



Effects of outdoor high-intensity interval training by perceived exertion on 24-hour ambulatory blood pressure in older adults: a pilot study

Efecto del ejercicio interválico al aire libre en la presión arterial de 24 horas en adultos mayores: estudio piloto

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Abstract

Introduction: High-intensity interval training promotes significant reductions in blood pressure among older adults with hypertension. However, there is a lack of evidence regarding its application in low-cost models that are feasible and scalable in everyday settings.

Purpose: This pilot study was conducted to examine the feasibility and preliminary effects of an outdoor high-intensity interval training program guided by perceived exertion on 24-hour ambulatory blood pressure in older adults with hypertension, thereby providing evidence to guide the design and implementation of a subsequent, larger-scale clinical trial.

Methods: Thirty-one participants (66±4 years; hypertension duration: 14±9 years) were randomized to a six-week intervention: Exercise group (n=18) or control (n=13). The exercise group performed three weekly outdoor sessions, progressing from four to eight 1-minute bouts at a perceived exertion of 7–8, interspersed with active recovery at 3–4. Heart rate and affective response (Feeling Scale) were monitored. The control group attended weekly health education sessions.

Results: Feasibility was assessed via consent (18.6%), retention (83.3%), adherence (89%), and adverse events (11.1% reported musculoskeletal issues). Participants trained at >75% Heart rate reserve and >85%, maximum heart rate with positive affective ratings. The HIIT group showed reductions in 24-hour systolic (-3 mmHg), diastolic (-2 mmHg), and nighttime systolic BP (-5 mmHg) (p<0.05). Nighttime diastolic BP (-3 mmHg) and augmentation index (-5.6%) also decreased, though not significantly.

Conclusion: In conclusion, an outdoor high-intensity interval training program based on perceived exertion is feasible for older adults with hypertension and may lead to clinically meaningful reductions in 24-hour ABP.

Keywords

High-intensity intermittent exercise, aging, arterial stiffness, cardiovascular disease.

Resumen

Introducción: El entrenamiento interválico de alta intensidad (HIIT) puede reducir significativamente la presión arterial en adultos mayores con hipertensión. No obstante, la evidencia sobre su aplicación en modelos de bajo costo, factibles y escalables en contextos cotidianos, aún es limitada. **Objetivo:** Evaluar la viabilidad y los efectos preliminares de un programa de HIIT al aire libre, guiado por la percepción del esfuerzo, sobre la presión arterial ambulatoria de 24 horas en adultos mayores con hipertensión, con el fin de aportar evidencia para futuros ensayos clínicos a mayor escala.

Métodos: Treinta y un participantes (66±4 años; duración de la hipertensión: 14±9 años) fueron asignados aleatoriamente a un grupo de ejercicio (n=18) o a un grupo control (n=13) durante seis semanas. El grupo de ejercicio realizó tres sesiones semanales, progresando de cuatro a ocho intervalos de 1 minuto a una percepción de esfuerzo de 7–8, con recuperación activa a 3–4. Se monitorizaron frecuencia cardíaca y respuesta afectiva. El grupo control asistió a sesiones semanales de educación en salud.

Resultados: La viabilidad se confirmó mediante consentimiento (18,6%), retención (83,3%), adherencia (89%) y una tasa moderada de eventos adversos (11,1%). Los participantes entrenaron a intensidades >75% de la reserva de frecuencia cardíaca y >85% de la frecuencia máxima, con evaluaciones afectivas positivas. El grupo HIIT mostró reducciones en la presión arterial sistólica (-3 mmHg), diastólica (-2 mmHg) y sistólica nocturna (-5 mmHg) (p<0,05). También se observaron descensos en la presión diastólica nocturna (-3 mmHg) y en el índice de aumento (-5,6%), aunque sin significación estadística.

Conclusión: El HIIT al aire libre basado en la percepción del esfuerzo resulta factible y puede generar reducciones clínicamente relevantes en la presión arterial ambulatoria de adultos mayores con hipertensión.

Palabras clave

Entrenamiento en intervalos de alta intensidad; envejecimiento; rigidez arterial; enfermedad cardiovascular.



Introduction

Hypertension is the most prevalent risk factor for cardiovascular disease, which is the leading cause of premature death globally (Roth et al., 2017; Zhou et al., 2017). In older population, the prevalence of hypertension exceeds 50%, and in some countries, it is higher than 70% (Yang et al., 2016). Thus, appropriate clinical management of hypertension in older adults is pivotal given the aging process worldwide, particularly in low- and middle-income countries (Yang et al., 2016). Overall, both pharmacological and non-pharmacological approaches are part of clinical management of hypertension. Regarding non-pharmacological treatment, aerobic exercise training is cornerstone (Cornelissen & Smart, 2013; Pescatello et al., 2015). The blood pressure (BP)-lowering effects of moderate-intensity continuous training is well-documented in older adults with hypertension (Costa et al., 2018). However, mainly in the last decade, the high-intensity interval training (HIIT) has emerged as a promising intervention for managing hypertension (Costa et al., 2018; Hanssen et al., 2022; Sharman et al., 2019; Unger et al., 2020).

Studies have shown that HIIT reduces office BP in adults with pre- to established hypertension (Leal et al., 2020; Teixeira et al., 2023; Cortes-Chacón et al., 2025). A recent meta-analysis conducted by Carpes et al. (2022) demonstrated that HIIT led to reductions of office BP in older patients with hypertension. Importantly, all HIIT interventions included in that analysis were directly supervised and conducted in laboratory, gym, or hospital settings using treadmill or cycle ergometers, with most prescribing and monitoring exercise intensity based on heart rate (HR) or oxygen uptake – factors that limit their real-world applicability. Therefore, there is still a lack of evidence on practical, low-cost HIIT protocols that are feasible and scalable in everyday settings, particularly for older adults who have limited access to structured facilities. Furthermore, at least five systematic reviews have indicated that the effects of HIIT on 24-hour ambulatory BP in this population remain poorly understood (Carpes et al., 2022; Costa et al., 2018; de Souza Mesquita et al., 2023; Leal et al., 2020; Teixeira et al., 2023). This is a critical gap, as 24-hour ambulatory BP is more strongly associated with adverse cardiovascular outcomes and mortality in individuals with hypertension than office BP (Staessen et al., 1999, 2019).

To address these gaps, the present study was conducted as a pilot trial to assess the feasibility of an outdoor HIIT intervention, prescribed based on rating of perceived exertion (RPE), and its effects on 24-hour ambulatory BP in older adults with hypertension. Conducting a pilot study allows us to address key feasibility questions, including the ability to recruit and engage participants, their tolerance and safety during HIIT exercise sessions, adherence to the program, and the occurrence of adverse events. Results from this investigation may add relevant insights for guiding the design of larger-scale clinical trials.

