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ARTICLE

Effects of different aerobic exercise programs on cardiac autonomic modulation and hemodynamics in hypertension: data from EXERDIET-HTA randomized trial

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Abstract

The aims of the present study were to analyze the effects of 16 weeks of different aerobic exercise training (ExT) programs with diet on cardiac autonomic modulation and hemodynamics in nonphysically active and overweight/obese adults ($n = 249$, 53.7 ± 8.0 years) with primary hypertension, and the possible differences among ExT programs and their effects on heart rate (HR), blood pressure (BP), and long-term BP variability (BPV). Participants were randomly assigned into an attention control (AC) group (physical activity recommendations) or one of three supervised ExT groups: high volume of moderate-intensity continuous training, high-volume and high-intensity interval training (HIIT), and low-volume-HIIT. Twenty-four hours of ambulatory BP monitoring was used to analyze systolic (SBP) and diastolic (DBP) BP, HR, and BPV. A cardiopulmonary exercise test was performed to determine peak oxygen uptake (VO_{2peak}). Following intervention, resting and submaximal exercise (HR, SBP, and DBP), along with diurnal and nocturnal SBP and DBP values decreased ($P < 0.05$) in all groups with no differences between groups. When the ExT groups were combined, submaximal SBP ($P = 0.048$) and DBP ($P = 0.004$), VO_{2peak} ($P = 0.014$) and HR reserve ($P = 0.030$) were significantly improved compared with AC. Intervention did not have significant effects on BPV. In the present study better improvements in the autonomic nervous system were seen when the aerobic ExT was individually designed and supervised with pari passu effects irrespective of exercise intensity and volume. Low-volume-HIIT ExT combined with a healthy diet should be considered as a time efficient and safe mechanism for reducing the cardiovascular risk in hypertensive individuals.

Introduction

Primary hypertension (HTN) is associated with dysfunctional autonomic cardiovascular control (i.e., inappropriate activation of the sympathetic and reduction of the parasympathetic divisions), both at rest and in response to exercise [1]. This dysfunction is mainly due to neural factors such as an enhanced pressor reflex, decreased baroreflex sensitivity, and impaired functional sympatholysis, leading to a progressively greater decrease in blood flow to the working muscles during exercise [2]. Hence, compared with normotensive individuals, those with HTN show a significant increase in heart rate (HR), blood pressure (BP), and BP variability (BPV, i.e., the variation of BP over time) [1]. Current HTN guidelines highlight the risk associated with high BPV, since it represents an additional risk factor for cardiovascular complications [3] and is an independent predictor of the incidence of cardiovascular disease and mortality [4, 5].

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The aforementioned abnormal cardiovascular response to exercise in those individuals with HTN may induce untoward events. However, a single session of aerobic exercise yields a reduced sympathetic outflow, which is associated with a sustained postexercise vasodilation in the exercising muscle, and this contributes to the fall in arterial BP; through adaptation this can lead to potential benefits to the individual [6]. Likewise, a recent study assessing the acute effects of a single bout of three different exercise modalities (i.e., moderate-intensity continuous training (MICT), high-intensity interval training (HIIT), or combined training including MICT and resistance training) found different changes on BPV favoring the combined training [7]. Regular aerobic exercise training (ExT), carefully designed and supervised by exercise specialists and a healthy diet are known to be an excellent nonpharmacological treatment against HTN-caused disturbances. As such ExT is strongly recommended by current European and American HTN guidelines [8, 9].

Whilst there is a lack of consistency between studies regarding exercise intensity and duration [10], previous it has been demonstrated that ExT induces positive changes in hemodynamic, autonomic, and cardiac adaptations in individuals with HTN [11–13]. Previously, aerobic ExT programs in individuals with HTN have included MICT and different volumes of HIIT of which all showed a significant reduction in BP with no between-group differences [14]. Nevertheless, to the best of our knowledge, there are no investigations analyzing the impact of aerobic ExT programs which differ in intensity and volume on resting, submaximal exercise, peak and recovery autonomic modulation, and long-term BPV (i.e., visit-to-visit measures spaced by months) in overweight/obese adults suffering from HTN. Given the clinical relevance of autonomic cardiovascular control, the aim of the present investigation was to study the effects of 16 weeks of different aerobic ExT programs with a hypocaloric diet on cardiac autonomic modulation and hemodynamics in overweight/obese adults with HTN. The secondary objective was to analyze the possible differences in HR, BP, and long-term BPV variables between different ExT programs.

