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CLINICAL RESEARCH

Ambulatory blood pressure reduction following 2 weeks of high-intensity interval training on an immersed ergocycle

Réduction de la pression artérielle ambulatoire suivant 2 semaines d'entraînement par intervalle à haute intensité sur cycloergomètre immergé

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Abbreviations: ABPM, Ambulatory Blood Pressure Monitoring; BP, Blood Pressure; d, Cohen's d; DBP, Diastolic Blood Pressure; g, Hedges' g; HIIT, High-Intensity Interval Training; MICT, Moderate-Intensity Continuous Training; PACES, Physical Activity Enjoyment Scale; POMS, Profile of Mood States; PPO, Peak Power Output; PWV, Pulse Wave Velocity; SBP, Systolic Blood Pressure.

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KEYWORDS
Ambulatory blood pressure monitoring;
Arterial stiffness;
High-intensity interval training;
Profile of Mood States;
Water-based exercise

Summary
Background. — Hypertension guidelines recommend moderate-intensity continuous training (MICT) for the primary or secondary prevention of hypertension. However, alternative modalities, such as high-intensity interval training (HIIT) on dry land or in water, have been studied less widely.
Aim. — To assess chronic blood pressure (BP) response to a 2-week training programme involving six sessions of either MICT or HIIT performed on dry land or HIIT performed in an immersed condition, in participants with baseline office systolic/diastolic BP (SBP/DBP) $\geq$ 130/85 mmHg.
Methods. — We randomly assigned 42 individuals (mean age 65 $\pm$ 7 years; 52% men) with baseline office SBP/DBP $\geq$ 130/85 mmHg to perform six 24-minute sessions on an ergocycle (three times a week for 2 weeks) of either MICT on dry land, HIIT on dry land or HIIT in a swimming pool, and assessed BP responses using 24-hour ambulatory BP monitoring.
Results. — While 2-week MICT and HIIT on dry land modified none of the 24-hour average haemodynamic variables significantly, immersed HIIT induced a significant decrease in 24-hour BP (SBP -5.1 ± 7.3 [$P = 0.02$]; DBP -2.9 ± 4.1 mmHg [$P = 0.02$]) and daytime BP (SBP -6.2 ± 8.3 [$P = 0.015$]; DBP -3.4 ± 4.0 mmHg [$P = 0.008$]), and slightly improved 24-hour and daytime pulse wave velocity (PWV) (24-hour PWV -0.17 ± 0.23 m/s [$P = 0.015$]; daytime PWV -0.18 ± 0.24 m/s [$P = 0.02$]).
Conclusion. — HIIT on an immersed stationary ergocycle is an innovative method that should be considered as an efficient non-pharmacological treatment of hypertension. As such, it should now be implemented in a larger cohort to study its long-term effects on the cardiovascular system.

MOTS CLÉS
Mesure ambulatoire de pression artérielle ;
Rigidité artérielle ;
Entraînement par intervalles de haute intensité ;
Profil des états émotionnels ;
Activité physique dans l'eau

Résumé
Contexte. — Les recommandations proposent la pratique d'une activité physique aérobie de type continu à intensité modérée (MICT) pour la prévention et le traitement de l'hypertension artérielle. Cependant, d'autres modalités, telles que l'entraînement par intervalles à haute intensité (HIIT) sur terre ferme ou dans l'eau, ont été peu étudiées.
Objectifs. — Évaluer la réponse en termes de pression artérielle (PA) ambulatoire suivant un programme d'entraînement de 2 semaines comprenant 6 séances de MICT ou HIIT en gymnase, ou d'HIIT effectuées de façon immergée en piscine, chez des personnes avec une PA clinique systolique ou diastolique (PAS/PAD) $\geq$ 130/85 mmHg.
Méthodes. — Quarante-deux participants (âge moyen de 65 $\pm$ 7 ans ; 52 % d'hommes) avec une PAS/PAD clinique $\geq$ 130/85 mmHg ont été inclus, afin d'effectuer 24 min d'exercice sur un ergocycle stationnaire, 3 fois par semaine pendant 2 semaines (soit 6 séances). Ceux-ci ont été randomisés en 3 groupes : MICT en gymnase, HIIT en gymnase, HIIT en piscine. Les réponses tensionnelles ont été étudiées par mesure ambulatoire de PA (MAPA) des 24 h.
Résultats. — Bien que les 2 semaines de MICT et d'HIIT en gymnase n'aient pas modifié de façon significative les variables hémodynamiques sur les 24 h, l'HIIT en piscine a induit une diminution significative de PA des 24 h (PAS $-5,1 \pm 7,3$ [$p = 0,02$] ; PAD $-2,9 \pm 4,1$ mmHg [$p = 0,02$]) et diurne (PAS $-6,2 \pm 8,3$ [$p = 0,015$] ; PAD $-3,4 \pm 4,0$ mmHg [$p = 0,008$]). Les vitesses de l'onde de pouls (VOP) des 24 h et diurne ont été légèrement améliorées (VOP 24 h $-0,17 \pm 0,23$ m/s [$p = 0,015$] ; VOP diurne $-0,18 \pm 0,24$ m/s [$p = 0,02$]).
Conclusion. — L'HIIT sur cycloergomètre stationnaire immergé en piscine est une méthode innovante qui devrait être considérée comme un traitement non pharmacologique efficace de l'hypertension artérielle. À ce titre, il serait intéressant d'étudier ses effets cardiovasculaires à plus long terme et plus grande échelle.

