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Original Research

Inter-Individual Responses to Acute Resistance Training in the Blood Pressure Dipping Response in Normotensive and Hypertensive Men

ELIZABETH CARPIO-RIVERA†[1], JOSÉ MONCADA-JIMÉNEZ‡[1,2], ALEJANDRO SALICETTI-FONSECA‡[1], and ANDREA SOLERA-HERRERA‡[1]

[1]School of Physical Education and Sports, University of Costa Rica, San José, COSTA RICA; [2]Human Movement Sciences Research Center (CIMOHU), University of Costa Rica, San José, COSTA RICA

†Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 17(3): 1361-1376, 2024. The blood pressure dipping response to acute resistance training exercise (RTE) is scarce in the literature. We determined the inter-individual blood pressure (BP) dipping variability of normotensive (NT) and hypertensive (HT) men completing two modalities of a single session of RTE. Volunteers (NT n = 21, HT n = 20) underwent a non-exercise control (CTRL), RTE high-sets low-repetitions (HSLR), and RTE high-repetitions low-sets (HRLS) conditions. Twenty-four-hour ambulatory BP monitoring recorded diurnal and nocturnal systolic (SBP) and diastolic (DBP) BP. Non-significant interactions were found between the category of individuals and the experimental conditions on the SBP ($p = 0.511$, $\eta^2_p = 0.02$) and DBP ($p = 0.807$, $\eta^2_p = 0.01$) differences. Diurnal SBP ($p = 0.0001$) and DBP ($p \leq 0.0001$) were lower in the NT than in the HT groups. Nocturnal SBP ($p \leq 0.0001$) and DBP ($p = 0.014$) were lower in the NT than in the HT groups. The percentage of dipping responders for SBP in the CTRL condition were 71.4% for NT and 70.0% for HT, in the HRLS condition were 66.7% for NT and 60.0% for HT, and in the HSLR condition were 57.1% for NT and 60.0% for HT. The dipping responders for DBP in the CTRL condition were 57.1% for NT and 60.0% for HT, in the HRLS condition were 61.9% for NT and 70.0% for HT, and in the HSLR condition were 71.4% for NT and 65.0% for HT ($p > 0.05$ for all). In conclusion, the dipping response was similar between NT and HT individuals. The proportion of responders was similar between NT and HT individuals completing acute RTE.

KEY WORDS: Weight training, cardiovascular, hemodynamic response, disease

INTRODUCTION

Elevated systolic (SBP) and diastolic (DBP) blood pressure are well-known risk factors for developing cardiovascular, metabolic, and cognitive diseases. Besides the typical pharmacological method used for hypertension (HT) control, other effective strategies to prevent the development of and to control HT include lifestyle modification, health education, low-sodium and high-potassium salt, breathing-control, diet management, exercise training, and their combination (1). Countries such as the United States and Costa Rica show high HT treatment and control rates; furthermore, Costa Rica outperforms most high-income nations in pharmacologically treating and controlling individuals with HT (27, 38, 49).

Exercise is an effective strategy to prevent the development of and to clinically control HT (12). Current evidence from a network meta-analysis suggests that several exercise modalities improve resting blood pressure values (e.g., isometric exercise, combined training, dynamic resistance training, aerobic exercise training, and high-intensity interval training) (18). The different exercise modalities elicit a gradual reduction in blood pressure in the minutes and hours following training. The dipping and post-exercise hypotension concepts are two different phenomena, although both refer to the decrease in blood pressure values. Dipping is a natural, non-exercise-induced decrease in blood pressure values of approximately 10–20% during sleep compared to daytime blood pressure values while the person is awake. It is an essential phenomenon since if it does not occur, it is considered a cardiovascular risk factor (1, 19). On the other hand, post-exercise hypotension or hypotensive effect of exercise is a transient decrease in blood pressure resulting from an exercise session (26).

Different acute and chronic exercise paradigms have shown positive hypotensive effects. For instance, regular aerobic exercise training elicited reductions in 24-h ambulatory blood pressure monitoring (ABPM) ranging from −1.6 to −9.2 mmHg for SBP and −0.6 to −5.4 mmHg for DBP (39). Furthermore, beneficial reductions in night time have been also reported for SBP (−1.0 to −8.4 mmHg) and DBP (−0.9 to −5.3 mmHg) following aerobic interval training (39). The beneficial changes have been reported for acute and chronic (≥ 8 weeks) aerobic exercise programs (8). For instance, acute aerobic, resistance and concurrent exercise reduced SBP (−6.22 mmHg, −3.36 mmHg, and −7.33 mmHg, respectively) and DBP (−3.80 mmHg, −2.73 mmHg, and −2.93 mmHg, respectively) regardless of gender, initial blood pressure, and physical activity level (10).

Little attention has been given to changes in blood pressure at night resulting from exercise performed during day time, with currently registered prospective protocols lasting 12 months (24). In normotensive and controlled hypertensive individuals, the reduction in nocturnal blood pressure (i.e., dipping), both SBP and DBP reaches values of approximately 10–20% than those values recorded during day time (i.e., dipping individuals) (42). Dipping values < 10% might be considered abnormal (i.e., non-dipper individual) and are associated to organ damage, increased mortality, heart failure, stroke, and sudden death (42, 45).

Previously classified non-dipping older adults who completed 6 months of aerobic exercise improved their blood pressure dipping response from baseline (ΔSBP = −3.08 mmHg; ΔDBP = −2.67 mmHg) (5). African-American men and women also improved their SBP (3.6%) dipping response following 6 months of aerobic exercise; however, no significant change was observed in the DBP (2.8%) dipping response. In coronary heart disease patients, the SBP and DBP dipping (11.1% and 14.1%) resulting from an exercise intervention was superior to the usual care and stress management (41).