Methods

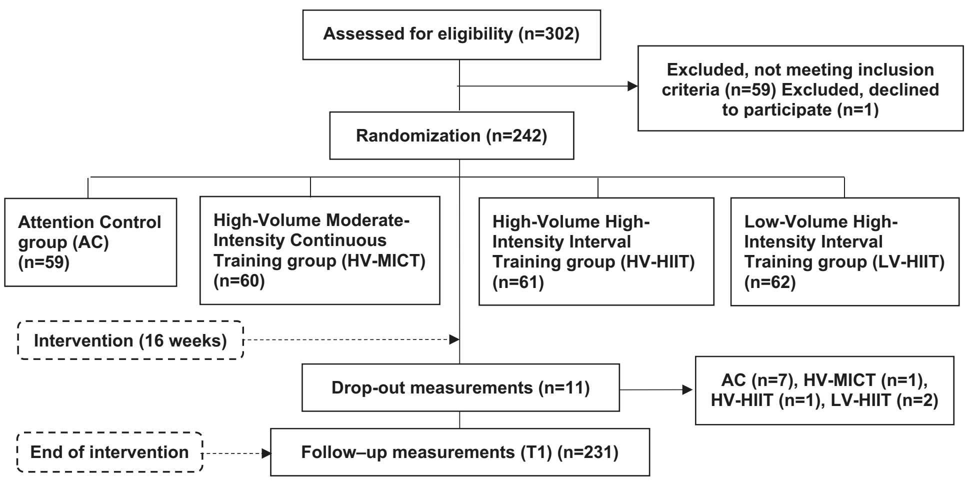
Study design

The EXERDIET-HTA study is a multi-arm parallel, randomized, single-blind controlled experimental trial comparing the effects of different 16-week aerobic ExT programs (performed 2 days/week), in overweight/obese participants with HTN (www.clinicaltrials.gov, number NCT02283047). The study protocol was approved by the ethics committees of the University of the Basque Country (CEISH UPV/EHU, 279/2014, 229/2018) and clinical investigation of Araba University Hospital (2015-030). Medical staff were blinded to the participant randomization process. The design, selection criteria, and procedures for the EXERDIET-HTA study have been detailed previously [15].

Participants

Non-Hispanic white EXERDIET-HTA participants ($n = 249$, 158 men [63.5%] and 91 women [36.5%]) took part in the present study. All participants provided written informed consent before any data collection. Figure 1 presents a flow diagram of the study process for this sample. On the other hand, a HEALTHY sample ($n = 30$) was recruited from the community and excluded if they had any chronic medical illness, were taking any daily prescription medications, had current medical symptoms, had abnormal findings on physical examination (including BP ≥ 140/90 mmHg, or overweight ≥ 25 kg/m^2), or had abnormal results on screening test (rest and exercise electrocardiogram).

Fig. 1 Flow chart of the study.



Measurements

The measurements for the current study were taken pre (T0) and post a 16-week intervention period (T1). The HEALTHY sample only performed baseline measurements with no intervention procedures.

Blood pressure

Participants wore an ambulatory blood pressure monitor (ABPM) over a 24-h period using an oscillometric ABPM 6100 (Welch Allyn, New York City, NY, USA) device to evaluate BP in line with the European guidelines [5]. Values of ABPM are shown as the mean of global (24 h), day and night hours for systolic BP (SBP) and diastolic BP (DBP). BP variability, expressed as coefficient of variation (CV), was calculated by the standard deviation (SD) of the BP values over a defined period of the 24 h and by the day and night hour period, respectively [13, 16]. Resting HR was assessed as the mean global of the 24 h measurements.

Cardiorespiratory fitness (CRF)

A cardiopulmonary exercise test was used to determine peak oxygen uptake (VO_{2peak}) and ventilatory thresholds (VT). The cardiopulmonary exercise test was performed on an electronically braked Lode Excalibur Sport cycle ergometer (Groningen, The Netherlands). The test protocol started at 40 W for HTN individuals and at 70 W for the HEALTHY group (~70 rpm), with gradual increments of 10 W being applied every minute until volitional exhaustion occurred. Continuous electrocardiogram monitoring was conducted throughout each test. Expired gas was analyzed using a commercially available metabolic cart (Ergo CardMedi-soft S.S, Belgium; Ref. USM001 V1.0). Achievement of VO_{2peak} criteria has previously been defined [17]. Submaximal BP and HR were obtained at the fourth minute of the test and peak values were taken from the peak at maximal effort. Ventilatory thresholds (VT1 and VT2) were assessed using standardized methods using the ventilatory equivalents [17]. After completion of the test, participants remained seated on the bike for 5 min of recovery to assess electrocardiogram, HR and BP. HR variables during the recovery period were calculated from the cardiopulmonary exercise test as follows: heart rate reserve (HRR), difference between HR_{peak} during exercise and preexercise HR_{rest}; HR_{rec1}, HR at 1 min recovery; and HR_{rec}, difference between HR_{peak} and HR_{rec1}. BP recovery variables (SBP and DBP) were obtained at 3 min of the recovery period. Based on VT1 and VT2, the three exercise intensity domains (i.e., R1, light to moderate, HR < VT1; R2, moderate to high, HR between VT1 and VT2; R3, high to severe HR > VT2 to HR_{peak}) were determined [17].