Method

Study design

This pilot study employed a parallel-arm design to examine the feasibility and short-term antihypertensive effects of an RPE-based HIIT intervention among older adults with hypertension. Ethical approval was granted by the Research Ethics Committee linked to the authors' institution (protocol 3.180.310), in alignment with the Declaration of Helsinki.

Participants

Participants were recruited using various methods, including word of mouth, e-flyers on social media platforms (e.g., Instagram and Facebook, messaging apps like WhatsApp), advertisements on radio and TV, as well as through the institutional email system linked to the authors' university. Eligible individuals were between 60 and 80 years of age, had a clinical diagnosis of hypertension, were physically inactive, and were on stable antihypertensive pharmacological therapy for at least three months. Participants were considered physically inactive if they failed to meet at least 150 minutes per week of moderate or 75 minutes per week of vigorous physical activity, as confirmed by accelerometry over seven consecutive days. Exclusion criteria included: uncontrolled blood pressure (office BP >160/105 mmHg), high alcohol consumption (>14 drinks/week), current smoking, sensory or cognitive



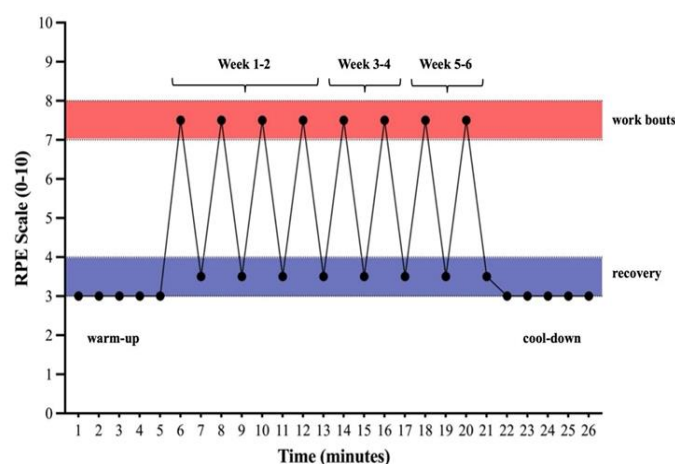
impairments hindering participation, major cardiovascular, pulmonary, renal or neurological disorders, recent cancer treatment (within two years), or any physical limitations or contraindications for moderate to vigorous exercise identified in the maximal cardiopulmonary exercise testing. Additional information regarding the inclusion and exclusion criteria is available in the supplementary materials (Supplementary Table 1). All participants provided written informed consent.

Procedure

High-intensity interval training

The HIIT sessions were carried out on a 400-meter outdoor track three times per week for six weeks between 4:00 pm and 6:00 pm. Each training group included up to four participants supervised by a research team member. The intensity of HIIT sessions was autonomously guided using the 0-10 RPE scale (Chodzko-Zajko et al., 2009). Familiarization with the RPE scale was conducted during the maximal cardiopulmonary exercise testing administered as part of the pre-intervention health screening. This process was further reinforced through two structured familiarization sessions conducted on the 400-meter outdoor track in the week preceding the initiation of the HIIT intervention. Large-format RPE scales (1 m by 0.5 m) were positioned every 100 m along the outdoor track, providing visual feedback to help participants maintain their RPE-based training zones (Dalton-Alves et al., 2024). During the intervention, HIIT sessions comprised 1-minute high-intensity work bouts (RPE 7-8) interspersed by 1-minute active recovery periods (RPE 3-4). Heart rate monitors (Polar H10, Finland) were used to assess the fidelity to HIIT program during the training sessions. Each participant wore the monitor in at least one session per week. Exercise training fidelity was considered adequate when high-intensity work bouts exceeded 59% of heart rate reserve and 76% of maximal heart rate (i.e., vigorous intensity) during HIIT sessions, in accordance with the recommendations of the American College of Sports Medicine (ACSM) (Nelson et al., 2007). In addition, affective responses were recorded during the final 10 seconds of both the high-intensity work bouts and the recovery periods using the Feeling Scale (-5 to +5) (Hardy & Rejeski, 1989) during the first HIIT session every week. The summary of the six-week HIIT intervention is shown in Figure 1. To promote participants' adherence, motivational strategies were employed, including weekly telephone contact in cases of absence and individual feedback on session performance.

Figure 1. High-intensity interval training protocol. RPE: ranting perceived exertion



Active control (health education)

Participants in the active control attended a weekly, 1-hour health education session covering hypertension-related topics: disease overview, cardiovascular risks, signs of poor blood pressure control, treatment options (pharmacological and non-pharmacological), medication adherence, and dietary guidance (especially sodium intake) (Umpierre et al., 2019). Health professionals led the sessions, and participants who missed a session received a follow-up phone call to encourage them to stay engaged.



Feasibility outcomes

For this pilot study, the following feasibility outcomes were assessed (Eldridge et al., 2016): i) consent rate: the proportion of eligible patients approached who met the inclusion criteria and provided written informed consent; ii) retention rate: the proportion of participants who remained in the study through the final follow-up visit; iii) intervention adherence: the percentage of exercise sessions attended by participants in the intervention group, relative to the total number of sessions offered; and iv) adverse events: any intervention-related adverse events reported during the study period.

24-hour ambulatory blood pressure

Twenty-four-hour ambulatory BP was measured using the CardioMapa system (Cardios, Brazil), following the VI Brazilian guidelines for ambulatory BP monitoring (Sociedade Brasileira de Cardiologia, 2018). Daytime BP was measured every 15 minutes (06:00 am to 10:00 pm), and nighttime BP every 30 minutes (10:01 pm to 05:59 am), with actual periods defined by participants' sleep diaries. Valid ambulatory BP monitoring data required at least 16 daytime and 8 nighttime readings (Sociedade Brasileira de Cardiologia, 2018). Variables included 24-hour, daytime, and nighttime BP. Office BP was taken prior to ambulatory BP monitoring using a semi-automated device (HEM-742INT, Omron, Japan), with inter-arm differences confirmed to be <10 mmHg (El Feghali et al., 2007).