Background

High blood pressure (BP) is a common disease, with more than 1 billion cases worldwide; it is associated with many cardiovascular complications, and is responsible for 10.4 million deaths and 208.1 million disability-adjusted life-years [1]. Non-drug measures, such as diet and physical activity, are the first-line approach in guidelines for hypertension management [2,3]. The mechanisms of the hypotensive benefit of physical training are complex and are not fully understood. The ''acute'' BP drop following a bout of exercise contributes to the ''chronic'' antihypertensive effect of physical training [4]. In hypertensive individuals, physical training induces both functional and structural adaptations, with many improvements to capillary density and arteriolar wall-to-lumen ratio [5], renin-angiotensin-aldosterone system activity and arterial stiffness [6], endothelial function [7] and cardiac autonomic modulation [8].

In comparison with the classic mode of moderate-intensity continuous training (MICT) (45—65% of maximal oxygen consumption [VO_{2max}] in a continuous way) [9] two or three times a week, the antihypertensive effect of alternative exercise modalities, such as aerobic high-intensity interval training (HIIT) performed on dry land or in a swimming pool, have been studied less widely. Water immersion theoretically induces an additional antihypertensive effect compared with dry-land conditions, which is mainly explained by a more pronounced reduction in peripheral vascular resistance, and also by specific adaptations to the autonomic control of the cardiovascular system or the endocrine control of blood volume [10,11]. In a preliminary report, we observed a greater acute antihypertensive effect of one session of HIIT compared with one session of MICT, particularly when HIIT was performed in an immersed condition [12]. Consequently, we aimed to assess the chronic BP response to a 2-week training programme, involving six sessions of either MICT or HIIT performed on dry land or HIIT performed in immersed condition, in participants with baseline office systolic/diastolic BP (SBP/DBP) $\geq$ 130/85 mmHg. We hypothesized that HIIT would be more effective than MICT in improving 24-hour ambulatory BP monitoring (ABPM) values, and that HIIT in immersed condition would have an additional effect compared with dry-land conditions.

Methods

Participants

Forty-two participants (22 men, 20 women; mean age 65 $\pm$ 7 years, range 43—80 years) were recruited at the Cardiovascular Prevention and Rehabilitation Centre (ÉPIC) of the Montreal Heart Institute. Inclusion criteria were age > 18 years and office SBP $\geq$ 130 mmHg and/or office DBP $\geq$ 85 mmHg. Exclusion criteria were office SBP $\geq$ 180 mmHg and/or office DBP $\geq$ 110 mmHg, any contraindications to high-intensity exercise, major cardiovascular event or procedure within the 12 months preceding enrolment, chronic atrial fibrillation, night-time professional activity or pregnancy. Following the ethical guidelines of the Tri-Council Policy Statement (TCPS), each participant provided written informed consent, and the research protocol was approved by the Research Ethics and New Technology Development Committee (CÉRDNT) of the Montreal Heart Institute (number registration MHI#12-1367).

Experimental design

On the first visit, participants underwent a medical evaluation, with measurement of office BP (automated oscillometric BP measuring device) and a resting electrocardiogram. When inclusion criteria were fulfilled, they were allocated to one of the three groups (MICT, HIIT on dry land [$HIIT_{dryland}$] or HIIT in up-to-the-chest immersed condition [$HIIT_{immersed}$]) using a stratified randomization in terms of both baseline office BP level (mean arterial pressure < 107 or $\geq$ 107 mmHg, corresponding to a mean arterial pressure for SBP/DBP of 140/90 mmHg) and antihypertensive treatment (presence or absence). This stratified randomization in two levels was built by the statistical department, and results were placed inside individual sealed envelopes. Then, participants underwent baseline 24-hour ABPM, which was followed the day after by a maximal continuous graded exercise test. After that, they performed six exercise sessions on a stationary cycle (three times a week for 2 weeks) of either MICT, $HIIT_{dryland}$ or $HIIT_{immersed}$. The design of our study followed the CONSORT diagram illustrated in Fig. A.1. Seven individuals identified as eligible declined to participate because of their lack of availability for the six-session 2-week training programme.

Maximal continuous graded exercise test

The baseline maximal exercise test was performed on an electromagnetically braked cycle ergometer (Ergometrics 800, Ergoline, Blitz, Germany); initial power output was set at 30 W, and was increased by 15 W every minute until exercise cessation. Electrocardiographic activity was monitored continuously using a 12-lead electrocardiogram (CASE™ Marquette™; GE Healthcare, Chicago, IL, USA). Criteria for exercise cessation were volitional exhaustion, significant electrocardiogram abnormalities or abnormal BP response. The power of the last completed stage was considered as the peak power output (PPO, in W) for use as the reference for training intensity.

Twenty-four-hour ABPM

Twenty-four-hour ABPM was performed with a brachial cuff-based oscillometric device (Mobil-O-Graph® pulse wave analysis monitor; IEM GmbH, Stolberg, Germany), programmed to measure BP every 20 min over 24 h [2]. Daytime and night-time periods were adjusted individually according to the times for bed and wake-up notified by each participant. Patients were also asked to fill out a diary indicating their activities over the 24-hour period. Data were analysed as average 24-hour, daytime and night-time periods, for SBP/DBP (in mmHg) and heart rate (in bpm). The first 24-hour ABPM was performed before the 2-week training period, and the second one after the last training session.