Medication

In the EXERDIET-HTA sample, prescribed medications were recorded and classified into the following groups: beta-blockers, angiotensin-converting enzyme inhibitors (ACEIs), angiotensin II receptor blockers (ARBs), calcium channel blockers, diuretics, and other antihypertensive drugs. Medical staff controlled and prescribed all necessary changes to medication before intervention. Pharmacological treatment was not changed during the intervention.

Intervention

All participants from the EXERDIET-HTA sample underwent a hypocaloric and controlled sodium diet (3–6 g/d) [14]. Following baseline data collection, participants were randomly allocated to one of the four intervention groups: the attention control (AC) group (only received general physical activity recommendations in one face-to-face session, with no supervised exercise), or the three supervised ExT groups: high-volume (HV) MICT, HV-HIIT, or low-volume (LV) HIIT. Each group was stratified by sex, SBP, body mass index (BMI), and age [14, 15].

The three ExT groups trained two nonconsecutive days per week under the supervision of exercise specialists. All sessions started and finished with BP monitoring, and training intensity was dictated by individual HR responses (Polar Electro, Kempele, Finland) and the rate of perceived exertion (Borg's 6–20 point scale). Each session included a 5–10-min warm-up and a 10-min cool-down. The core part of each training session consisted of a range of aerobic exercises, i.e., 1 day of the week on the treadmill, and the second one on the bike (BH Fitness equipment, Vitoria-Gasteiz, Spain). The HV-MICT group performed 45 min aerobic exercise (i.e., continuous steady training at R2), the HV- and LV-HIIT groups performed 45 and 20 min, respectively. The intensity in HIIT groups was individually tailored to each participant's HR at moderate (R2) or vigorous (R3) intensities, adjusting the speed and/or incline of the treadmill or the power and speed on the exercise bike. Supervised ExT protocols have previously been explained in detail [14, 15].

As participants were overweight/obese the combined used of stationary exercise bike and treadmill was used to avoid the osteoarticular impact of two weekly treadmill sessions.

Statistical analysis

Descriptive statistics were calculated for all variables. Comparison between HEALTHY vs. HTN groups was conducted using the Student *t* test for independent samples. Analysis of variance was used to determine if there were significant preintervention between-group differences. The comparison of frequencies in categorical variables among groups was performed using the chi-square test. A two sample paired *t* test was used to determine whether there was a significant difference in the recorded data between T0 and T1 within each group. Analysis of covariance was used to examine the delta (Δ) score for each group (AC, HV-MICT, HV-HIIT, and LV-HIIT), adjusting for age, sex, body mass, and the initial value of each of the dependent variables. Helmert contrasts were performed to analyze the difference between the three ExT groups pooled together and the AC group. Bonferroni correction was used to determine the significance when a significant main effect was found. The required sample size was determined for the primary outcome variable (SBP). It was identified that adequate power (0.80) to evaluate differences in our design consisting of four experimental groups would be achieved with 164 people (41 each group, $\alpha = 0.05$, effect size $f = 0.27$) based on the pilot study with an SD of 9 mmHg. Data were analyzed according to the intention-to-treat principle. Statistical significance was set at $P < 0.05$. All statistical analyses were performed with SPSS version 24.0.

Results

The characteristics of the HTN population and HEALTHY group are presented in Table 1. At baseline, mean BMI in all HTN groups was above 30 kg/m^2, which is considered obesity, and waist circumference was >100 cm, which is considered a cardiovascular risk factor [18]. No significant between-group differences were found in any variable for the groups with HTN.

Comparing the entire HTN sample with the HEALTHY group, significant differences were found in all baseline variables ($P < 0.001$). BMI, waist circumference, rest BP, and HR_{rest} values were significantly higher in the HTN group compared with the HEALTHY group. However, HR_{peak} and VO_{2peak} were significantly lower (Table 1).

Regarding pharmacological therapy, 87.1% of HTN participants were taking regular medication. The percentage of participants who took one, two, three, four or more medications was 38.7%, 29%, 13.7%, and 5.6%, respectively. Regarding medication type, 7.3% of participants took beta-blockers, 37.7% ACEIs, 41.7% ARBs, 13.8% calcium channel blockers, 38.5% diuretics, and 4.6% other antihypertensive drugs. With respect to other concomitant diseases, 6.1% had diabetes mellitus and 10.6% were smokers. No significant differences were found among HTN groups for any baseline variable.