Early evidence from Baum, Rüther and Essfeld (3), demonstrated that intermittent muscle relaxation during resistance training exercise (RTE) reduced the blood pressure increase response observed during exercise. Given this finding, questions arose about whether performing RTE with intermittent pauses and decreasing the increase in blood pressure immediately after the RTE session affects the hypotensive response (i.e., dipping). To answer this question and, based on the literature on progression models in resistance training (2, 14, 37), a comparison was proposed between two RTE protocols with multijoint exercise, an exercise prescription aimed at muscle strengthening in individuals without previous experience performing this exercise modality. In this context, positive dipping responses have been reported from aerobic exercise interventions; however, the 24-h blood pressure in response to an acute bout of RTE varies between individuals and has received little attention in the dipping response (28, 40). Therefore, the purpose of the study was to determine the inter-individual blood pressure dipping variability of normotensive (NT) and hypertensive (HT) men to a single session of RTE. Our hypothesis was that HT men would show a higher SBP and DBP dipping response to the acute RTE session than NT men. A secondary hypothesis was that both RTE regimens would elicit similar dipping responses in all the individuals.

METHODS

An experimental study was designed, where in a randomized order the participants performed three experimental conditions (described in detail later): 1) Control (CTRL) session, 2) high-repetitions and low-sets (HRLS), and 3) high-sets and low-repetitions (HSLR).

Participants

Evidence is available showing that men present higher resting BP compared to women, specifically in a population with characteristics similar to those included in the present study (11). Thus, a priori sample size using an effect size of 2 mmHg in SBP, $\beta = 0.85$, and $\alpha = 0.05$ showed that 20 individuals were needed. We determined the minimum difference representing significant clinical changes based on evidence that analyzes the implications of the INTERSALT study (43), showing that a decrease in 2 mmHg in SBP reduces mortality due to stroke by 6% and 4% due to coronary heart disease. Volunteers were allowed to participate if they met the following inclusion criteria: a) males, b) adults ≥ 18 yr., c) sedentary (not exercising for at least 30-min, three times per week in the previous three months) (2) and d) able to complete RTE. Volunteers were excluded from participating in the study if their resting SBP ≥ 160 mmHg and/or DBP ≥ 100 mmHg, and if they were taking antihypertensive medications in the four weeks preceding the study. Volunteers ($n = 41$) meeting the inclusion criteria were screened and classified by a physician as either NT ($n = 21$; age = 19.7 ± 2.3 yr., weight = 72.5 ± 17.3 kg, height = 171.0 ± 5.0 cm) or HT ($n = 20$; age = 21.7 ± 4.6 yr., weight = 78.1 ± 11.0 kg, height = 174.0 ± 5.0 cm) based on adult guidelines (15, 17). The classification considered a clinical history and a 24-h ambulatory blood pressure monitoring (ABPM) of the individuals before any experimental sessions were carried out. According to the guidelines mentioned above and considering the values obtained through ABPM, individuals classified as hypertensive were those who maintained ambulatory SBP values in the waking period ≥ 135 mmHg, in the sleeping period ≥ 120 mmHg, and in the 24-hour average ≥ 130 mmHg and/or, DBP values in the waking period

≥ 85 mmHg, in the sleeping period ≥ 70 mmHg and a 24-hour DBP ≥ 80 mmHg. The group of normotensive participants were those with SBP and DBP values lower than those previously mentioned. The study was approved by the University of Costa Rica's Scientific Ethics Committee and all volunteers were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study. In addition, this research was carried out fully in accordance to the ethical standards of the *International Journal of Exercise Science* (30).

Volunteers were 41 males; for the NT group (n = 21) the demographic characteristics were age = 19.7 ± 2.3 yr., weight = 72.5 ± 17.3 kg, height = 171.0 ± 5.0 cm, SBP = 114.4 ± 10.1 mmHg, and DBP = 69.8 ± 8.8 mmHg. For the HT group (n = 20), demographic characteristics were age = 21.7 ± 4.6 yr., weight = 78.1 ± 11.0 kg, height = 174.0 ± 5.0 cm, SBP = 133.9 ± 11.9 mmHg, and DBP = 80.0 ± 10.5 mmHg. Blood pressure descriptive statistics, TEM and threshold for change for NT and HT individuals completing three experimental sessions is presented in Table 1.

Protocol

Prior to the experiment, the individuals completed eight sessions separated seven days from each other. During the first session, anthropometric measures were recorded and resting ECG. Anthropometric values were recorded for body weight (Tanita sale model HD-313, Arlington Heights, IL) and body height (stadiometer Novel Products Inc., Rockton, IL). A Polar HR monitor model FT7 (Polar Electro Oy, Kempele, Finland) recorded heart rate (HR). The resting ECG recordings were assessed by a physician who cleared participants to perform the RT experimental sessions. The familiarization process was completed from the 2^{nd} to the 4^{th} session and consisted of completing three sets of 10 repetitions in each of the 10 exercises that would be performed later in the experimental sessions using machine/machine pulley equipment: a) knee extension, b) neutral grip row, c) knee flexion, d) incline bench press on a machine, e) leg press, f) hip flexion, g) hip adduction, h) elbow flexion with machine pulley, i) hip abductor, and j) elbow extension with machine pulley. A 2:2 tempo was used during RT exercises (i.e., 2 beats in the concentric phase by 2 beats in the eccentric phase). The intensity was set between two and three on the OMNI-RES perceived exertion scale (23). In session five, participants completed the one-maximum repetition test (1-RM) in each of the 10 exercises mentioned before.