Arterial stiffness

Arterial stiffness was assessed using the same oscillometric device (Mobil-O-Graph® pulse wave analysis monitor), at rest with the patient in the supine position in a quiet atmosphere for the first measurement, and ambulatory every 20 min over the following 24 h. For each BP measurement, captors in the cuff analysed pulse wave, and ARCSolver software (AIT Austrian Institute of Technology, Vienna, Austria) automatically calculated aortic central BP and pulse wave velocity (PWV) [13]. This device had previously been validated in a resting condition in comparison with standard carotid-to-femoral PWV using tonometry [13]. Data were analysed as resting and average 24-hour, daytime and nighttime periods, for central SBP/central DBP (in mmHg) and PWV (in m/s).

Subjective appreciation and mood state

The subjective appreciation of the training programme was assessed at the last visit using the ''Physical Activity Enjoyment Scale'' (PACES) questionnaire [14]. The ''Profile Of Mood States'' (POMS) test, which assesses six dimensions of mood (tension, depression, anger, vigour, fatigue and confusion) [15,16], was also applied at baseline and at the end of the programme to assess changes in mood state.

Training sessions

Participants were asked to refrain from strenuous exercise the day before each session, and to arrive fully hydrated to the laboratory, at least 3 h after their last meal. No attempt was made to control meal size or content. Exercise sessions were performed three times a week, on a stationary bicycle.

The MICT session was carried out on an electromagnetically braked cycle ergometer (Ergometrics 800, Ergoline, Blitz, Germany) in a room at constant temperature (21 °C) and humidity (45%). Each session was preceded by a 5-minute warm-up, consisting of cycling at 50 W, followed by a 24-minute period of MICT. Exercise intensity was set at 50% of PPO, which was in line with current recommendations [17]. Exercise duration was set at 24 min to match the 500—1000 METs/min/week recommended by the American College of Sports Medicine [9]. A 5-minute period of recovery in a sitting position was proposed at the end of the workout.

The $HIIT_{dryland}$ session was carried out on an electromagnetically braked cycle ergometer, and consisted of a 5-minute warm-up at 50% of PPO, followed by two 10-minute sets of exercise, composed of repeated phases of 15 s of cycling at 100% of PPO, interspersed by 15 s of passive recovery. Four minutes of passive recovery were allowed between the two sets, as well as 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 (Fig. 1) [18,19].

$HIIT_{immersed}$ was performed on a mechanically braked cycle ergometer (HYDRORIDER®, DIESSE, San Lazzaro di Savena, Italia) in an indoor swimming pool at constant temperature (30 °C, which is considered thermoneutral for water exercise) [20]. The protocol was the same as on dry land, with two 10-minute sets of repeated phases of 15 s of cycling at 100% of PPO, interspersed by 15 s of passive recovery (Fig. 1). External power output was determined from pedalling cadence (in rpm) [21]. Each training session was preceded by a 5-minute warm-up, consisting of pedalling at 40 rpm, and was followed by a 5-minute passive recovery period in a sitting position.

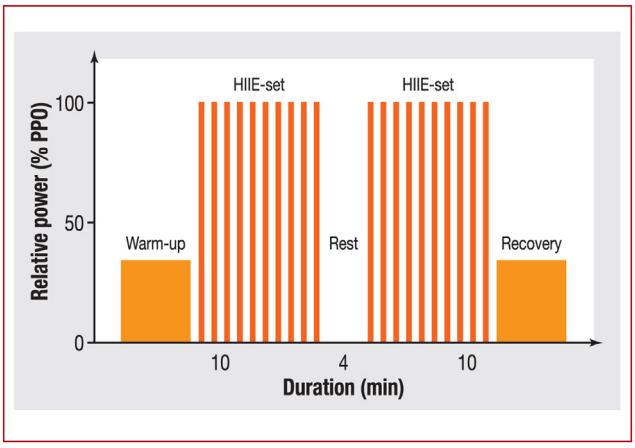

Figure 1. Schematic illustration of the high-intensity interval exercise (HIIE) mode. PPO: peak power output.

Statistical analysis

Our study was an exploratory study. At the time of study conception, we had no data assessing the difference in BP change between HIIT and MICT programmes for a 2-week duration and using the ambulatory method. We assumed a higher response following 2-week HIIT than MICT, taking into account one study by Ciolac et al. [22] comparing the acute effects between HIIE and MICE, and another by Molmen-Hansen et al. [23] comparing the chronic effects between HIIT and MICT for a 12-week programme. For the sample size calculation, assuming a decrease in SBP of 3.5 mmHg in the HIIT groups and of 1.5 mmHg in the MICT group ($\Delta = 2$ mmHg), with a standard deviation of 4 mmHg reduced to 2.83 mmHg, assuming an intraclass correlation at 0.75, for a bilateral alpha of 0.05 and a power of 80% to demonstrate a significant difference between HIIT groups and MICT group in the SBP variable, the number of subjects required was 54 (18 per group). Unfortunately, the period of inclusion was closed before we could reach this number of participants, because of logistical limitations.

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. Between-group comparisons were made with the Bonferroni post-hoc test. Pre- versus post-training comparisons were made with Student's paired *t* test. The magnitude of the difference was assessed by the Hedges' g (g) to assess the effect of intervention, and by Cohen's d (d) to assess the effect of sex. The scale proposed by Cohen was used for the interpretation of both measures, as presented elsewhere [24]. The magnitude of the difference was considered either small ($0.2 < |g| \leq 0.5$), moderate ($0.5 < |g| \leq 0.8$), or large ($|g| > 0.8$). Calculations were carried out with StatView software, version 5.0 (SAS

Institute Inc., Cary, NC, USA). Statistical significance was set at $P < 0.05$.