Following the 16-week intervention period, resting and submaximal HR, SBP and DBP decreased ($P < 0.05$) in all groups (Table 2), except AC group's submaximal SBP. Furthermore, peak DBP decreased in the HV-HIIT group ($\Delta = -9.9\%$, $P < 0.001$) only. CRF expressed as VO_{2peak} (mL kg^{-1} min^{-1}) increased in all ExT groups (HV-MICT $\Delta = 10.5\%$, $P = 0.025$; HV-HIIT $\Delta = 23.8\%$, $P < 0.001$, and LV-HIIT $\Delta = 17.6\%$; $P = 0.005$). In addition, HV-MICT and LV-HIIT showed an increase in HRR ($\Delta = 13.5\%$, $P = 0.004$ and $\Delta = 7.7\%$, $P = 0.017$, respectively), and only LV-HIIT group decreased SBP after 3 min of recovery ($\Delta = -4.4\%$, $P = 0.001$). On the other hand, DPB at 3 min of recovery was reduced in all ExT groups (HV-MICT $\Delta = -5.8\%$, $P = 0.013$; HV-HIIT $\Delta = -10.8\%$ and LV-HIIT $\Delta = -5.2\%$, $P < 0.001$) after the intervention period. Only LV-HIIT group showed an increased number of beats between HR_{peak} and the HR_{rec1} ($\Delta = 13.1\%$, $P = 0.015$). Following Bonferroni correction, there were no significant between-group differences in any resting variable. However, AC showed a smaller reduction compared with HV-HIIT group in submaximal DBP ($P = 0.017$) mean difference 8.319, 95% confidence interval (CI) 0.968 −15.671 mmHg; VO_{2peak} ($P = 0.049$) mean difference −4.564, 95% (CI) −9.126-0.002 mL kg^{-1} min^{-1}; and DBP_{rec3} ($P = 0.041$) mean difference 6.498, 95% (CI) 0.166–12.830 mmHg. Furthermore, there were significant differences between all ExT groups as a whole and AC group in submaximal SBP ($P = 0.048$), DBP ($P = 0.004$), VO_{2peak} ($P = 0.014$), and HRR ($P = 0.030$).

After the 16-week intervention, diurnal and nocturnal SBP and DBP significantly ($P < 0.05$) decreased in all groups (Table 3), with no between-group differences. However, the intervention did not have significant effects on any of the BPV variables (i.e., CV of BP). Taking into account all ExT groups together, a significant decrease was found in daytime DBP's CV ($\Delta = -4.4\%$, $P = 0.023$).

Discussion

To our knowledge, this is the first intervention investigating the effects of different volume (HV vs. LV) and intensity (MICT vs. HIIT) aerobic ExT programs on hemodynamics and cardiac autonomic modulation in hypertensive and overweight/obese individuals. The present investigation confirms that a dual treatment with aerobic ExT and diet is helpful to reduce resting and submaximal HR, together with global, day and night BP values. Further, ExT groups showed a greater improvement in CRF, HRR, and submaximal BP compared with the AC group. Nevertheless, 16 weeks of aerobic ExT and diet intervention did not reduce BPV. Importantly, the lack of post intervention difference between-ExT groups in most of the studied variables suggested that the most effective method was ExT using the LV-HIIT protocol.

Table 1 Baseline characteristics for each group of participants.