For the experimental study, the participants performed the conditions under a repeated measures design with randomized order (i.e., the order in which each subject executed the conditions was assigned randomly). In addition, each participant executed the corresponding session in the morning at the same hour. The CTRL session consisted of sitting still for 55 min, a similar time the participants used to complete the sessions where they performed RTE. In the HRLS session the participants performed 3 sets of 10 repetitions with a 2:2 tempo at 60% 1-RM, with a rest of 60-s between sets and exercises in each of the 10 RTE. The HSLR session consisted of performing 10 sets of 3 repetitions with a 2:2 tempo at 60% 1-RM, with 13-s rest between sets and 60-s rest between exercises in each of the 10 exercises. The exercise sessions were preceded by a warm-up where participants pedaled 5-min on a stationary bike at 50% of the HR reserve (2) The formula reported by Tanaka, Monahan and Seals (44) for sedentary males was used to obtain the maximum HR necessary to calculate the HR reserve. The participants were instructed to refrain from any exercise or physical activity before these sessions and to avoid alcohol consumption; they were not instructed to avoid caffeine consumption to avoid a caffeine withdrawal effect. Participants were encouraged to maintain their daily life activities; however, if they were to consume coffee, they were instructed to drink the exact amount at the same time the day before each session. We tried to control possible effects by using a repeated measures research design in which each participant was in their own control. In addition, during the experimental sessions, the participants were required to avoid ingesting beverages or food and when the sessions that included exercise were completed, they were asked to avoid the Valsalva maneuver.

Measurements of SBP and DBP were recorded by a Spacelabs ABPM monitor model 90217 (Spacelabs, Snoqualmie, WA). To determine whether the participants were able to maintain values < 160/100 mmHg and could complete the exercise session, the BP was assessed after 5-min of sitting rest before each session that included physical exertion (i.e., sessions 2 to 8). The 24-h ABPM was recorded following a standardized protocol (15) to quantify diurnal and nocturnal (i.e., dipping) SBP and DBP responses. During a 24 h period, blood pressure was recorded starting from the first minute of the post-experimental session (i.e., CTRL and RTE sessions). Measurements were recorded every 30 min during daytime and every 60 min at night to ensure participant comfort. Quality control included only ABPM data reaching at least 70% successful readings. The protocol is summarized in Figure 1.

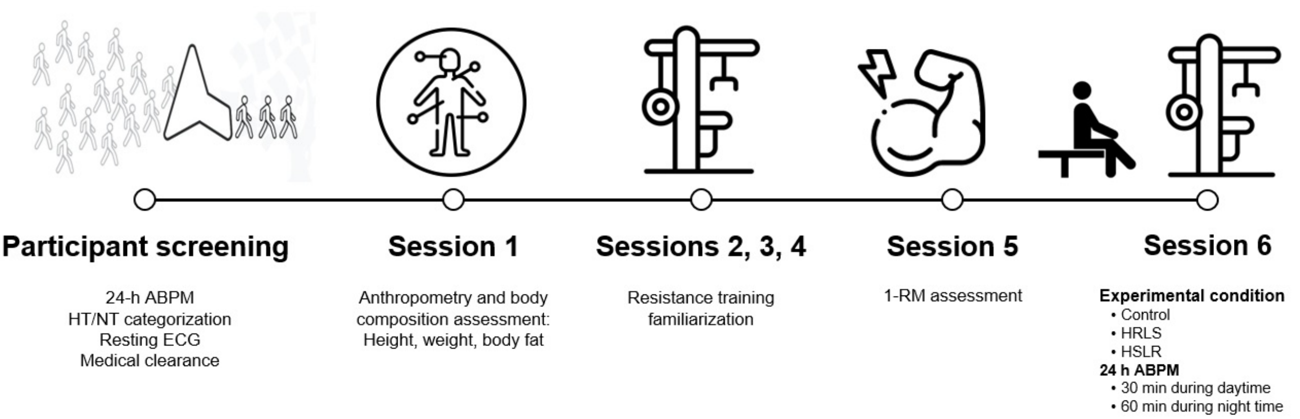

Figure 1. Overview of the study protocol involving hypertensive (HT) and normotensive (NT) men. For the acute intervention, the experimental conditions in session six were randomly assigned to participants. Experimental conditions were a non-exercise control, resistance training performed at high-sets low-repetitions (HSLR), and at high-repetitions low-sets (HRLS). The 24-hour ambulatory blood pressure monitoring (ABPM) commenced immediately following the corresponding experimental condition.

Table 1. Blood pressure (mmHg) descriptive statistics for normotensive and hypertensive individuals completing three experimental sessions (n = 41).

	Non-exercise Control				Resistance Training Exercise Groups							
					High-Repetitions and Low-Sets				High-Sets and Low-Repetitions			
	Diurnal	Nocturnal	TEM	Threshold	Diurnal	Nocturnal	TEM	Threshold	Diurnal	Nocturnal	TEM	Threshold
NT												
SBP	117.7 ± 6.9	106.5 ± 7.5	3.6	7.1	117.1 ± 7.1	105.2 ± 7.7	4.5	8.8	117.4 ± 6.9	107.9 ± 8.8	3.5	6.8
DBP	71.1 ± 6.7	60.9 ± 5.8	3.5	6.9	70.1 ± 7.0	59.6 ± 6.5	3.8	7.4	70.3 ± 5.9	60.9 ± 6.4	3.1	6.0
HT												
SBP	133.9 ± 8.2	120.7 ± 9.5	6.0	11.9	130.5 ± 8.8	118.6 ± 10.0	5.1	10.0	131.6 ± 9.0	119.1 ± 9.5	4.8	9.5
DBP	78.9 ± 7.8	66.5 ± 9.4	4.7	9.3	77.2 ± 8.0	65.9 ± 9.4	4.8	9.5	77.1 ± 8.4	65.9 ± 7.8	4.0	7.9

TEM = technical error of measurement; NT = Normotensives; HT = hypertensives; SBP = systolic blood pressure; DBP = diastolic blood pressure.