Office blood pressure and arterial stiffness

Office central and peripheral BP, as well as arterial stiffness, were assessed using the Mobil-O-Graph PWA device (IEM Healthcare, Germany). After a 10-minute supine rest, four BP measurements were obtained in a quiet, temperature-controlled room (24-26°C). The mean of the final three readings was used for data analysis. Aortic pulse wave velocity (aPWV) and augmentation index (AIx) were derived via pulse wave and wave separation analyses using ARCSolver algorithms (Austrian Institute of Technology, Austria). Briefly, aPWV was estimated based on the time delay between the forward and reflected pressure waves, while AIx was calculated as the ratio of augmentation pressure to pulse pressure, standardized to a heart rate of 75 beats per minute (Brunner-La Rocca, 2010; Wassertheurer et al., 2008). The Mobil-O-Graph PWA method has been validated against both invasive intra-aortic catheter-based aPWV measurements (Hametner et al., 2013; Papaioannou et al., 2016) and non-invasive applanation tonometry (Hametner et al., 2013.; Hoshida, 2018; Weiss et al., 2012).

Health status, medication use, and anthropometric measures

Data on age (in years), educational status, smoking history, alcohol consumption, medical history (e.g., diagnoses of hypertension, diabetes, and dyslipidemia), and medication use were collected through face-to-face interviews with participants. Regarding hypertension, participants reported the time since diagnosis (in years). Height (m) was measured using a stadiometer fixed on the wall (ES2040, Sanny, Brazil), and weight (kg) was measured using a digital scale (InBody 270, Ottoboni, Brazil). Body mass index (BMI) was calculated as weight divided by height squared (kg/m^2).

Cardiopulmonary exercise testing

Peak oxygen uptake (VO_2 peak) was assessed using a graded cardiopulmonary exercise testing on a treadmill (Centurion 300, Micromed, Brazil). The protocol began at 2.5 km/h for females and 3.5 km/h for males, with speed and incline increasing by 0.4 km/h and 0.6% per minute, respectively. These protocols were adapted from a previous study conducted by our research group in older adults with hypertension (Moura et al., 2022). VO_2 , carbon dioxide production (VCO_2), and minute ventilation (VE) were recorded every 30 seconds using the VO2000 metabolic analyzer (MedGraphics, USA), calibrated prior to each test according to the manufacturer's instructions. A 12-lead ECG (Micromed, Brazil) was used to monitor participants throughout the exercise test and recovery period. VO_2 peak was defined as the highest VO_2 value achieved during the final stage of the test. Verbal encouragement was provided to participants throughout the test to stimulate them reach voluntary exhaustion.

Accelerometer-measured physical activity and sedentary time

Movement behaviors were assessed using a tri-axial accelerometer (Actigraph GT3X, Actigraph LLC, USA), worn on the hip for seven consecutive days and removed only for water-based activities. Participants kept a log of non-wear times and sleep. Data were sampled at 60 Hz and aggregated into

60-second epochs. Valid data required at least three weekdays and one weekend day with a minimum of 10 hours of wear time per day. Non-wear time was defined as at least 90 consecutive minutes of zero activity counts, allowing for up to 2 minutes with activity of counts ≥ 100 counts/min (Choi et al., 2011). Activity intensity was classified using established cut-points: sedentary (0-99 cpm), light (100-1951 cpm), moderate (1952-5724 cpm), and vigorous (≥ 5725 cpm) physical activity (Choi et al., 2011). Step count was calculated by the sum of steps per day divided by the number of valid accelerometer days. Data were processed using ActiLife software (version 6.13.3.2).

Sample size, randomization, and blinding

As a pilot study, no formal statistical sample size calculation was performed. Instead, the sample size was estimated based on data from prior studies with similar designs and target populations (Herrod et al., 2020). For example, in the meta-analysis conducted by (Carpes et al., 2022) on the effects of HIIT in older adults with hypertension, the included trials had sample sizes ranging from 15 to 40 participants. In our study, the primary objective was to assess the practical feasibility of the RPE-based HIIT intervention and to generate estimates to inform future trials. Accordingly, the goal was to randomize 30 participants. This is consistent with current practice in feasibility and pilot studies: while there is no consensus on the ideal sample size for pilot and feasibility studies, recommendations typically range from 10-12 participants per group to as many as 60-75 (Lewis et al., 2021), depending on the study's objectives. A recent review of 761 UK-based pilot and feasibility studies registered on the International Standard Randomised Controlled Trial Number (ISRCTN) platform between 2013 and 2020 found a median target sample size of 30 participants (interquartile range 20-50) (Totton et al., 2023). Participants in our study were randomized without stratification or blocking into one of two groups (HIIT and control). Allocation was concealed in sealed, opaque, numbered envelopes and managed by designated researchers uninvolved in assessments. Outcome assessors and analysts remained blinded to group assignments.

Data analysis

Normality was assessed using the Shapiro-Wilk test, along with skewness and kurtosis (z-score ± 1.96). Continuous variables were expressed as mean and standard deviation, while categorical data were presented as counts and percentages. At baseline, for intergroup comparisons, we employed the independent t-test or Mann-Whitney U test for continuous data and the chi-square or Fisher's exact tests for categorical data. A t-test was conducted to compare heart rate and affective responses between groups. Group-by-time interactions and main effects were analyzed using generalized estimating equations (GEE) with Bonferroni-adjusted post hoc comparisons, controlling for body mass index. GEE models were specified with a gamma distribution and an identity link function. Model fit was assessed via normal Q-Q plots and the Akaike Information Criterion (AIC). Results are presented as estimated marginal means, mean differences (β), and 95% confidence intervals (CI). Statistical significance was set at $p < 0.05$. All analyses were conducted using IBM SPSS version 29.0.

Results

Figure 2 shows the detailed flowchart of the study, while Table 1 presents the participants' baseline characteristics.

On average, participants had a hypertension diagnosis for 14 ± 9 years. There were no significant differences between the groups regarding age, sex distribution, ethnicity (i.e., self-reported skin color), or educational status. Participants in the control group had a higher BMI than those in the HIIT group ($p = 0.014$). Additionally, diuretic use was more prevalent in the control group (66.7% vs. 11.8%; $p = 0.005$). No differences between groups were observed regarding accelerometer-measured movement behaviors, including sedentary time, light physical activity, moderate physical activity, vigorous physical activity, and step count ($p > 0.05$). Of note, both groups demonstrated very low participation in vigorous-intensity physical activity (HIIT: 0.7 ± 1.0 min/day; Active control: 0.5 ± 0.7 min/day). Finally, no differences between groups were observed regarding BP levels (ambulatory and office) and arterial stiffness markers (PWV and AIX) ($p > 0.05$).



Figure 2. Study flowchart. HTN, hypertension; MACE, major adverse cardiovascular event; CPET, cardiopulmonary exercise testing.