	HEALTHY ($N = 30$)	HTN ($N = 259$)	P value HEALTHY vs. HTN	HTN groups				P value intergroups HTN
				AC ($N = 59$)	HV-MICT ($N = 60$)	HV-HIIT ($N = 61$)	LV-HIIT ($N = 62$)	
Sex (men/women)	13/17	163/96	<0.001	33/26	38/22	40/21	41/21	0.642
Age (years)	40.5 ± 8.7	53.7 ± 8.0	<0.001	52.9 ± 8.5	54.2 ± 7.2	53.1 ± 8.6	54.4 ± 7.2	0.650
BMI (kg/m^2)	23.1 ± 2.7	32.1 ± 4.2	<0.001	32.4 ± 4.6	32.1 ± 4.3	31.6 ± 3.7	32.0 ± 4.2	0.751
Waist perimeter (cm)	75.1 ± 8.0	103.1 ± 11.1	<0.001	102.9 ± 10.6	104.1 ± 12.4	101.2 ± 11.0	104.1 ± 10.6	0.449
Rest SBP (mmHg)	114.1 ± 6.7	136.5 ± 12.6	<0.001	138.5 ± 14.0	135.4 ± 11.5	134.8 ± 11.8	137.2 ± 13.3	0.353
Rest DBP (mmHg)	68.3 ± 7.2	78.2 ± 8.4	<0.001	78.2 ± 8.8	76.7 ± 8.0	78.8 ± 7.9	79.0 ± 8.2	0.392
HR_{rest} (bpm)	58.2 ± 6.9	71.2 ± 10.1	<0.001	70.4 ± 9.2	72.9 ± 10.7	70.3 ± 9.9	72.1 ± 11.1	0.396
HR_{peak} (bpm)	178.7 ± 9.7	154.5 ± 16.8	<0.001	150.2 ± 17.6	154.9 ± 16.5	156.2 ± 15.7	158.3 ± 15.7	0.052
HR_{rec} (bpm)	35.3 ± 11.1	26.8 ± 10.9	<0.001	26.0 ± 8.8	27.5 ± 11.7	27.3 ± 12.6	26.2 ± 10.6	0.814
VO_{2peak} (mL kg^{-1} min^{-1})	48.1 ± 9.0	22.6 ± 5.5	<0.001	22.1 ± 5.5	22.0 ± 5.2	22.7 ± 4.8	22.7 ± 5.4	0.816
Concomitant diseases								
DM (%)				3.5	6.7	4.9	8.1	0.732
Smoking (%)				4.2	9.9	18.7	9.4	0.076
Antiypertensive medication								
Medication (%)				87.9	91.7	83.6	88.7	0.594
Number antihypertensive drugs				1.6 ± 1.0	1.8 ± 1.2	1.5 ± 1.1	1.6 ± 1.1	0.492
Beta-blockers (%)				10.5	8.3	6.6	4.8	0.678
ACEI (%)				43.9	38.3	42.6	27.4	0.229
ARB (%)				45.6	43.3	29.5	50.0	0.119
Calcium channel blocker (%)				7.0	20	13.1	14.5	0.242
Diuretic (%)				36.8	43.3	41.0	35.5	0.801
Other antihypertensive drugs (%)				3.9	5.3	3.3	5.8	0.617

Values are mean ± SD, percentage (%) or number. Blood pressure (BP) values show the mean BP calculated by 24-h ambulatory blood pressure monitoring. $P < 0.05$

HTN hypertension, *AC* attention control group, *HV* high volume, *LV* low volume, *MICT* moderate-intensity continuous training group, *HIIT* high-intensity interval training group, *BMI* body mass index, *SBP* systolic blood pressure, *DBP* diastolic blood pressure, HR_{rest} resting heart rate, HR_{peak} peak heart rate, HR_{rec} difference between HR_{peak} and HR after recovery's first minute, $VO2_{peak}$ peak oxygen uptake, *DM* diabetes mellitus, *ACEI* angiotensin-converting enzyme inhibitors, *ARB* angiotensin II receptor blockers

Table 2 Heart rate and blood pressure responses before and after 16 weeks intervention.