Statistical Analysis

Statistical analyses were performed using the IBM SPSS version 26 (Armonk, NY). Descriptive statistics are presented as the mean and standard deviation (M ± SD). Mixed factorial 2 x 3 (Category of participants by Experimental conditions) analysis of variance were computed for the SBP and DBP difference (i.e., diurnal minus nocturnal BP). Partial eta-squared (η^2_p) reported effect sizes. Inter-individual responses to the experimental conditions were studied by partitioning the random change (i.e., technical and/or biological error) and the systematic change (i.e., exercise intervention). For the random change, the typical error of measurement (TEM) was computed as the standard deviation of the sum of the observed differences (SD_{diff}) between awake and sleep blood pressure measurements within each individual divided by the square root of two (i.e., TEM = $SD_{diff}/\sqrt{2}$). Since for normally distributed data, 95% of the observations fall within 1.96 SD of the mean, the threshold values for responders and non-responders to the intervention (i.e., systematic change) were computed as 1.96 x TEM. Thus, participants at or below the specific thresholds were considered responders, else, non-responders. In addition, NT and HT individuals were also classified as "non-dippers" or "dippers" based on the 10% decrease compared with the daytime BP reported in the literature (31). Thus, if the dipping response reached 10% from daytime values, the individuals were considered "dippers"; otherwise, they were "non-dippers." The categorizations of "dippers" and "non-dippers" and "responders" and "non-responders" obey to different approaches. The 10% threshold is a subjective figure based on literature and findings from clinical practice. In contrast, the threshold based on TEM is a statistical approach that quantifies the two components of change; the random change (i.e., change produced by TEM and the biological variability of the individuals) and the systematic change (i.e., change caused by exercise) (22). Non-parametric Chi-squared tests were used to study the proportion of responder and non-responder NT and HT individuals, and Yates correction was used when cells had less than four observations. For all analyses, the statistical significance was set a priori at $p \leq 0.05$.

RESULTS

Inferential analysis showed non-significant interactions between the category of individuals and the experimental conditions on the SBP (p = 0.511, η^2_p = 0.02) and DBP (p = 0.807, η^2_p = 0.01) differences (i.e., dipping) (Figure 2). Overall, the diurnal SBP was lower in the NT than in the HT groups (M = 117.4 ± 6.4 vs. 132.0 ± 8.2 mmHg, $p \leq 0.0001$, η^2_p = 0.51). The diurnal DBP was lower in the NT than in the HT groups (M = 70.5 ± 6.2 vs. 77.7 ± 7.7 mmHg, p = 0.0001, η^2_p = 0.22). The nocturnal SBP was lower in the NT than in the HT groups (M = 106.6 ± 7.2 vs. 119.5 ± 8.3 mmHg, $p \leq 0.0001$, η^2_p = 0.42). The nocturnal DBP was lower in the NT than in the HT groups (M = 60.4 ± 5.7 vs. 66.1 ± 8.2 mmHg, p = 0.014, η^2_p = 0.14).

In Table 2, participants were classified as non-dippers or dippers based on the 10% decrease compared with the daytime BP. For SBP, the non-parametric χ^2 test showed similar proportions of dippers and non-dippers in the CTRL (χ^2 = 0.03, p = 0.867), HRLS (χ^2 = 1.17, p = 0.279), and HSLR (χ^2 = 1.9, p = 0.162) experimental conditions. For DBP, the χ^2 test showed similar proportions of dippers and non-dippers in the CTRL (χ^2 = 0.37, p = 0.541), HRLS (χ^2 = 0.08, p = 0.783), and HSLR (χ^2 = 0.07, p = 0.796) experimental conditions.

The nocturnal blood pressure (i.e., dipping) individual response for the NT and HT participants based on the TEM and the threshold for improvement is shown in Table 3 and Figure 3 and 4. For SBP, the χ^2 test showed similar proportions in the CTRL (χ^2 = 0.20, p = 0.655), HRLS (χ^2 = 0.20, p = 0.658), and HSLR (χ^2 = 0.03, p = 0.853) experimental conditions. For DBP, the χ^2 test showed similar proportions in the CTRL (χ^2 = 0.27, p = 0.606), HRLS (χ^2 = 0.41, p = 0.523), and HSLR (χ^2 = 0.01, p = 0.920) experimental conditions.

Table 2. Classification of the nocturnal blood pressure (i.e., dipping) response based on a 10% decrease (31) compared with the daytime BP values in normotensive and hypertensive individuals completing three experimental conditions (n = 41).

Condition		Normotensives (n = 21)		Difference (%)	Hypertensives (n = 20)		Difference (%)
		Non-Dippers (%)	Dippers (%)		Non-Dippers (%)	Dippers (%)	
Control	SBP	48	52	−4	45	55	−10
	DBP	29	71	−42	20	80	−60
HRLS	SBP	67	33	34	50	50	0
	DBP	24	76	−52	20	80	−60
HSLR	SBP	67	33	34	45	55	−10
	DBP	29	71	−42	30	70	−40

SBP = systolic blood pressure; DBP = diastolic blood pressure; HRLS = high-repetitions and low-sets; HSLR = high-sets and low-repetitions.