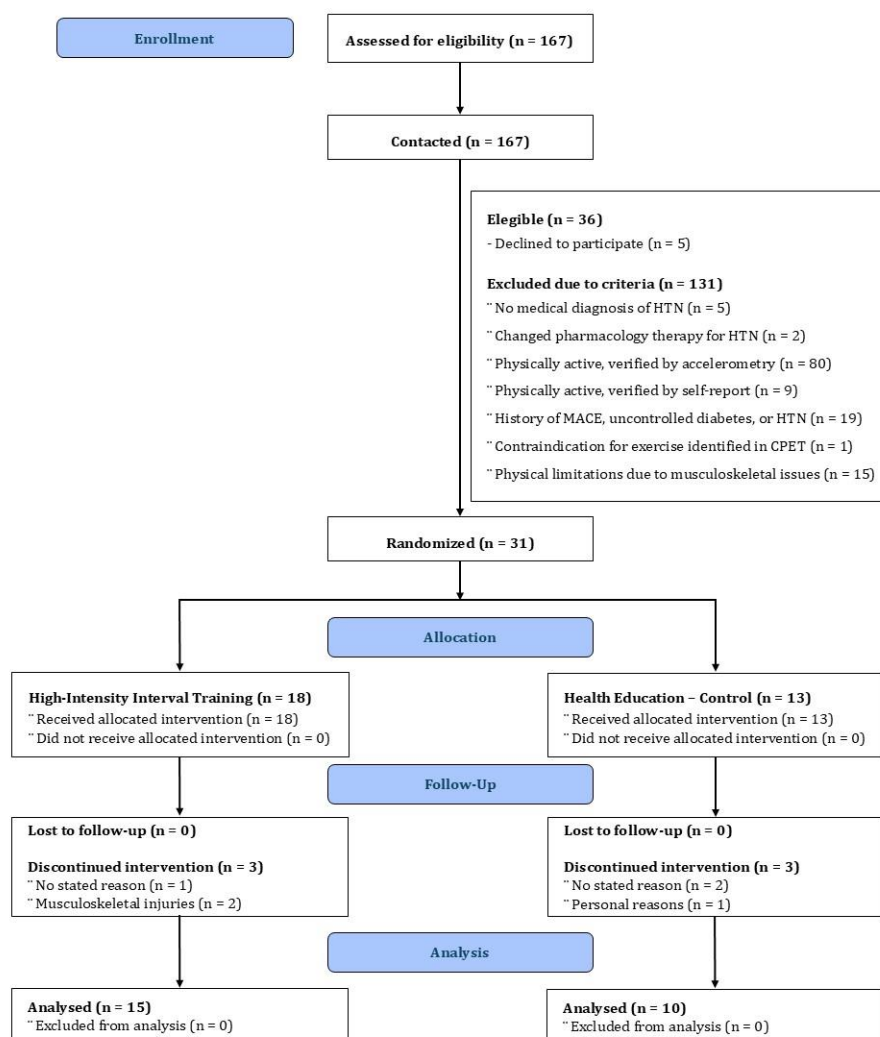


Table 1. Characteristics of the participants (n = 25)

	HIIT	Control	P
<i>N</i>	15	10	
Age, years	66.3 ± 3.1	66.1 ± 5.3	0.891
Female, n (%)	10 (66.7)	9 (90.0)	0.345
Skin color, n (%)			
Black/Brown	10 (66.7)	5 (50.0)	0.442
White	5 (33.3)	5 (50.0)	
Post-secondary education, n (%)	5 (35.7)	3 (33.3)	1.000
Body mass index, kg/m ²	26.9 ± 3.5	31.3 ± 3.2	0.004
Antihypertensive medications, n (%)			
Calcium channel blocker	2 (14.3)	3 (33.3)	0.343
Diuretics	2 (14.3)	6 (66.7)	0.023
Angiotensin receptor antagonists	8 (57.1)	6 (66.7)	1.000
Beta-blocker	3 (21.4)	3 (33.3)	0.643
ACE inhibitor	3 (21.4)	1 (11.1)	1.000
Diabetes medication, n (%)	3 (12)	2 (8)	1.000
Lipid-lowering medication, n (%)	7 (46.6)	4 (40.0)	1.000
Accelerometer-measured movement behaviors			
Sedentary time, min/day	654 ± 45	686 ± 56	0.564
Light PA, min/day	246 ± 148	290 ± 148	0.855
Moderate PA, min/day	14 ± 10	15 ± 13	0.679
Vigorous PA, min/day	0.7 ± 1.0	0.5 ± 0.7	0.220
Step count, steps/day	5,782 ± 2,029	5,915 ± 2,530	0.717
Peak oxygen uptake, ml·kg ⁻¹ ·min ⁻¹	21.7 ± 5.3	18.7 ± 3.3	0.770
Peak heart rate, bpm	156 ± 15	146 ± 17	0.484

Values expressed as mean ± SD or absolute and relative frequency (%). HIIT: high-intensity interval training; ACE: angiotensin converting enzyme; PA: physical activity.



Regarding the feasibility outcomes, a total of 31 participants were randomized, resulting in a consent rate of 18.6% (i.e., 167 potentially eligible). The low consent rate was primarily due to the exclusion of physically active individuals, which accounted for 61% of the reasons for exclusion. Due to logistical constraints during the implementation phase, a slight imbalance in the group sizes occurred, with 18 participants allocated to the HIIT group and 13 to the control group. This imbalance resulted from variations in participant eligibility, scheduling availability, and enrollment capacity within the study's time frame. However, 25 participants were included in final analysis (HIIT, $n = 15$; retention rate: 83.3%; Active control, $n = 10$; retention rate: 76.9%). On average, adherence to the HIIT sessions was 89% (ranging from 16 to 18 sessions), while adherence rate with health education meetings was 88% (ranging from 5 to 6 sessions) in the active control group. Additionally, all participants in both HIIT and control groups attended $\geq 70\%$ of the planned sessions during the 6-week period. Regarding adverse events, in the HIIT group there were two dropouts due to musculoskeletal issues related to the intervention (11.1%; ankle sprain and knee pain; moderate severity). In the control group, no adverse events were reported.

Table 2 shows the weekly HR and Feeling Scale responses during the RPE-based HIIT intervention. No significant differences were observed between weeks in either the high-intensity bouts or the recovery periods for HR responses ($p > 0.05$). Regarding Feeling Scale responses, a significant difference was observed between weeks 2 and 3 in the high-intensity bouts ($p < 0.05$). HR responses were higher in the 2nd half of HIIT sessions in both high-intensity bouts and recovery periods during the 6-week period ($p < 0.05$). Additionally, Feeling Scale responses were lower in the 2nd half of HIIT sessions during high-intensity bouts during the 6-week period ($p < 0.05$). However, during recovery periods the Feeling Scale responses were lower in the 2nd half of HIIT sessions only in the first, third, and fifth week ($p < 0.05$).