Results

Baseline characteristics of the 42 participants are presented in Table 1. Regarding the cardiovascular risk factors, 23 (55%) participants had an antihypertensive treatment (angiotensin-converting enzyme inhibitors or angiotensin II receptor blockers, 50%; thiazide diuretics, 24%; calcium channel blockers, 10%; and beta-blockers, 17%), 19 (45%) had a statin for dyslipidaemia, eight (19%) had diabetes mellitus, three (7%) were current smokers and eight (19%) had a personal history of cardiovascular disease. The mean waist circumference and percentage of fat mass were 98.7 ± 12.6 cm and 39.0 ± 5.7%, respectively, in women, and 107.2 ± 9.6 cm and 29.4 ± 4.9%, respectively, in men.

The number of valid BP measurements taken over the 24-hour period, with a minimum of one per hour, was 61 ± 9 (percentage of success 85 ± 13%) for baseline ABPM, 59 ± 11 (82 ± 16%) for post-training ABPM and 61 ± 9 (85 ± 13%) for the last ABPM.

The average ABPM results at baseline and changes in ambulatory BP load after each condition of training are presented in Table 2. Despite the absence of significant difference in between-group analysis of variance analysis, we observed a number of differences in ABPM data at baseline versus after exercise. Haemodynamic measures were not altered significantly by MICT or $HIIT_{dryland}$, whatever the period (24-hour, daytime or night-time). In contrast, $HIIT_{immersed}$ induced a decrease in BP and heart rate over the 24-hour and daytime periods (24-hour SBP −5.1 ± 7.3 mmHg, g = −0.42 [$P = 0.02$]; 24-hour DBP −2.9 ± 4.1 mmHg, g = −0.35 [$P = 0.02$]; daytime SBP −6.2 ± 8.3 mmHg, g = −0.49 [$P = 0.015$]; daytime DBP −3.4 ± 4.0 mmHg, g = −0.35 [$P = 0.008$]; 24-hour heart rate −2.0 ± 2.6 bpm, g = −0.21 [$P = 0.01$]; daytime heart rate−2.4 ± 3.9 bpm, g = −0.25 [$P = 0.04$]). Night/day SBP dipping was not modified by any of the training interventions.

We did not find any interaction between training conditions. Furthermore, the BP response following training was not uniform: 27 participants (64%) had a reduction in their 24-hour SBP after the training period (seven [50%] in the MICT group, nine [64%] in the $HIIT_{dryland}$ group and 11 [79%] in the $HIIT_{immersed}$ group; Fig. 2). Regarding the effect of sex, while we observed no difference between men and women in main baseline characteristics (Table 1) and baseline ABPM results (24-hour SBP for men 128.8 ± 10.4 and for women 128.0 ± 14.2 mmHg, d = 0.1 [$P = 0.8$]; 24-hour DBP for men 78.0 ± 8.2 and for women 76.7 ± 8.7 mmHg, d = 0.2 [$P = 0.6$]; 24-hour heart rate for men 67.7 ± 11.7 and for women 70.5 ± 7.0 bpm, d = −0.3 [$P = 0.4$]; 24-hour PWV for men 9.42 ± 1.39 and for women 9.11 ± 1.12, d = 0.2 [$P = 0.4$]), improvement in 24-hour SBP was similar in men and women (−3.59 ± 7.58 in men and −3.45 ± 8.19 mmHg in women, d = −0.02 [$P = 0.9$]), and whatever the group (MICT: d = 0.4 [$P = 0.5$]; $HIIT_{dryland}$: d = 0.1 [$P = 0.9$]; $HIIT_{immersed}$: d = −0.9 [$P = 0.2$]).

Changes in central BP (Table 2) were similar to those observed in peripheral BP ($HIIT_{immersed}$: 24-hour central SBP −5.6 ± 6.4 mmHg, g = −0.52 [$P = 0.006$]; 24-hour central DBP −3.0 ± 4.0 mmHg, g = −0.33 [$P = 0.02$]; daytime central SBP −5.6 ± 7.0 mmHg, g = −0.49 [$P = 0.01$]; daytime central DBP −3.4 ± 4.3 mmHg, g = −0.34 [$P = 0.01$]). Central SBP also decreased after $HIIT_{immersed}$ during the night-time (−4.6 ± 7.8 mmHg, g = −0.41; $P = 0.006$). This exercise condition also resulted in small improvements in 24-hour and daytime PWV (24-hour PWV −0.17 ± 0.23 m/s, g = −0.11 [$P = 0.015$]; daytime PWV −0.18 ± 0.24 m/s, g = −0.12 [$P = 0.02$]).

Regarding subjective appreciation of the training programme, the PACES score reached 18.9 ± 3.2 (minimum, 8/21; maximum, 21/21), which indicates good appreciation, without significant difference between groups (MICT: 17.8 ± 4.4; $HIIT_{dryland}$: 18.9 ± 2.6; $HIIT_{immersed}$: 20.1 ± 2.0). The POMS test results at baseline and after the 2-week training programme are presented in Table 3. Whereas MICT did not change any dimension of the questionnaire, $HIIT_{dryland}$ moderately improved the perception of fatigue (−4.25 ± 6.36, g = −0.32; $P = 0.04$) and the energy index (+6.42 ± 8.11, g = 0.31; $P = 0.02$), while $HIIT_{immersed}$ resulted in a moderate decrease in anxiety (−3.18 ± 4.27, g = −0.56; $P = 0.04$) and confusion (−2.66 ± 2.17, g = −0.58; $P = 0.004$).