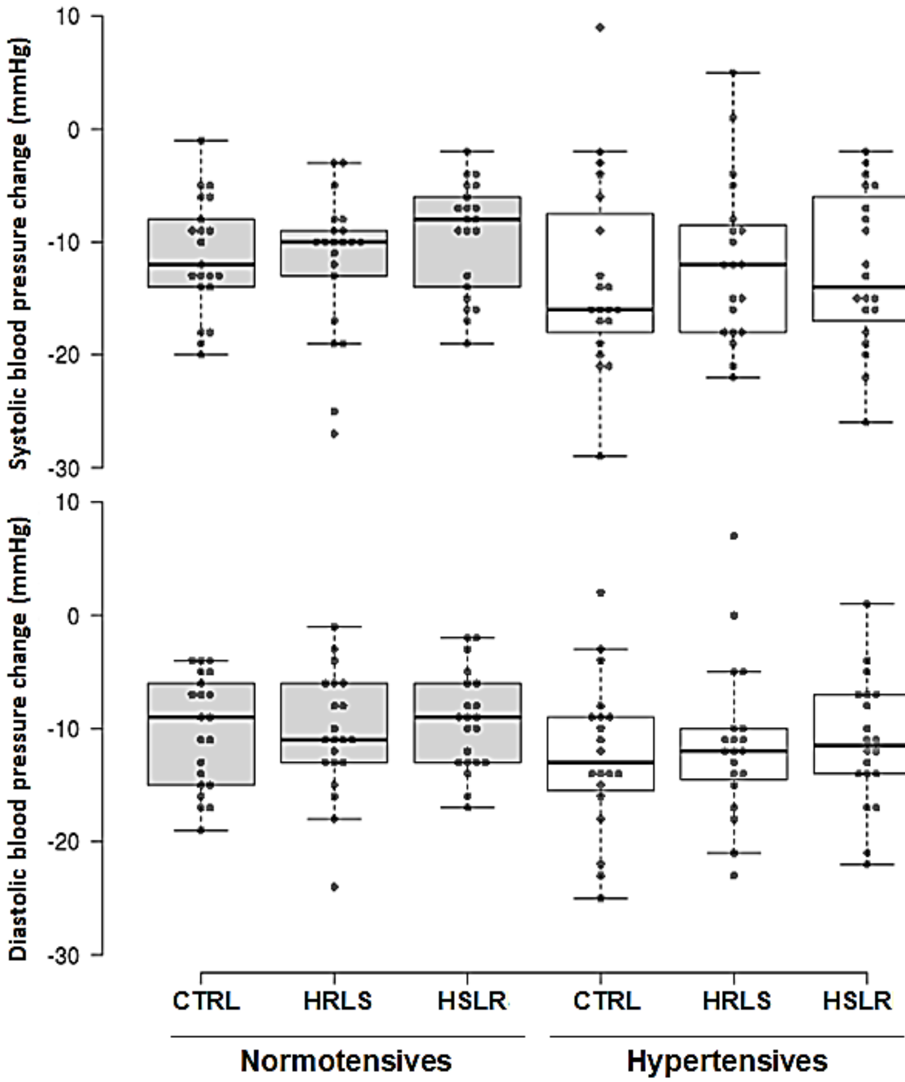

Figure 2. Differences in systolic and diastolic blood pressure (mmHg) in normotensive and hypertensive men completing a non-exercise control (CTRL), high-repetitions low-sets (HRLS), and high-sets low-repetitions (HSLR) acute resistance training conditions.

Table 3. Nocturnal blood pressure (i.e., dipping) inter-individual response for normotensive and hypertensive individuals completing two modalities of a single session of resistance training exercise (*n* = 41).

Variable	Responders		Difference (%)	Non-responders		Difference (%)
	NT (%)	HT (%)		NT (%)	HT (%)	
Systolic blood pressure						
Control	71	70	1	29	30	−1
HRLS	67	60	7	33	40	−7
HSLR	57	60	−3	43	40	3
Diastolic blood pressure						
Control	57	60	−3	43	40	3
HRLS	62	70	−8	38	30	8
HSLR	71	65	6	29	35	−6

NT = normotensive; HT = hypertensives; HRLS = high-repetitions and low-sets; HSLR = high-sets low-repetitions.