Table 2. Weekly heart rate and Feeling Scale responses during the RPE-based outdoor HIIT intervention

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Heart Rate Reserve, %						
High-intensity bouts						
Average training session	76.0 $\pm$ 13.5*	77.2 $\pm$ 12.0*	81.0 $\pm$ 13.9*	78.9 $\pm$ 14.1*	78.8 $\pm$ 12.5*	80.8 $\pm$ 13.8*
1 st half of training session	69.2 $\pm$ 12.9	70.5 $\pm$ 10.5	74.6 $\pm$ 14.0	72.3 $\pm$ 13.0	71.7 $\pm$ 12.2	74.8 $\pm$ 13.6
2 nd half of training session	79.6 $\pm$ 13.0 ^a	80.9 $\pm$ 10.9 ^a	84.8 $\pm$ 14.0 ^a	83.4 $\pm$ 13.5 ^a	82.2 $\pm$ 11.8 ^a	84.9 $\pm$ 13.6 ^a
Recovery periods						
Average training session	61.4 $\pm$ 12.9	63.3 $\pm$ 10.5	65.6 $\pm$ 14.0	64.7 $\pm$ 13.0	63.6 $\pm$ 12.2	64.9 $\pm$ 13.6
1 st half of training session	57.1 $\pm$ 13.0	60.2 $\pm$ 10.9	60.9 $\pm$ 14.0	60.6 $\pm$ 13.5	59.3 $\pm$ 11.8	61.6 $\pm$ 13.6
2 nd half of training session	64.9 $\pm$ 13.5 ^a	67.0 $\pm$ 12.0 ^a	68.2 $\pm$ 13.9 ^a	67.9 $\pm$ 14.1 ^a	66.8 $\pm$ 12.5 ^a	67.6 $\pm$ 13.8 ^a
Maximum Heart Rate, %						
High-intensity bouts						
Average training session	86.0 $\pm$ 7.7*	86.7 $\pm$ 6.6*	88.8 $\pm$ 8.1*	87.7 $\pm$ 7.7*	87.6 $\pm$ 7.1*	88.7 $\pm$ 8.1*
1 st half of training session	82.1 $\pm$ 7.7	82.8 $\pm$ 6.7	85.1 $\pm$ 8.2	83.8 $\pm$ 8.1	83.6 $\pm$ 6.9	85.2 $\pm$ 8.2
2 nd half of training session	88.0 $\pm$ 7.9 ^a	88.8 $\pm$ 7.3 ^a	91.0 $\pm$ 8.0 ^a	90.2 $\pm$ 8.2 ^a	89.5 $\pm$ 7.4 ^a	91.0 $\pm$ 8.2 ^a
Recovery periods						
Average training session	77.6 $\pm$ 7.7	78.6 $\pm$ 6.6	80.0 $\pm$ 8.1	79.9 $\pm$ 7.7	78.9 $\pm$ 7.1	79.5 $\pm$ 8.1
1 st half of training session	75.1 $\pm$ 7.7	76.8 $\pm$ 6.7	72.2 $\pm$ 8.2	77.1 $\pm$ 8.1	76.5 $\pm$ 6.9	77.6 $\pm$ 8.2
2 nd half of training session	79.6 $\pm$ 7.9 ^a	80.7 $\pm$ 7.3 ^a	81.4 $\pm$ 8.0 ^a	81.3 $\pm$ 8.2 ^a	80.7 $\pm$ 7.4 ^a	81.1 $\pm$ 8.2 ^a
Feeling Scale, -5/+5						
High-intensity bouts						
Average training session	1.0 $\pm$ 1.9*	1.1 $\pm$ 1.5*	1.1 $\pm$ 1.5*	0.8 $\pm$ 1.9*	0.5 $\pm$ 1.9*	0.4 $\pm$ 2.3*
1 st half of training session	1.8 $\pm$ 2.6	2.3 $\pm$ 2.3	2.3 $\pm$ 2.2	1.7 $\pm$ 2.3	1.6 $\pm$ 2.3	1.6 $\pm$ 2.8
2 nd half of training session	0.4 $\pm$ 2.5 ^a	0.4 $\pm$ 2.4 ^a	0.1 $\pm$ 2.6 ^a	0.0 $\pm$ 2.6 ^a	-0.1 $\pm$ 2.9 ^a	-0.1 $\pm$ 3.5 ^a
Recovery periods						
Average training session	2.2 $\pm$ 1.9	2.8 $\pm$ 1.5	2.5 $\pm$ 1.5	1.7 $\pm$ 1.9	1.9 $\pm$ 1.9	2.0 $\pm$ 2.3
1 st half of training session	3.0 $\pm$ 2.3	3.1 $\pm$ 1.8	3.3 $\pm$ 1.5	2.2 $\pm$ 1.7	2.9 $\pm$ 2.0	2.6 $\pm$ 2.0
2 nd half of training session	2.0 $\pm$ 2.1 ^a	2.6 $\pm$ 1.7	1.7 $\pm$ 1.7 ^a	1.4 $\pm$ 2.2	1.8 $\pm$ 2.3 ^a	1.8 $\pm$ 2.4

Values expressed as mean $\pm$ SD. HIIT: high-intensity interval training; RPE: rating of perceived exertion. High-intensity bouts (1 min): RPE between 7-8; Recovery periods (1 min): RPE between 3-4. * = Significant difference compared to the average session in the recovery periods. ^a = Significant difference compared to the 1st half of the training session.

Table 3 displays the effects of the 6-week RPE-based HIIT intervention on 24-hour ambulatory BP. A significant group-by-time interaction was observed for 24-hour systolic ($p = 0.040$) and diastolic BP ($p = 0.021$), with the HIIT group experiencing a 3-mmHg reduction in systolic BP and a 2-mmHg reduction in diastolic BP. A group-by-time interaction was also observed for nighttime systolic BP ($p = 0.040$), with the HIIT group experiencing a 5-mmHg reduction in systolic BP. Despite a nonsignificant group-by-time interaction for nighttime diastolic BP ($p = 0.171$), a significant time effect was observed, with reductions

occurring only in the HIIT group (-3 mmHg) ($p < 0.05$). No significant modifications were observed for daytime BP ($p > 0.05$). Finally, no significant changes were observed in the control group regarding 24-hour BP outcomes ($p > 0.05$).