	AC ($N = 52$)	HV-MICT ($N = 59$)	HV-HIIT ($N = 60$)	LV-HIIT ($N = 60$)	P value AC vs. ExT	*P* value intergroups	*F* value	Effect size
Rest								
HR_{rest} (bpm)								
T0	70.1 ± 9.2	72.8 ± 10.1	69.9 ± 10.3	72.3 ± 11.3				
T1	66.3 ± 8.8*	67.4 ± 9.1*	63.6 ± 8.3*	66.1 ± 10.7*	0.054	0.331	1.148	0.016
Global SBP (mmHg)								
T0	138.6 ± 13.9	135.0 ± 11.4	134.5 ± 11.9	136.9 ± 13.5				
T1	133.7 ± 14.5*	130.2 ± 10.4*	130.3 ± 11.3*	130.5 ± 11.7*	0.905	0.777	0.366	0.005
Global DBP (mmHg)								
T0	78.5 ± 8.1	76.2 ± 7.9	78.5 ± 8.0	79.1 ± 8.3				
T1	75.5 ± 8.9*	73.6 ± 7.8*	74.5 ± 7.0*	75.4 ± 7.7*	0.661	0.700	0.475	0.007
Submaximal								
HR_{submax} (bpm)								
T0	121.6 ± 16.8	126.8 ± 18.5	123.7 ± 23.0	123.2 ± 16.8				
T1	115.3 ± 15.5*	116.5 ± 17.9*	110.9 ± 13.3*	114.6 ± 16.8*	0.109	0.239	1.418	0.019
SBP (mmHg)								
T0	178.9 ± 35.8	182.8 ± 34.9	177.8 ± 23.3	173.6 ± 24.3				
T1	169.8 ± 25.3	164.7 ± 30.4*	158.5 ± 23.1*	155.0 ± 25.0*	0.048	0.395	0.997	0.014
DBP (mmHg)								
T0	96.0 ± 13.6	97.8 ± 15.2	99.6 ± 15.6	97.6 ± 14.7				
T1	92.1 ± 12.9*	90.1 ± 15.2*	87.0 ± 12.2**	88.9 ± 11.9*	0.004	0.027	3.106	0.042
Peak								
HR_{peak} (bpm)								
T0	151.5 ± 17.7	155.0 ± 16.8	155.7 ± 16.0	157.6 ± 15.7				
T1	152.5 ± 15.6	157.0 ± 16.4	157.4 ± 13.0	158.7 ± 13.0	0.748	0.978	0.067	0.001
SBP (mmHg)								
T0	218.5 ± 25.6	214.8 ± 27.9	207.3 ± 27.6	209.5 ± 26.1				
T1	216.7 ± 21.8	210.0 ± 28.0	205.9 ± 26.1	208.3 ± 23.4	0.425	0.722	0.444	0.006
DBP (mmHg)								
T0	102.1 ± 24.1	99.9 ± 15.0	100.9 ± 14.7	102.0 ± 16.6				
T1	98.6 ± 17.4	99.1 ± 14.7	95.1 ± 14.5*	99.0 ± 17.3	0.930	0.574	0.666	0.009
VO_{2peak} (mL kg^{-1} min^{-1})								
T0	22.3 ± 5.6	22.0 ± 5.2	22.7 ± 4.9	22.7 ± 5.3				
T1	22.8 ± 8.0	24.3 ± 8.8*	28.1 ± 9.7**	26.7 ± 11.3*	0.014	0.046	2.708	0.036
Recovery								
HRR (bpm)								
T0	80.2 ± 20.3	81.6 ± 16.8	85.8 ± 16.5	85.6 ± 17.6				
T1	79.9 ± 27.8	92.6 ± 28.2*	93.4 ± 34.1	92.2 ± 20.5*	0.030	0.274	1.304	0.017
HR_{rec1} (bpm)								
T0	125.5 ± 20.2	127.8 ± 19.4	128.6 ± 19.7	131.6 ± 17.1				
T1	126.8 ± 15.7	130.1 ± 20.6	129.2 ± 15.9	129.0 ± 15.9	0.608	0.353	1.092	0.015
HR_{rec} (bpm)								
T0	26.3 ± 8.3	27.0 ± 11.2	27.2 ± 12.7	25.9 ± 10.6				
T1	26.2 ± 17.3	26.5 ± 10.7	26.8 ± 11.7	29.3 ± 9.3*	0.698	0.350	1.099	0.014
SBP_{rec3} (mmHg)								
T0	155.4 ± 24.7	154.3 ± 20.1	147.0 ± 23.6	152.7 ± 22.4				
T1	150.5 ± 22.1	147.1 ± 28.1	141.3 ± 22.1	142.3 ± 18.7*	0.829	0.771	0.375	0.005

Table 2 (continued)

	AC (*N* = 52)	HV-MICT (*N* = 59)	HV-HIIT (*N* = 60)	LV-HIIT (*N* = 60)	P value AC vs. ExT	*P* value intergroups	*F* value	Effect size
DBP_{rec3} (mmHg)								
T0	85.7 ± 12.8	84.3 ± 10.6	88.7 ± 10.7	86.1 ± 12.7				
T1	82.6 ± 11.9	79.4 ± 12.4*	79.1 ± 10.7**	81.6 ± 10.9*	0.141	0.039	2.833	0.039

Mean ± SD

HRR heart rate reserve (peak HR-rest HR), *HRrec1* heart rate after recovery's first minute, HR_{rec} difference between HR_{peak} and HR_{rec1}, *SBP* systolic blood pressure, *DBP* diastolic blood pressure, VO_{2peak} peak oxygen uptake, *AC* attention control group, *ExT* exercise training group, *HV* high volume, *LV* low volume, *MICT* moderate-intensity continuous training group, *HIIT* high-intensity interval training group