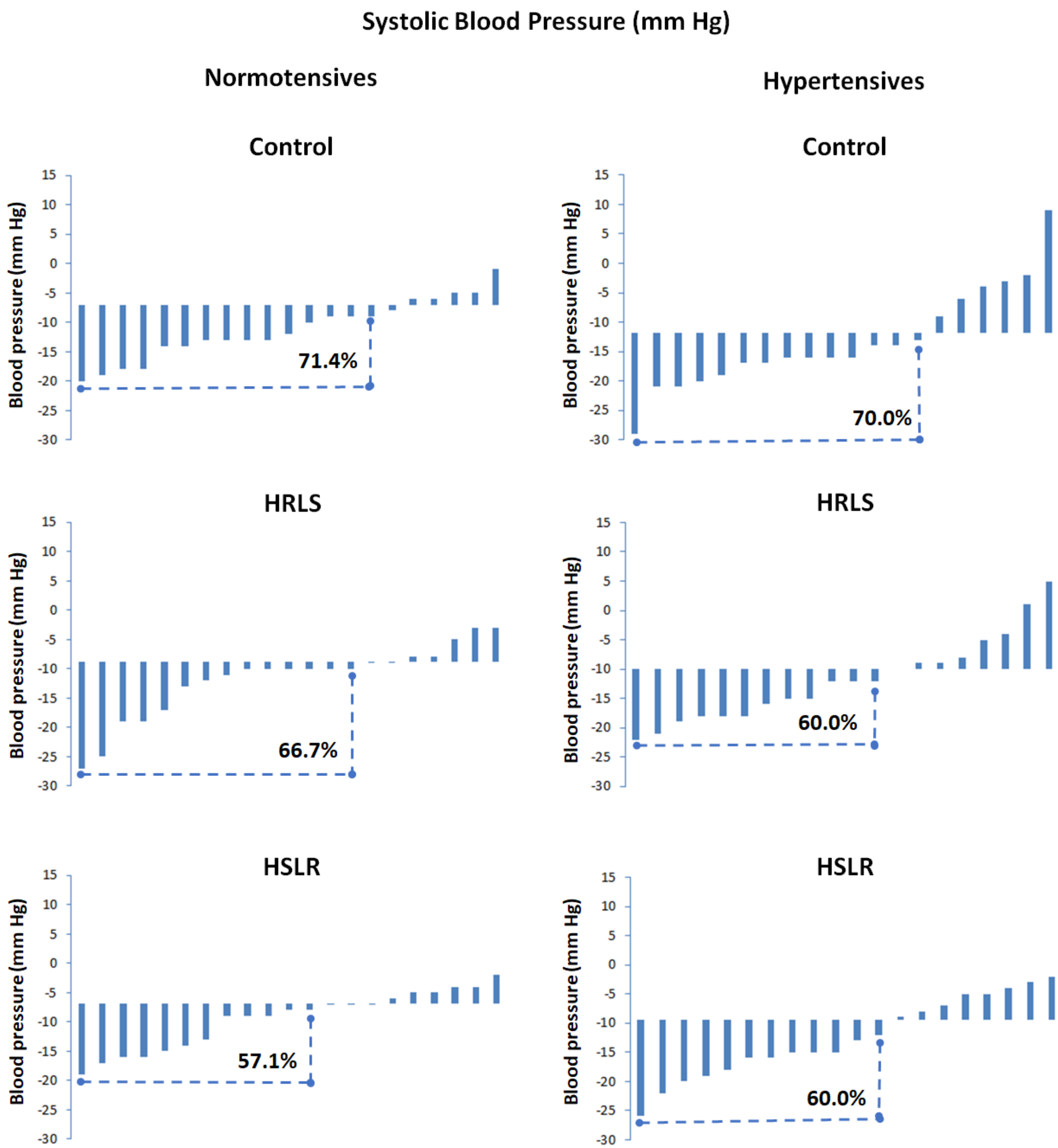

Figure 3. Inter-individual differences in systolic blood pressure (mmHg) in normotensive and hypertensive men completing three experimental conditions. The experimental condition's y-axis mmHg is set at the specific calculated threshold. Values below the threshold are considered responders, else, non-responders.

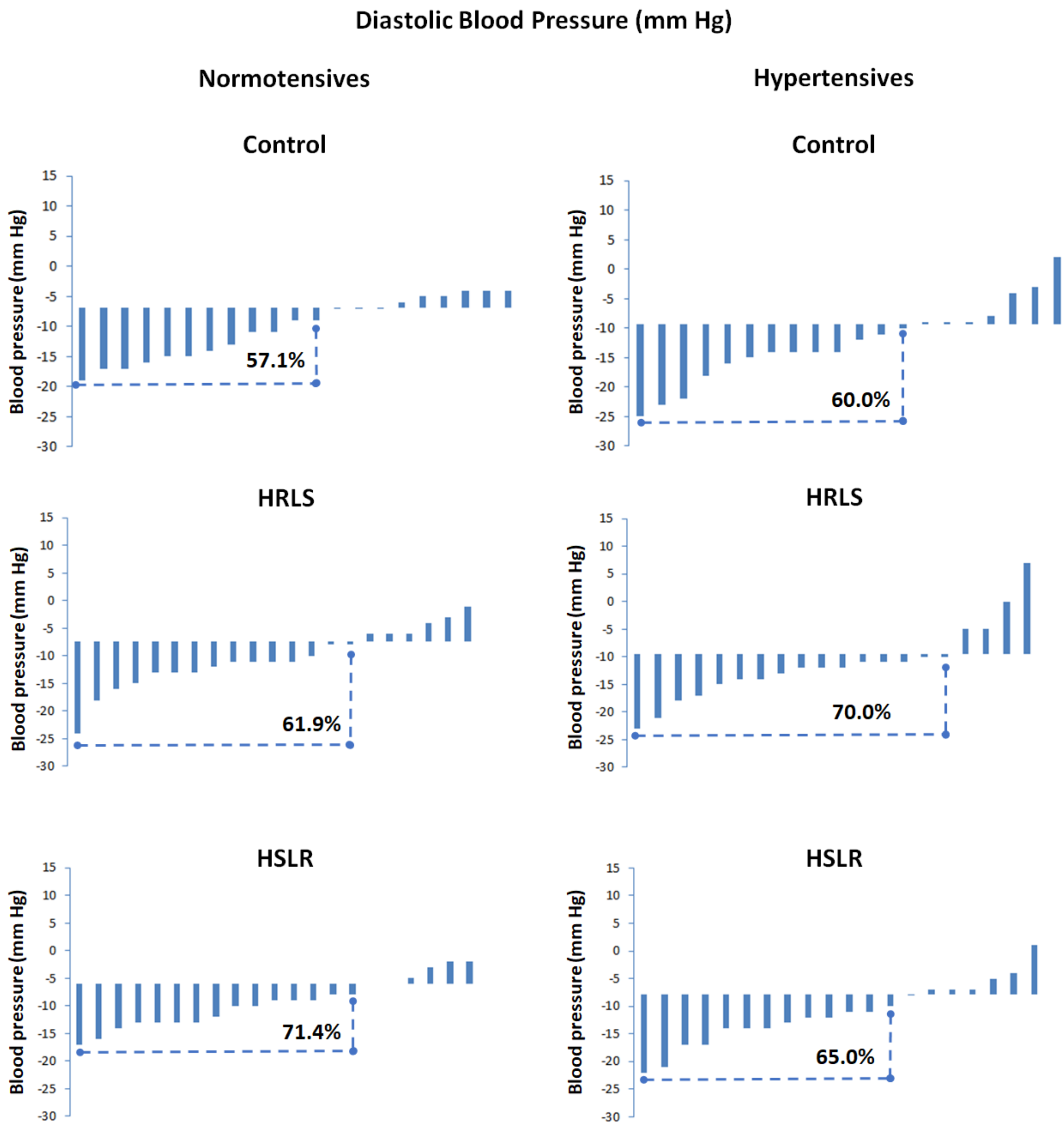

Figure 4. Inter-individual differences in diastolic blood pressure (mmHg) in normotensive and hypertensive men completing three experimental conditions. The experimental condition's y-axis mmHg is set at the specific calculated threshold. Values below the threshold are considered responders, else, non-responders.