Table 4 shows the effects of the 6-week RPE-based HIIT intervention on office BP and arterial stiffness markers. No significant group-by-time interaction was observed for either office BP or arterial stiffness markers (AIx and PWV) ($p > 0.05$). However, a time-effect was observed for office brachial systolic BP and AIx, with reductions noted exclusively in the HIIT group (office brachial systolic BP: -6 mmHg; AIx: -5.6%) ($p < 0.05$). No significant changes were found in office central BP or PWV in the HIIT group after six weeks ($p > 0.05$). Lastly, no significant changes were observed in the control group for any of the outcomes investigated ($p > 0.05$).

Table 3. 24-hour ambulatory blood pressure at baseline and after 6 weeks: RPE-based outdoor HIIT vs control

	HIIT			Control			p*
	Baseline	Post-6 weeks	β (95% CI)	Baseline	Post-6 weeks	β (95% CI)	
	Mean (95% CI)	Mean (95% CI)		Mean (95% CI)	Mean (95% CI)		
24-hour blood pressure							
Systolic, mmHg	128 (121, 134)	124 (118, 130)	-3 (-7, -1) ^a	128 (119, 138)	131 (122, 139)	2 (-2, 7)	0.040
Diastolic, mmHg	71 (66, 77)	69 (64, 74)	-2 (-5, -1) ^a	68 (64, 72)	70 (65, 74)	2 (-1, 4)	0.021
Daytime blood pressure							
Systolic, mmHg	128 (121, 135)	126 (119, 132)	-3 (-7, 1)	130 (120, 139)	131 (122, 140)	1 (-3, 5)	0.213
Diastolic, mmHg	72 (66, 77)	70 (65, 75)	-1 (-4, 1)	69 (65, 73)	71 (66, 75)	2 (-1, 5)	0.115
Nighttime blood pressure							
Systolic, mmHg	126 (119, 133)	121 (115, 128)	-5 (-8, -2) ^a	126 (117, 137)	127 (120, 135)	1 (-4, 5)	0.040
Diastolic, mmHg	69 (63, 75)	66 (61, 71)	-3 (-6, -1) ^a	66 (62, 70)	66 (62, 72)	0 (-1, 3)	0.171

Values are expressed as estimated marginal means, mean difference (β), and 95% confidence interval (CI). * Results of the group-by-time interaction effect, adjusted for body mass index. ^a $p < 0.05$ in intra-group pairwise comparisons. HIIT: high-intensity interval training.

Table 4. Office blood pressure and arterial stiffness markers at baseline and after 6 weeks: RPE-based outdoor HIIT vs control

	HIIT			Control			p*
	Baseline	Post-6 weeks	β (95% CI)	Baseline	Post-6 weeks	β (95% CI)	
	Mean (95% CI)	Mean (95% CI)		Mean (95% CI)	Mean (95% CI)		
Office blood pressure							
Brachial systolic, mmHg	119 (112, 127)	113 (108, 119)	-6 (-10, -2) ^a	122 (116, 129)	120 (111, 129)	-2 (-9, 4)	0.373
Brachial diastolic, mmHg	76 (69, 82)	73 (67, 79)	-2 (-4, 0)	77 (71, 83)	77 (70, 84)	0 (-6, 5)	0.557
Central systolic, mmHg	123 (115, 131)	118 (113, 124)	-5 (-11, 2)	127 (119, 136)	129 (118, 140)	2 (-7, 11)	0.257
Central diastolic, mmHg	76 (70, 83)	74 (68, 80)	-2 (-5, -1) ^a	78 (72, 83)	78 (71, 85)	0 (-5, 6)	0.392
Arterial stiffness							
Augmentation index, %	27.4 (22.3, 32.5)	21.8 (16.2, 27.4)	-5.6 (-10.5, -0.7) ^a	30.1 (23.2, 37.0)	29.6 (22.9, 36.3)	-0.5 (-6.0, 5.1)	0.174
Pulse wave velocity, m/s	9.7 (9.3, 10.1)	9.6 (9.3, 9.9)	-0.1 (-0.3, 0.2)	9.8 (9.0, 10.6)	9.9 (9.0, 10.8)	0.1 (-0.3, 0.5)	0.427

Values are expressed as estimated marginal means, mean difference (β), and 95% confidence interval (CI). * Results of the group-by-time interaction effect, adjusted for body mass index. ^a $p < 0.05$ in intra-group pairwise comparisons. HIIT: high-intensity interval training.

Discussion

This pilot study aimed to assess the practical feasibility of RPE-based outdoor HIIT and its effects on 24-hour ambulatory BP in older adults with hypertension. The main findings were: i) the consent rate was low (18.6%), primarily due to the exclusion of physically active individuals; retention (83.3%) and adherence (89%) rates were high, despite a non-negligible occurrence of musculoskeletal issues related to HIIT sessions (11.1%). No serious adverse events were reported; ii) participants consistently reached the target HR zones for vigorous-intensity exercise during the RPE-based high-intensity bouts; iii) on average, participants reported high-intensity bouts as positive ("fairly good"). However, they reported neutral affective responses in the second half of the planned high-intensity bouts within the HIIT sessions; iv) significant and clinically meaningful reductions were observed on 24-hour BP, mainly driven by a BP-lowering effect on nighttime period.

The main challenge in implementing the study occurred during the recruitment phase, where we observed a low consent rate (18.6%). This was mostly because many older adults with hypertension who were interested in the study were already physically active and did not meet the inclusion criteria. Interestingly, our results are similar to those of a previous multicenter randomized trial conducted in Brazil, which looked at the effects of exercise training on 24-hour ambulatory BP in older adults with hypertension (Botton et al., 2022). That study also reported a low consent rate (23.4%), mainly due to the exclusion of physically active individuals (61.5%). This multicenter study utilized as a criterion



“Those who performed ≥ 30 min of physical activity at moderate intensity, at least three days/week, in the last three months before screening were excluded”. Our study applied a similar self-reported criterion and additionally incorporated objective data obtained through accelerometry. Conversely, the high retention and adherence rates observed in our study are consistent with those reported in a previous meta-analysis that examined the effects of HIIT and moderate-intensity continuous training on BP in individuals with pre- to established hypertension (Costa et al., 2018).

The observed HR responses throughout the intervention suggest that an autonomously guided, RPE-based approach can be a feasible method for prescribing and monitoring outdoor HIIT in older adults with hypertension. The ACSM points out that HR responses $\geq 60\%$ of HRreserve and $\geq 77\%$ of HRmax are considered within the vigorous-intensity domain (Garber et al., 2011). Practical recommendations for HIIT prescription indicate that the high-intensity bouts should be performed at HR $> 80\%$ of HRmax (Weston et al., 2014). Our data clearly indicate that the participants performed the HIIT sessions according to the current recommendations for HIIT prescription (on average, $> 75\%$ of HRreserve and $> 85\%$ of HRmax). Importantly, this pattern was consistent throughout the intervention. Interestingly, by the end of the recovery periods, HR remained elevated ($\sim 60\text{--}65\%$ of HRreserve and $\sim 77\text{--}80\%$ of HRmax). This response may be explained by the delayed HR increase during short high-intensity bouts (Farias-Junior et al., 2019), along with reduced HR recovery due to impaired autonomic control, a common feature in inactive older adults with hypertension (Best et al., 2014).