**P* value < 0.05 from T0

***P* value < 0.05 from the AC

The lower VO_{2peak} seen in HTN group compared with HEALTHY group (22.6 ± 5.5 mL kg^{-1} min^{-1} vs. 48.1 ± 9.0 mL kg^{-1} min^{-1}, Table 1) [19] at baseline may be the result of both reduced peak cardiac output, secondary to impaired resting, peak and reserve HR, or arterialvenous oxygen content difference, secondary to an impaired sympatholysis with high BP values [2, 20]. These alterations are presented as a result of sustained sympathoexcitation and reduced vagal activity, which explains the likely association of HR and HTN, facilitating further body fat gain and progression of associated co-morbidities [20, 21]. Therefore, autonomic modulation through diet (caloric restriction) and aerobic exercise is currently the recommended approach [8]. Findings from the current study support this as we report a decrease in resting (AC = −5.4%, HV-MICT = −7.4%, HV-HIIT = −9%, and LV-HIIT = −8.6%) and submaximal HR (AC = −5.2%, HV-MICT = −8.1%, HV-HIIT = −10.3%, and LV-HIIT = −7.0%). Further, it was found an average net reduction of 5 mmHg in resting SBP and 3–4 mmHg in resting DBP, with no between-group differences. Although one session of HIIT seems to promote a greater postexercise hypotension compared with isocaloric MICT [22], in the present study long-term physical activity and ExT improved cardiovascular autonomic function by shifting the balance toward vagal dominance and decreased sympathetic activity, independent of FITT principle (i.e., frequency, intensity, time, type of exercise). Thus, the diet intervention along with hypertensive medication in the study population might have induced a similar effect regardless of physical activity program (unsupervised or supervised). Hence, it could be suggested that ExT provided no additional benefit to cardiovascular health than caloric restriction in lowering HR and BP [23]. However, consistent with previous studies [12, 24], the lower submaximal SBP and DBP, and higher VO_{2peak} and HRR found in the supervised ExT groups (Table 2) highlights the additional beneficial effects of supervised ExT. Adding to that, although peak HR remained unchanged in the present study, the higher VO_{2peak} and HRR together with a lower submaximal HR and a reduction in resting HR are independent risk factors for the reduction of coronary heart disease and cardiovascular disease morbidity and mortality [25]. Further, previous studies have shown that a higher CRF is associated with lower SBP responses during submaximal exercise in hypertensive population, leading to an important reduction in the risk of left ventricular hypertrophy [26]. Thus, a lower ambulatory and exercise BP, secondary to aerobic ExT, is driven by a reduction in systemic vascular resistance and is included as a behavioral intervention, since even the smallest reduction (1 mmHg) in SBP is associated with lower cardiovascular risk [27]. The underlying mechanisms suggested to be responsible for the aforementioned benefits of ExT have previously been explored [2], i.e., a decrease of the enhanced exercise pressor reflex, including mechano- and metaboreflex, and an improvement of the impaired functional sympatholysis, leading to a greater muscle blood flow to the active muscles during exercise and normal cardiovascular response. Therefore, although in the present study the autonomic function was nondirectly assessed, the changes observed in HR and BP could be considered the mirror of an improved autonomic function taking into account that in HTN the parasympathetic impairment is not only related to the heart or cardiovascular system, but also to all parasympathetically dependent functions [1].

An increased BPV may carry some additional risk for higher incidence and faster progression of cardiovascular disease [28]. Previous literature has suggested that BPV is highly related to 24-h mean BP (quantified as the SD of the 24-h, day and night mean values) and is found to be an independent predictor of the incidence of cardiovascular events [4]. In the present study (Table 3) all groups significantly decreased day- and nighttime SBP and DBP. However, after the intervention visit-to-visit long-term BPV (expressed as CV, Table 3) was not significantly changed which is similar to previous studies [13]. Previously, it has been observed that in individuals with an SD of daytime SBP lower than 16 mmHg, the rate of cardiovascular

Table 3 Changes of ambulatory blood pressure and blood pressure variability after 16 weeks intervention period.