DISCUSSION

The aim of the study was to determine the inter-individual blood pressure dipping response of NT and HT individuals completing two modalities of a single session of RTE. We hypothesized that HT individuals would show a higher SBP and DBP dipping response to the acute RTE sessions than NT individuals. Our secondary hypothesis was that the RTE regimens would elicit similar dipping responses in all the individuals. The main finding was that NT and HT individuals showed similar SBP and DBP dipping responses to the RTE sessions. We also found that the three experimental sessions elicited similar dipping responses in all the individuals, regardless of their category (Figure 2). Furthermore, the proportion of dipping responders and non-responders were similar between RTE modalities; yet, for DBP, there were more HT responders than NT individuals completing a single session of HRLS RTE. For SBP, a larger proportion of NT responders was found compared to HT responders when performing the HRLS experimental condition; yet, the proportion of individuals did not reach statistical significance. In addition, during the CTRL session, there were more NT and HT dipping responders for SBP compared to the exercise sessions; however, there were fewer NT dipping responders for DBP in the CTRL session than in the exercise session. Again, the proportion of individuals did not reach statistical significance.

The lack of nocturnal blood pressure reduction (i.e., dipping) beyond a specific threshold has been associated with increased cardiovascular disease risk factors (32). Little evidence exists regarding the use of acute RTE to study the dipping response in NT and HT individuals. Furthermore, the individual response to acute RTE as related to dipping is missing in the literature. A consistent body of evidence supports chronic aerobic exercise performed at different intensities and modalities for daytime and nocturnal BP control (7, 9, 13, 25, 36, 46). For instance, aerobic exercise performed over four months showed positive reductions in BP dipping in medicated HT individuals (36). The chronic combination of aerobic and RTE also shows reductions in the dipping response in HT individuals (7). Indeed, in medicated HT older adults, 12 weeks of RTE elicited a greater dipping than interval aerobic training or a control condition (4). There is also, meta-analytical evidence supporting beneficial acute exercise for BP control (10). Also, correlational evidence suggests that fitness levels are positively associated to the dipping response in individuals older than 55 yr. (21, 47, 48).

Scarce experimental research is available regarding the effects of a single session (i.e., acute) of aerobic, RTE or their combination on the nocturnal BP response (28, 29, 40). For instance, type II diabetic hypertensive patients completed between 8:30 a.m. and 9:00 a.m., one single session of moderate-intensity aerobic exercise, maximal-intensity aerobic exercise, or a non-exercise control condition (29). The 24 h ABPM assessment showed a greater dipping following the maximal-intensity exercise condition compared to the non-exercise control (29). In a similar design, a single session of RTE was compared in the dipping response to aerobic exercise (i.e., 20-min of cycling at 90% lactate threshold) and a control condition in 10 adults with type II diabetes (28). Between 8:00 a.m. and 9:00 a.m., the participants performed three sets of a circuit of six exercises (i.e., leg extensions, bench press, leg press, seated pulley, leg curls, rowing machine) with eight repetitions (1-s in the concentric phase, 1-s in the eccentric phase) at 70% 1-

RM, 40 s recovery, and 1 min between sets. The main finding of the study was that compared with pre-exercise values, there was DBP dipping response only following the RTE (28). The only study where different RTE variations were used included HT older adults, where two RTE protocols and a non-exercise control condition were compared (40). Thus, following four sessions of RTE familiarization, the participants performed one set of 20 repetitions for 20-min of 10 RTE (i.e., leg press, bench press, biceps curl, knee extension in an extensor chair, lat pull down, triceps extension in pulley, peck deck, knee flexion in a flexor chair, seated row, dumbbell lateral shoulder raise), or two sets of 40-min of the same 10 exercises listed before. Therefore, the RTE intensity was held constant at 40% 1-RM and the total volume was different. Both RTE protocols elicited a greater SBP and DBP dipping response compared to the non-exercise control. In addition, the RTE protocol with higher volume produced a higher DBP dipping response than the lower volume RTE protocol (40). A shortcoming of all the previous studies is that the reporting of the individual responses (i.e., responders vs. non-responders) to the exercise protocols is missing; therefore, the true effect of the reported exercise interventions (i.e., the effect of the exercise intervention considering the TEM and the group responses) on the individual dipping response to exercise is unknown.

In the present experimental study, we report that the proportion of responders to the acute HRLS RTE session for SBP was higher for NT than for HT individuals; for both groups, responders to the exercise intervention reached ≥ 60%; yet, this finding lacks of statistical significance. However, we also unexpectedly found ~70% non-exercise control SBP dipping responders (Table 3); again, this proportion did not reach statistical significance. The dipping response is common in most of the population (42). However, in the present study's repeated measures design, we anticipated that the proportion of dippers would be lower in the control condition compared to the exercise condition, considering the known hypotensive effect of exercise. Nevertheless, the observed proportion could have occurred by chance, or because there was no noticeable immediate effect on the nighttime blood pressure response beyond what is normally expected for most individuals. In addition, although the non-parametric tests showed non-significant proportions, the lowest proportion of SBP non-responders was found in the NT control individuals and the highest proportion of non-responders in the NT HSLR RTE session. For DBP, the lowest proportion of non-responders was found in the NT HSLR RTE session individuals and the highest proportion of non-responders in the NT control individuals. Again, we unexpectedly found ~58% non-exercise control SBP dipping responders (Table 2). Baum et al.'s previous work (3) allowed us to design the present study based on the premise that performing RTE with intermittent pauses would affect the dipping response; yet, our results highlight the need for further studies with different RTE prescriptions to find a more appropriate exercise protocol and doses for eliciting a beneficial dipping response in HT individuals. We also suggest to developing a methodological study quality evaluation checklist aimed at studying the dipping response to RTE protocols, both, acute and chronic. Such guidelines are currently available for aerobic exercise protocols (16).