Most participants self-selected their pacing during training sessions alternating brisk walking during high-intensity bouts with slow walking during recovery periods. Only few participants jogged during high-intensity bouts. Given that walking is a common daily activity, it is likely that this familiarity helped participants effectively self-regulate their pacing throughout the work-recovery cycles of the HIIT session. In addition to being a low-cost and easy-to-use method, the RPE-based HIIT can be particularly useful for individuals taking beta-blockers or non-dihydropyridine calcium channel blockers, as HR-based prescription and monitoring may be inaccurate due to the HR-suppressing effects of these medications during exercise. Taken together, our findings demonstrate the practical feasibility of the RPE-based approach for prescribing and monitoring outdoor HIIT sessions in older adults with hypertension, aligning with previous studies involving both healthy individuals and clinical populations in various settings (Ciolac et al., 2015; Marçal IR, Falqueiro PG, et al., 2021; Marçal IR, Fernandes B, et al., 2021).

Regarding affective responses, our data suggest two distinct scenarios within the HIIT sessions throughout the 6-week intervention. During the first half of the planned high-intensity bouts, participants consistently reported positive scores on the Feeling Scale, indicating positive in-task affective responses (i.e., feelings of pleasure; on average, “fairly good”). In contrast, during the second half of the planned high-intensity bouts, participants reported neutral scores, showing a trend toward more negative in-task affective responses, as demonstrated in previous studies (Farias-Junior et al., 2020). During the recovery periods, the affective responses were consistently positive (on average, “good”), suggesting a recurring occurrence of the “affective rebound” phenomenon, in which individuals experience a positive affective response following the cessation of an exercise or activity that was not perceived as pleasant (Ekkkekakis et al., 2011). It has been suggested that the autonomy in self-selecting intensities, such as the RPE-based approach used in our study, may promote a more favorable “affective rebound” during the work-recovery dynamic of a HIIT session (Box & Petruzzello, 2021; Lins-Filho OL et al., 2020), which could partially explain our findings. From a practical perspective, our data support the idea that the RPE-based outdoor HIIT approach used was well-tolerated by older adults with hypertension, with no clear indications of strongly aversive or highly unpleasant responses to exercise. However, the decline in and the more neutral or negative affective responses reported by participants during the last high-intensity bouts should not be neglected. To minimize this, personalized adjustments can be implemented, such as longer recovery periods and/or shorter high-intensity bouts. Although there is intense debate about acute affective responses to HIIT and their implications for exercise adherence (Biddle & Batterham, 2015), the available evidence directly linking these variables remains limited (Santos et al., 2023).

In terms of antihypertensive effects, we observed a significant and clinically meaningful reduction in 24-hour BP following the 6-week HIIT intervention, with a 3-mmHg decrease in systolic BP and a 2-mmHg decrease in diastolic BP. To the best of our knowledge, this is the first study to report the short-term



effects of HIIT on 24-hour BP in older adults with hypertension. Interestingly, the BP-lowering effect on 24-hour BP seems to be driven by reductions in BP during the nighttime period rather than during the daytime period, where changes were non-significant. It should be noted that participants performed HIIT sessions between 4:00 and 6:00 pm. Some evidence suggests that exercise performed in the late afternoon and evening can maximize benefits for BP control and its regulatory mechanisms, such as muscle sympathetic nerve activity and baroreflex sensitivity (Brito LC et al., 2024). Exercising at these times of day may also induce more adaptations in nighttime BP control (Brito et al., 2023), which could partially explain our findings. Two previous studies have investigated the short-term effects of interval training on 24-hour ambulatory BP, targeting young healthy adults with normal BP (Edwards JJ et al., 2021) and middle-aged individuals with pre- to established hypertension (Sosner et al., 2019). Both studies employed sprint interval training (SIT) protocols, characterized by repeated very short bouts (15 and 30 s) of “all-out” efforts or at $\geq 100\%$ of individuals’ peak power output (PPO) (Weston et al., 2014), conducted in supervised settings with specialized cycle ergometers. Although both studies observed significant reductions in 24-hour BP (~ 5 mmHg in systolic BP and ~ 2 -3 mmHg in diastolic BP) following 2- and 4-week training periods, the applicability of these training protocols to older patients with hypertension appears to be very limited in real-world settings under unsupervised conditions.

A recent meta-analysis focusing on the effects of exercise on ambulatory BP in hypertensive patients demonstrated that aerobic training elicits a BP-lowering effect of ~ 5 mmHg for systolic BP and ~ 4 mmHg for diastolic BP during 24-hour monitoring (Saco-Ledo et al., 2020). Notably, the studies involved mix samples of middle-aged and older adults (ages 45 to 70) with intervention lengths ranging from 8 to 24 weeks. The pooled analysis for aerobic training included both moderate-intensity continuous training and aerobic interval training. However, among the six studies included in the analysis, one involved HIIT combined with resistance training (Guimarães et al., 2010), four had training intensities that were not consistent with a vigorous-intensity stimulus during the high-intensity bouts (Bertani et al., 2017; Dimeo et al., 2012; Pagonas et al., 2014; Westhoff et al., 2007), and one study (Molmen-Hansen et al., 2012) involved patients whose antihypertensive medications were discontinued prior to the exercise intervention. In addition, all of these studies included supervised interventions conducted in hospital or laboratory settings. This aligns with other previous meta-analyses that reported a lack of evidence regarding the effects of HIIT on 24-hour ambulatory BP in patients with hypertension (Carpes et al., 2022; Costa et al., 2018).

