect of walking during 45 minutes on dry land at 40% of VO_2max versus walking in chest-deep water at a similar intensity (using Borg scale).[17] In this study, no differences in inducing PEH at 60 minutes after exercise were observed between conditions (SBP: −8 mm Hg in land vs. −11 mm Hg in water). No previous study has assessed 24-hour ABPM following water-based exercise, nor compared dryland HIIE versus HIIE in immersed condition.

Arterial Stiffness Following Exercise

One team reported the aortic stiffness assessment after exercise.[34] In a group of 20 healthy sedentary participants cycling during 30 minutes at 65% of VO_2max, the PWV was reduced at 30 minutes after exercise, but returned to resting levels within 1 hour of exercise cessation. No study reported results of PWV more than 1 hour after exercise using ambulatory method, and we cannot compare the slight improvement of PWV we observed in HIIE groups.

The differences in BP and PWV response through the mode of exercise could be explained by several hypotheses: (1) the autonomic nervous system, while postexercise sympathoinhibition has been documented with microneurography in borderline hypertensive men,[35] the reduction in PWV for both HIIE conditions could have been driven by changes during the day in peripheral sympathetic tone which plays an important role also in vascular stiffness regulation[36]; (2) the endothelial function, with the shear stress-induced vasodilatation in the blood flow response to exercise[37]; (3) the peripheral vascular resistance, of which improvement should be greater following HIIE (25 minutes with alternation of 30 seconds max/30 seconds light) than MICE (60 minutes at 60% of heart rate reserve).[12]

Study Limitations

Our study was an exploratory study. The number of subjects appeared too small when the data were being analyzed, leading to a lack of power for between-group comparison. That said, while the method for central BP and PWV measurements is a validated method,[19] unlike tonometry it is not the gold standard. But our ambulatory method presents the advantage of being automatically implemented during the 24-hour following exercise bouts. We did not directly measure the VO_2 to warrant that both HIIE sessions were equivalent in terms of exercise intensity and energy expenditure. However, energy-cost predictive equations published by our laboratory allowed us to adjust the exercise characteristics of HIIE in immersed condition to make sure they were equivalent with HIIE in dry land condition.[20] Water temperature has an influence on BP that was reported in 11 older men, doing upper-body aquatic exercises with different water temperatures (28°C vs. 36°C).[38] For the warmest condition, SBP/DBP was lower while heart rate was higher and VO_2 equal. The temperature of our swimming pool was 30°C, which is considered thermoneutral for water exercise.[39]

Perspectives

Water-based exercise and HIIE represent interesting prospects with good playfulness that can promote patient adherence to physical exercise, but these modalities have never been compared among individuals with hypertension or prehypertension. The PEH is a key for BP improvement with exercise training, even if its mechanism is not clearly understood; and we are the first team, to our knowledge, to report, beyond PEH, the improvement of 24-hour BP load following cycling in water in these types of individuals. The appreciable results we observed in HIIE groups, particularly in immersed condition for at least 24-hour using ABPM, led us to assess the beneficial BP effects of such exercises as part of a training program, which may be prescribed for hypertensive individuals.

We concluded that, in individuals with a baseline office BP $\geq$ 130/85 mm Hg, the 24-hour BP load decreased significantly following a bout of HIIE performed on a stationary cycle in immersed condition, also by cycling in dry land, but not following MICE. In addition, cycling in water was associated with an alleviation of 24-hour PWV.

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