	AC (*N* = 52)	HV-MICT (*N* = 59)	HV-HIIT (*N* = 60)	LV-HIIT (*N* = 60)	*P* value AC vs. ExT	*P* value intergroups	*F* value	Size effect
Daytime SBP (mmHg)								
T0	141.9 ± 14.0	138.0 ± 11.6	138.4 ± 12.1	140.3 ± 14.0				
T1	137.1 ± 14.4*	133.2 ± 11.0*	133.0 ± 11.2*	134.1 ± 12.0*	0.589	0.921	0.163	0.002
Daytime DBP (mmHg)								
T0	81.3 ± 8.6	78.7 ± 8.4	82.0 ± 7.9	81.8 ± 9.0				
T1	78.1 ± 9.3*	76.2 ± 8.5*	77.2 ± 7.0*	78.1 ± 8.0*	0.701	0.431	0.922	0.013
Nighttime SBP (mmHg)								
T0	127.9 ± 17.9	123.5 ± 13.6	121.8 ± 14.8	122.9 ± 15.2				
T1	121.8 ± 18.0*	118.4 ± 13.5*	118.5 ± 15.2*	116.6 ± 13.9*	0.766	0.507	0.678	0.007
Nighttime DBP (mmHg)								
T0	68.4 ± 8.8	66.6 ± 8.5	68.5 ± 7.2	67.7 ± 8.2				
T1	65.3 ± 9.3*	62.4 ± 7.2*	65.7 ± 7.1*	63.3 ± 11.2*	0.553	0.700	0.475	0.007
CV of global SBP (%)								
T0	10.4 ± 2.8	10.6 ± 2.0	10.6 ± 2.6	11.1 ± 2.6				
T1	10.8 ± 2.8	10.3 ± 2.5	10.4 ± 2.5	10.7 ± 2.1	0.098	0.450	0.884	0.012
CV of global DBP (%)								
T0	14.0 ± 3.3	14.4 ± 2.5	13.8 ± 3.0	14.3 ± 3.1				
T1	14.1 ± 3.7	14.1 ± 3.3	13.3 ± 3.1	13.6 ± 2.9	0.277	0.723	0.442	0.006
CV of daytime SBP (%)								
T0	8.8 ± 2.2	9.1 ± 1.9	8.8 ± 2.4	9.2 ± 2.5				
T1	9.0 ± 2.5	8.6 ± 2.8	9.0 ± 2.3	8.8 ± 2.0	0.283	0.317	1.182	0.016
CV of daytime DBP (%)								
T0	11.1 ± 3.4	12.1 ± 2.9	11.0 ± 3.0	11.4 ± 3.6				
T1	11.7 ± 3.4	11.4 ± 3.5	11.1 ± 3.0	10.7 ± 3.0	0.023	0.072	2.364	0.032
CV of nighttime SBP (%)								
T0	10.1 ± 3.9	10.5 ± 6.8	9.1 ± 3.6	10.1 ± 4.0				
T1	9.6 ± 3.4	10.2 ± 5.4	9.0 ± 4.0	9.9 ± 3.4	0.733	0.974	0.073	0.001
CV of nighttime DBP (%)								
T0	14.1 ± 5.6	13.1 ± 5.6	12.8 ± 5.1	13.9 ± 5.9				
T1	13.1 ± 4.5	12.9. ± 5.4	12.5 ± 4.7	13.6 ± 4.9	0.395	0.854	0.261	0.004

Mean ± SD

SBP systolic blood pressure, *DBP* diastolic blood pressure, *CV* coefficient of variation, *AC* attention control group, *ExT* exercise training group, *HV* high volume, *LV* low volume, *MICT* moderate-intensity continuous training group, *HIIT* high-intensity interval training group

**P* value < 0.05 from T0

mortality was significantly less than in those with an SD equal to or above 16 mmHg [29]. In the current study, following the 16-week intervention, the SD was less than 16 mmHg in all ExT groups, but not in AC group's nocturnal SBP. As such, it seems likely that the current 16-week intervention decreases the development of cardiovascular risk events. Further, daytime DBP showed lower values in ExT groups compared with AC group, further suggesting positive cardiovascular benefits to all ExT groups. The exact reasons for the lack of effect of ExT on BPV remain elusive [13]. Previous reports have highlighted that the level of the 24 h BP and not BPV should remain the primary BP-related risk factor to account for in clinical practice [30].

All the aforementioned results and discussion confirm that ExT pari passu improves hemodynamics and autonomic responses in overweight/obese and hypertensive population, irrespective of intensity and volume. The current study adds further evidence to the argument that LV-HIIT (twice a week) is an efficient ExT alternative for this population due to: (1) time efficiency (less time to get similar results) [14, 31], and (2) lower stress of autonomic modulation [31]. These findings are relevant for both practitioners and clinicians alike.

Study limitations

Despite the novelty of our results providing clear evidence for the benefits of aerobic exercise on hemodynamics and cardiac autonomic modulation in overweight/obese population with HTN, we should acknowledge a few limitations of our study. First, physical activity performed by participants in the AC group could not be controlled. Second, other BPV quantifying methods, such as the calculation of the "residual BPV" or the average of the absolute differences between consecutive measurements (i.e., "average real variability") have been proposed by other authors [3], and the comparability between results obtained in by different techniques is limited.

Summary

What is known about topic

- Hypertension is associated with an inappropriate activation of the sympathetic and reduction of the parasympathetic divisions at rest and in response to exercise.
- Regular aerobic exercise training is an excellent nonpharmacological treatment against hypertension-caused disturbances.

What this study adds

- Supervised aerobic physical activity and healthy diet may have produced a significant improvement in the autonomic nervous system functioning (reducing heart rate and blood pressure).
- Low-volume-HIIT exercise training combined with a hypocaloric diet should be considered as a time efficient and safe mechanism for reducing the cardiovascular risk in hypertensive individuals.
- The better improvements seen when the exercise training was individually designed and supervised in overweight/obese individuals with hypertension empowers the existing professional exercise recommendations.

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Compliance with ethical standards

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

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