In addition to reductions in 24-hour ambulatory BP, we observed a significant time effect, or a trend toward significance, for office brachial and central BP after the 6-week period, with lower values exclusively in the HIIT group (~ 5 -6 mmHg for systolic BP and ~ 2 mmHg for diastolic BP). The absence of a significant group by time interaction can be attributed to the limited statistical power resulting from a small sample size in this pilot study. Despite this limitation, our findings suggest a short-term antihypertensive effect of HIIT on BP control under resting conditions, such as TV watching and prolonged sitting, common sedentary behaviors in older adults. Overall, sedentary behaviors account for approximately 60-70% of waking hours in the older adult population (Matthews et al., 2008). Our findings are consistent with previous meta-analysis that reported the antihypertensive effects of HIIT on office BP in adults with pre- to established hypertension (~ 6 mmHg for systolic BP and ~ 4 mmHg for diastolic BP) (Costa et al., 2018; Edwards JJ et al., 2021) and medicated older patients with hypertension (~ 7 mmHg for systolic BP and ~ 6 mmHg for diastolic BP) (Carpes et al., 2022). Regarding central BP, the effects of HIIT on individuals with hypertension are less known. Although some studies suggest a BP-lowering effect of HIIT on central BP, the evidence is limited and does not include older patients with hypertension (de Oliveira et al., 2023). Thus, our preliminary findings are novel, contributing to a better understanding of the broader short-term antihypertensive effects of HIIT in older adults with hypertension.

We also observed a significant time effect on AIx, with a significant reduction of $\sim 6\%$ only in the HIIT group following a 6-week period. No changes were observed in aPWV. Although not measured in our study, enhanced endothelial function, as assessed by flow-mediated dilation, is commonly reported following HIIT interventions in patients with cardiometabolic diseases, including those with hypertension (Khalafi et al., 2022). Thus, the observed reduction in AIx could be associated with improvements in endothelial function and, consequently, reduced peripheral vascular resistance post-training. The high-intensity bouts during HIIT sessions elicit a high shear stress on the vasculature of exercising muscles, resulting in an increase in nitric oxide release, which plays a potent vasodilatory



role. Our HIIT model stimulates large muscle groups during high-intensity bouts, potentially promoting improvements in peripheral vascular function (via enhanced endothelial function). Ultimately, this could have contributed to the reduction in AIx due to decreased peripheral vascular resistance (Ashor et al., 2014). Regarding aPWV, while studies have shown improvements following HIIT interventions with a duration of at least eight weeks (Luo et al., 2024), we did not observe this effect in the short term. As aPWV is influenced by the interaction of both vascular function and structure, the HIIT model used in the present study may not have been sufficient to improve this variable in older adults with hypertension in a short-term period. Further studies are needed to better understand the dynamic of the short-term effects of HIIT on the vasculature of older patients with hypertension, considering a broader range of markers (e.g., FMD, AIx, PWV).

From a practical perspective, our study provides valuable insights into the potential short-term clinical benefits of an easy-to-implement, low-cost, autonomously guided RPE-based outdoor HIIT model for managing BP in older patients with hypertension. However, it is important to highlight that 2 out of 18 participants (~11%) dropped out of the HIIT intervention due to musculoskeletal issues. Most older adults performed brisk walking during the high-intensity bouts in the HIIT sessions. The step cadence threshold for vigorous intensity in older adults aged 61-85 years is ~120-130 step/min (5.6-6.4 km/h) (McAvoy et al., 2023; Tudor-Locke et al., 2018). Based on accelerometer-measured data, a previous study from our group observed that only 5.6% of community-dwelling older adults had a peak 30-min cadence > 100 steps/min (Cabral et al., 2023). On average, participants had a peak 30-min cadence of ~68 steps/min, indicating that brisk walking is not common among most older adults. Peak 30-min cadence is considered the “natural best effort” of free-living ambulatory behavior because it represents the 30 highest cadence values (steps/min), which are not necessarily consecutive, over the course of a day (Aguiar et al., 2019). Our current data support this observation, as participants spent, on average, ~0.7 minutes per day in vigorous-intensity physical activity (Table 1). Thus, given that the brisk walking performed by the participants during the outdoor HIIT is unusual in their daily activities and elicits a high cardiovascular and musculoskeletal demand, the inclusion of specific strengthening-based exercises for lower-limb muscle groups prior to a HIIT program seems appropriate to prevent musculoskeletal issues in this population. Unfortunately, a very recent systematic review on quality reporting in randomized trials designed to investigate the effects of HIIT in individuals with hypertension demonstrated that only 1 out of 9 studies reported adverse events (Bünzen et al., 2025). Additionally, none of the included studies reported information on “fidelity to the exercise intervention” (i.e., the extent to which the exercise intervention occurred as the investigators intended it) and “motivation strategies” (i.e., strategies to achieve engagement to sustain exercise activity and/or achieve higher or progressively more intense performance) (Slade et al., 2016). These gaps limit a more thorough risk-to-benefit analysis of HIIT for patients with hypertension.

This study has limitations. First, participants were relatively healthy older adults with hypertension, aged 60-80 years, without major comorbidities or functional limitations, which may limit the applicability of the RPE-based HIIT intervention and its effects to broader older adult populations. Second, the small sample size, inherent to pilot and feasibility studies, may have limited the statistical power to detect between-group differences. Nonetheless, pilot and feasibility studies are essential for providing preliminary evidence on the practical viability and initial effects of interventions. Third, the six-week intervention period may have been insufficient to capture the impact of the RPE-based HIIT intervention on vascular outcomes. In addition, although the Mobil-O-Graph PWA method has been validated for assessing arterial stiffness markers (Hametner et al., 2013) it is not considered the gold-standard method. Our results suggest that RPE-based outdoor HIIT is a feasible exercise training approach for older adults with hypertension. Furthermore, it appears to elicit a clinically meaningful reduction in 24-hour ambulatory BP in the short term. Larger, randomized trials are needed to confirm these preliminary findings.

Based on the findings of this pilot study, adjustments should be considered for a larger trial. The very low consent rate, mostly due to the exclusion of physically active individuals who expressed interest in participating, may indicate two main issues. First, recruitment strategies through media channels may have primarily reached more physically active individuals already engaged in healthier lifestyles. To address this, a referral-based recruitment approach from clinical settings, such as cardiology or geriatric outpatient clinics, may increase the consent rate by targeting physically inactive older adults, who represent a more typical and relevant population for this type of intervention. In addition, clearer



communication of the “physical inactivity” criterion is needed: i) no structured exercise in the past three months; and ii) no regular leisure-time physical activity at least twice per week. Of note, retention and adherence rates were high. However, given the adverse lower-limb musculoskeletal events observed during the HIIT intervention, we highlight the potential benefit of incorporating targeted resistance exercise as an adjunct program. Taken together, our findings support the feasibility of a larger trial including the few methodological refinements mentioned.

Conclusions

Our results suggest that RPE-based outdoor HIIT is a feasible exercise training approach for older adults with hypertension. Furthermore, it appears to elicit a clinically meaningful reduction in 24-hour ambulatory BP in the short term. Larger randomized trials are needed to confirm these preliminary findings.

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