Table 1 Baseline characteristics.

	Overall population	Men	Women	MICT	$HIIT_{dryland}$	$HIIT_{immersed}$
	($n = 42$)	($n = 22$)	($n = 20$)	($n = 14$)	($n = 14$)	($n = 14$)
Age (years)	65 ± 7	66 ± 8	64 ± 7	65 ± 6	65 ± 8	63 ± 9
Male sex	22 (52.4)	–	–	8 (57.1)	9 (64.3)	5 (35.7)
Body mass index (kg/m^2)	29.7 ± 4.3	30.2 ± 4.0	29.2 ± 4.7	29.7 ± 4.5	30.7 ± 4.7	28.8 ± 3.9
SBP (mmHg)	143.1 ± 13.8	142.5 ± 14.1	143.9 ± 13.7	142.4 ± 11.4	144.2 ± 17.3	142.8 ± 12.9
DBP (mmHg)	85.1 ± 9.2	84.5 ± 10.3	85.7 ± 8.1	81.9 ± 6.2	87.6 ± 11.6	85.9 ± 8.8
Heart rate (bpm)	71.7 ± 12.1	68.0 ± 10.7[a]	75.9 ± 12.4[a]	69.2 ± 11.3	73.6 ± 10.8	72.4 ± 14.3
PWV (m/s)	9.59 ± 1.29	9.65 ± 1.45	9.53 ± 1.25	9.52 ± 1.26	9.86 ± 1.39	9.40 ± 1.26

Data are expressed as mean ± standard deviation or number (%). DBP: diastolic blood pressure; $HIIT_{dryland}$: high-intensity interval training on dry land; $HIIT_{immersed}$: high-intensity interval training in immersed condition; MICT: moderate-intensity continuous training; PWV: PWV, pulse wave velocity; SBP: systolic blood pressure.
[a] $P = 0.03$ between sexes.

Table 2 Ambulatory blood pressure monitoring results at baseline, and changes in ambulatory blood pressure load after the 2-week training intervention.

	Overall population ($n = 42$)	MICT ($n = 14$)			$HIIT_{dryland}$ ($n = 14$)			$HIIT_{immersed}$ ($n = 14$)		
		Baseline	Post-training BP changes	Hedge's g[a]	Baseline	Post-training BP changes	Hedge's g[a]	Baseline	Post-training BP changes	Hedge's g[a]
24-hour period										
SBP (mmHg)	128.4 ± 12.2	126.9 ± 12.9	−2.0 ± 8.0	−0.15	130.6 ± 12.2	−3.4 ± 8.3	−0.28	127.6 ± 12.1	−5.1 ± 7.3[b]	−0.42
DBP (mmHg)	77.4 ± 8.35	76.4 ± 7.5	−1.6 ± 5.3	−0.21	78.7 ± 9.7	−2.1 ± 5.3	−0.21	76.9 ± 8.2	−2.9 ± 4.1[b]	−0.35
Heart rate (bpm)	69.0 ± 9.7	67.3 ± 9.9	−0.6 ± 4.7	−0.06	72.6 ± 11.0	−1.3 ± 5.0	−0.11	67.1 ± 7.6	−2.0 ± 2.6[b]	−0.21
Central SBP (mmHg)	117.5 ± 11.7	116.3 ± 10.6	−3.2 ± 9.7	−0.24	118.7 ± 12.2	−2.9 ± 7.0	−0.23	117.5 ± 10.6	−5.6 ± 6.4[b]	−0.52
Central DBP (mmHg)	78.3 ± 8.5	76.7 ± 7.5	−1.5 ± 6.1	−0.21	80.1 ± 9.5	−2.4 ± 5.3	−0.25	78.0 ± 8.7	−3.0 ± 4.0[b]	−0.33
PWV (m/s)	9.28 ± 1.27	9.24 ± 1.35	−0.05 ± 0.33	−0.03	9.48 ± 1.10	−0.11 ± 0.28	−0.10	9.11 ± 1.45	−0.17 ± 0.23[b]	−0.11
Daytime period										
SBP (mmHg)	134.0 ± 12.4	133.1 ± 14.2	−2.4 ± 11.2	−0.16	135.1 ± 11.1	−3.7 ± 9.6	−0.34	133.9 ± 12.7	−6.2 ± 8.3[b]	−0.49
DBP (mmHg)	81.5 ± 8.7	80.8 ± 7.9	−1.9 ± 6.5	−0.22	81.8 ± 9.4	−2.3 ± 6.0	−0.24	81.9 ± 9.2	−3.4 ± 4.0[b]	−0.35
Heart rate (bpm)	73.7 ± 10.7	71.8 ± 11.9	−0.7 ± 5.4	−0.06	77.6 ± 11.0	−1.3 ± 5.3	−0.10	71.7 ± 8.8	−2.4 ± 3.9[b]	−0.25
Central SBP (mmHg)	122.0 ± 12.0	121.8 ± 14.3	−3.8 ± 12.8	−0.24	122.1 ± 11.2	−2.9 ± 8.5	−0.27	122.1 ± 11.3	−5.6 ± 7.0[b]	−0.49
Central DBP (mmHg)	83.2 ± 8.7	82.6 ± 7.7	−2.4 ± 8.5	−0.29	83.5 ± 9.4	−2.1 ± 6.5	−0.23	83.5 ± 9.4	−3.4 ± 4.3[b]	−0.34
PWV (m/s)	9.45 ± 1.26	9.46 ± 1.31	−0.09 ± 0.46	−0.07	9.61 ± 1.07	−0.13 ± 0.31	−0.11	9.26 ± 1.44	−0.18 ± 0.24[b]	−0.12
Night−time period										
SBP (mmHg)	119.2 ± 12.3	117.3 ± 10.5	−0.1 ± 6.0	−0.01	122.5 ± 14.2	−2.0 ± 7.0	−0.13	117.8 ± 12.1	−3.4 ± 8.2	−0.28
DBP (mmHg)	70.8 ± 8.5	69.9 ± 6.9	−0.8 ± 4.4	−0.11	73.5 ± 10.4	−1.4 ± 5.4	−0.11	68.9 ± 7.7	−1.4 ± 5.3	−0.18
Heart rate (bpm)	61.7 ± 8.9	60.9 ± 8.7	−0.1 ± 4.0	−0.02	64.4 ± 10.79	−0.4 ± 4.8	−0.03	59.9 ± 6.7	−1.1 ± 3.7	−0.15
Central SBP (mmHg)	110.9 ± 12.0	108.9 ± 13.4	−2.5 ± 7.1	−0.24	113.3 ± 14.4	−1.6 ± 6.4	−0.10	110.4 ± 11.2	−4.6 ± 7.8[b]	−0.41
Central DBP (mmHg)	71.1 ± 8.4	68.9 ± 6.5	−0.5 ± 5.7	0.07	74.6 ± 9.8	−1.5 ± 5.2	−0.13	69.6 ± 7.9	−1.3 ± 5.3	−0.16
PWV (m/s)	9.04 ± 1.28	9.00 ± 1.38	−0.03 ± 0.27	−0.02	9.26 ± 1.02	−0.03 ± 0.23	−0.03	8.85 ± 1.46	−0.13 ± 0.27	−0.08
Night-time/daytime SBP dip (%)	11.0 ± 5.3	11.7 ± 5.0	−1.8 ± 6.7	−0.26	9.4 ± 5.7	−1.0 ± 5.5	−0.14	11.9 ± 5.1	−1.6 ± 4.5	−0.31

Data are expressed as mean ± standard deviation. BP: blood pressure; DBP: diastolic blood pressure; $HIIT_{dryland}$: high-intensity interval training on dry land; $HIIT_{immersed}$: high-intensity interval training in immersed condition; MICT: moderate-intensity continuous training; SBP: systolic blood pressure; PWV: pulse wave velocity.

[a] Magnitudes of the difference assessed by Hedges' g are considered either small ($0.2 < |g| \leq 0.5$), moderate ($0.5 < |g| \leq 0.8$) or large ($|g| > 0.8$).

[b] $P < 0.05$ in post- versus pre-exercise intragroup comparison.

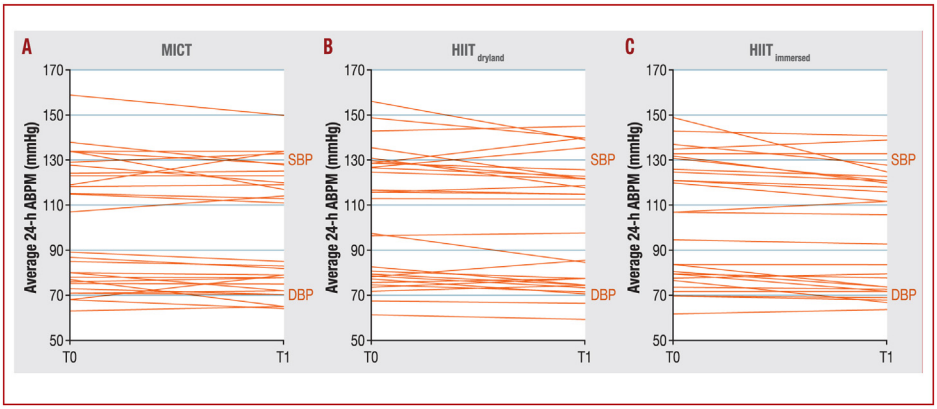

Figure 2. Individual responses in terms of 24-hour systolic/diastolic blood pressure (SBP/DBP) values from baseline (T0) to after the 2-week training period (T1), for the three groups: moderate-intensity continuous training (MICT); high-intensity interval training on dry land ($HIIT_{dryland}$,); and high-intensity interval training in immersed condition ($HIIT_{immersed}$). ABPM: ambulatory blood pressure monitoring.

Discussion

The aim of this study was to assess chronic changes in ABPM results following a 2-week training programme involving six sessions of either MICT on dry land or HIIT performed on dry land or in immersed condition, in participants with a baseline office SBP/DBP $\geq$ 130/85 mmHg. We hypothesized that HIIT would be more effective than MICT at improving 24-hour BP load, and that the immersed condition would have an additional effect compared with the dryland condition. In accordance with this hypothesis, $HIIT_{immersed}$ resulted in a (small, moderate or large depending on the Hedge's g) decrease in BP load and PWV during the 24-hour and daytime periods.

Many studies have examined BP decrease following training, and have consistently reported a greater BP drop in hypertensive than in normotensive participants [25]. The use of ABPM provides additional information — particularly regarding the sustained BP effect during the 24-hour period and the real improvement in BP load that is necessary to assess the chronic effect of an antihypertensive intervention. While the magnitude of BP decrease appeared lower in studies using ABPM than in those using office BP, in a recent meta-analysis we reported a weighted mean SBP/DBP decrease reaching −4.1/−2.8 mmHg for the 24-hour period, −3.8/−2.7 mmHg for daytime and −2.4/−1.7 mmHg for night-time [26]. Interestingly, in our study, the magnitude of decrease in ambulatory SBP/DBP following $HIIT_{immersed}$ was larger than these reference values, despite a rather small training volume.

During the night-time period, we observed a significant decrease only in mean central SBP, and only in the $HIIT_{immersed}$ group. Night/day dipping, known for its prognostic value for cardiovascular diseases [2], was not modified following training programmes, whatever the group.

The BP threshold of 130/85 mmHg that we chose for an inclusion criterion could be questionable. This threshold was highlighted by the SPRINT study [27], which included and treated individuals with office SBP $\geq$ 130 mmHg, with favourable results on non-fatal and fatal cardiovascular events and death from any cause in participants undergoing the aggressive BP-lowering strategy. In a meta-analysis assessing the effects of aerobic training on ABPM results, baseline office BP $\geq$ 130/85 mmHg was associated with a greater BP improvement than baseline office BP < 130/85 mmHg [26]. Following this tendency, the recent North American guidelines proposed a threshold of 130/80 mmHg (instead of 140/90 mmHg) for the diagnosis of high BP [28].

Few studies have assessed the effect of the manipulation of training modalities (MICT versus HIIT, dry land versus immersed condition) on 24-hour BP response. One randomized study compared the effect of MICT versus HIIT on ABPM results; participants were 48 men and women with hypertension (aged 52 ± 8 years) who trained three times a week for 12 weeks [23]. The mean decrease in 24-hour SBP/DBP load reached −12/−8 mmHg following HIIT versus −4.5/−3.5 mmHg following MICT. In our 2-week $HIIT_{immersed}$ group, we observed a higher mean change in ABPM results than they observed following their 12-week MICT, thus suggesting a better cost-benefit ratio for this exercise modality.

Regarding comparison of BP changes between aerobic training on dry land or in immersed condition, we did not find any studies using ABPM. However, we identified two studies describing the effect of training in a swimming pool on ambulatory BP. The first study reported an SBP/DBP drop reaching −9.0/−5.0 mmHg for daytime and −5.0/−3.0 mmHg for night-time periods, in a group of 24 individuals (58 ± 2 years) with prehypertension, who trained by swimming for 45 min three times a week for 12 weeks [29]. The comparison with our study is complex because of major differences observed previously in physiological blood flow response between upright practice of water exercise (such as cycling) and swimming practice [30], and the training programme duration was longer than in our study. The second study reported a much greater decrease in SBP/DBP (24-hour: −17.0/−9.0 mmHg; daytime: −18.0/−10.0 mmHg; night-time: −15.0/−8.0 mmHg) in 16 individuals younger than ours (mean age 55 ± 6 years) [31]. The explanation for their greater BP response partly relies on a higher BP level at baseline, as previously suggested by Sosner et al. [26] One study reported the BP change following HIIT in a swimming pool: the intervention was swimming HIIT three times a week for 15 weeks compared with

Table 3 *t*-scores for the subscales of the Profile of Mood States test at baseline and after the 2-week training programme.

	Overall population ($n = 33$)	MICT ($n = 11$)			$HIIT_{dryland}$ ($n = 12$)			$HIIT_{immersed}$ ($n = 10$)		
		Baseline	Post-training changes	Hedge's g[a]	Baseline	Post-training changes	Hedge's g[a]	Baseline	Post-training changes	Hedge's g[a]
Anxiety	45.39 ± 5.28	43.47 ± 4.54	−1.63 ± 4.04	−0.30	46.46 ± 5.55	−3.11 ± 9.55	−0.37	46.23 ± 5.64	−3.18 ± 4.27[b]	−0.56
Anger	43.09 ± 5.93	42.46 ± 4.72	−1.22 ± 4.07	−0.22	45.45 ± 7.69	−1.32 ± 8.17	−0.13	40.94 ± 3.88	−0.97 ± 3.18	−0.25
Confusion	43.91 ± 5.38	42.73 ± 5.19	−0.93 ± 5.37	−0.16	44.22 ± 6.48	−2.73 ± 6.26	−0.43	44.84 ± 4.33	−2.66 ± 2.17[b]	−0.58
Vigour	53.90 ± 8.67	57.64 ± 9.28	−1.10 ± 7.66	−0.11	52.16 ± 7.81	+2.17 ± 9.07	0.21	51.88 ± 8.44	+2.43 ± 5.74	0.28
Fatigue	42.94 ± 9.45	38.16 ± 2.70	+2.17 ± 4.58	0.62	47.40 ± 12.62	−4.25 ± 6.36[b]	−0.32	42.85 ± 7.78	−1.12 ± 3.98	−0.13
Depression	43.76 ± 5.51	40.95 ± 2.56	−0.30 ± 3.69	−0.10	45.95 ± 6.78	−2.00 ± 6.58	−0.28	44.24 ± 5.31	−1.75 ± 5.15	−0.26
Energy index	10.96 ± 15.43	19.48 ± 8.18	−3.28 ± 8.56	−0.30	4.76 ± 17.94	+6.42 ± 8.11[b]	0.31	9.02 ± 15.31	+3.55 ± 8.25	0.22
Total score mood disorder	14.36 ± 18.97	4.45 ± 6.28	−0.91 ± 12.72	−0.07	22.50 ± 21.62	−9.58 ± 19.98	−0.35	15.50 ± 21.32	−8.10 ± 11.36	−0.36

Data are expressed as mean ± standard deviation. $HIIT_{dryland}$: high-intensity interval training on dry land; $HIIT_{immersed}$: high-intensity interval training in immersed condition; MICT: moderate-intensity continuous training.

[a] Magnitudes of the difference assessed by Hedges' g are considered either small ($0.2 < |g| \leq 0.5$), moderate ($0.5 < |g| \leq 0.8$) or large ($|g| > 0.8$).

[b] $P < 0.05$ in post- versus pre-exercise intragroup comparison.

swimming MICT, and the participants were 42 women with hypertension (mean age 45 ± 2 years) [32]. The office (not ambulatory) SBP/DBP changes were higher following HIIT (−6.0/−2.0 mmHg) than following MICT (−4.0/0.0 mmHg). Another study assessed the effects of 9 months of a combined lifestyle programme, including HIIT on an ergocycle on dry land versus in immersed condition in obese individuals: resting office BP improved similarly in the two groups [33]. No previous study has assessed 24-hour ABPM results following water-ergocycle training. A comparison between water-ergocycle and swimming training would be interesting.

PWV is a marker of arterial stiffness, the reduction of which in the $HIIT_{immersed}$ group could have been driven by changes during the day in peripheral sympathetic tone, which also plays an important role in vascular stiffness regulation [34]. Interestingly, we also observed a decrease in mean heart rate that was significant following $HIIT_{immersed}$ (despite a non-significantly lower value at baseline in this group). This could be the marker of improvement in cardiac autonomic modulation [8], with an more pronounced increase in cardiac vagal tone following $HIIT_{immersed}$. Further studies are needed to understand the mechanisms involved in training-induced changes in BP following $HIIT_{immersed}$, including neurohormonal markers of plasma volume regulation (renin-angiotensin system or natriuretic peptide), direct or indirect markers of cardiovascular autonomic control (sympathetic nerve activity, baroreflex sensitivity or PWV) and endothelial function.

Regarding the subjective perception of the training programme, the score from the PACES questionnaire [14] favoured good appreciation, whatever the training modality. The changes in the POMS score were only significant for the HIIT groups, not for the MICT group. After exclusion of studies reporting mood profiling in sport or over-reaching patterns of athletes, we found only two studies assessing the impact of physical training on the POMS score in non-athletes: In 33 individuals from the general population randomized to 10 weeks of MICT or control, the training programme led to greater reductions in the anxiety, confusion and depression scores of the POMS test than the control condition, and these effects were maintained at 3-month follow-up [35]; in 49 individuals who were positive for the human immunodeficiency virus randomized to 6 weeks of MICT and resistance training or control, the training programme led to a greater reduction in the depression score of the POMS test than the control condition [36]. Hence, our results reinforce the observation of favourable effects on mood of exercise training programmes, and the hypothesis that these effects could be proportional to the intensity of the exercise.

Study limitations

Our study was an exploratory study with sample size limitation: the required number of subjects was not reached because of the logistical limitations of the inclusion period. The impact of this methodological pitfall on our results could have been essentially a global lack of statistical power. Thus, it can be assumed that the BP decrease following the training period observed in the $HIIT_{dryland}$ group could have been significant (to a less extent than in the $HIIT_{immersed}$ group), and some between-group differences could have been revealed. We did not assess at baseline the participants' habits in terms of physical activity; nevertheless they were non-athletes, and were asked to refrain from any other physical activity for the duration of the study. This limitation could be mitigated by the randomized nature of the inclusions, which allows a theoretical homogeneous distribution of the participants' characteristics. The post-training ABPM, performed over the 24 h after the last training session, consequently included both an acute effect of the session and a chronic effect of the cumulative 2-week six-session training. Regarding arterial stiffness assessment, while the gold standard method requires a tonometry device, we used another method, previously validated in resting condition [13].

Perspectives

Water-based training and HIIT represent interesting prospects with good enjoyment levels that can promote patient adherence to physical training. The appreciable results we observed in the HIIT group cycling in a swimming pool, led us to assess the beneficial antihypertensive effects of such training programmes, which may be prescribed for hypertensive individuals. To detail the mechanisms of the changes following HIIT in immersed condition, further multicentre studies should be performed, including a larger number of participants, with biological and physiological analysis, and extended to long-term follow-up. Endpoints of such a follow-up should take into account the epidemiological transition of long-term consequences of hypertension, such as atrial fibrillation and vascular dementia [37], which could perhaps be prevented by varied physical training programmes, including HIIT and immersed condition.

Conclusions

In individuals with a baseline office BP of ≥ 130/85 mmHg, the 24-hour and daytime BP loads, assessed by ABPM, decreased significantly following HIIT performed on a stationary cycle in immersed condition. In addition, cycling in water was associated with an alleviation of 24-hour and daytime average PWV and heart rate, and 2-week HIIT appeared to be sufficient to elicit an improvement in mood state, while MICT did not. This innovative method should be considered as an efficient non-pharmacological treatment of hypertension and, as such, should now be implemented in a larger cohort to study its long-term effects on the cardiovascular system.

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Disclosure of interest

The authors declare that they have no competing interest.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.acvd.2019.07.005.

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