The potential mechanisms explaining the dipping response to acute RTE are beyond the scope of this study; yet these range from regulatory genes (34, 35) and sleep (6) to circadian variations in the BP response (20, 33). For instance, the dipping response was studied in 20 pre-HT individuals who completed a graded exercise test to exhaustion followed by 30-min aerobic exercise at 65% heart rate peak at 7:00 a.m., 1:00 p.m., and 7:00 p.m. (20). The exercise session performed at 7:00 a.m. elicited greater SBP dipping response than 1:00 p.m. or 7:00 p.m., and the greater DBP dipping response was found for the protocol performed at 7:00 p.m. However, performing a single bout of exercise between 5:00 to 7:00 p.m. has shown greater SBP dipping response than exercising between 6:00 to 8:00 a.m. in individuals characterized as non-dippers compared to dippers (33). Thus, additional research must be summarized by systematic reviews and meta-analysis to detect stable patterns. In the present study, all participants performed the RTE sessions between 7:00 a.m. and 9:00 a.m., which reduced the variability attributed to circadian variations.

The present study has strengths and limitations. The research design was strong where the participants completed the three experimental conditions (i.e., full-repeated measures design). We also computed a priori sample size deemed large enough to detect changes in SBP. In addition, the parametric and non-parametric statistical analyses allowed us to show not only group but also individual responses, the latter been neglected in most, if not all, similar studies. We also used ABPM instruments, which allow for a more valid 24-h BP assessment. One of the limitations was to power the study using SBP as the main outcome, when DBP is less likely to change as a result of an exercise stimulus. Thus, we should have used DBP as our main outcome to power the study. Finally, in this study we only included men; therefore, our findings cannot be extrapolated to women.

Acute RTE elicited similar SBP dipping responses in NT and HT individuals. The proportion of NT and HT responders and non-responders was similar following three experimental conditions. Future studies are warranted regarding the efficacy of acute RTE for enhancing the dipping response.

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REFERENCES

1. Al Ghorani H, Götzinger F, Böhm M, Mahfoud F. Arterial hypertension - clinical trials update 2021. Nutr Metab Cardiovasc Dis 32(1): 21-31, 2022.

2. American College of Sports Medicine. ACSM's guidelines for exercise testing and prescription. 11th ed. Riverwoods, IL: Wolters Kluwer Health; 2022.

3. Baum K, Rüther T, Essfeld D. Reduction of blood pressure response during strength training through intermittent muscle relaxations. Int J Sports Med 24(6): 441-445, 2003.

4. Bertani RF, Campos GO, Perseguin DM, Bonardi JMT, Ferriolli E, Moriguti JC, Lima NKC. Resistance exercise training is more effective than interval aerobic training in reducing blood pressure during sleep in hypertensive elderly patients. J Strength Cond Res 32(7): 2085-2090, 2018.

5. Boa Sorte Silva NC, Gregory MA, Gill DP, McGowan CL, Petrella RJ. The impact of blood pressure dipping status on cognition, mobility, and cardiovascular health in older adults following an exercise program. Gerontol Geriatr Med 4: 2333721418770333, 2018.

6. Bock JM, Vungarala S, Covassin N, Somers VK. Sleep duration and hypertension: Epidemiological evidence and underlying mechanisms. Am J Hypertens 35(1): 3-11, 2022.

7. Caminiti G, Iellamo F, Perrone MA, Marazzi G, Gismondi A, Cerrito A, Franchini A, Volterrani M. Concurrent aerobic plus resistance training elicits different effects on short-term blood pressure variability of hypertensive patients in relation to their nocturnal blood pressure pattern. Medicina (Kaunas) 58(11): 1682, 2022.

8. Cao L, Li X, Yan P, Wang X, Li M, Li R, Shi X, Liu X, Yang K. The effectiveness of aerobic exercise for hypertensive population: A systematic review and meta-analysis. J Clin Hypertens (Greenwich) 21(7): 868-876, 2019.

9. Carpes L, Costa R, Schaarschmidt B, Reichert T, Ferrari R. High-intensity interval training reduces blood pressure in older adults: A systematic review and meta-analysis. Exp Gerontol 158: 111657, 2022.

10. Carpio-Rivera E, Moncada-Jiménez J, Salazar-Rojas W, Solera-Herrera A. Acute effects of exercise on blood pressure: A meta-analytic investigation. Arq Bras Cardiol 106(5): 422-433, 2016.

11. Carpio Rivera E, Solera Herrera A, Salicetti Fonseca A, Hernández Elizondo J, Moncada Jiménez J. The association between cardiovascular risk factors and resting blood pressure in college students. Rev Costarric Salud Pública 25(1): 47-58, 2016.

12. Correia RR, Veras ASC, Tebar WR, Rufino JC, Batista VRG, Teixeira GR. Strength training for arterial hypertension treatment: A systematic review and meta-analysis of randomized clinical trials. Sci Rep 13(1): 201, 2023.

13. Costa EC, Hay JL, Kehler DS, Boreskie KF, Arora RC, Umpierre D, Szwajcer A, Duhamel TA. Effects of high-intensity interval training versus moderate-intensity continuous training on blood pressure in adults with pre- to established hypertension: A systematic review and meta-analysis of randomized trials. Sports Med 48(9): 2127-2142, 2018.

14. Dalleck LC, Atwood JP, Prins RL, Buchanan CA, Curry MA. Developing a comprehensive exercise prescription: The optimal order for cardiorespiratory, resistance, flexibility, and neuromotor exercise. J Fit Res 3(2): 13-25, 2014.

15. Daskalopoulou SS, Rabi DM, Zarnke KB, Dasgupta K, Nerenberg K, Cloutier L, Gelfer M, Lamarre-Cliche M, Milot A, Bolli P. The 2015 Canadian hypertension education program recommendations for blood pressure measurement, diagnosis, assessment of risk, prevention, and treatment of hypertension. Can J Cardiol 31(5): 549-568, 2015.

16. Day C, Wu Y, Pescatello LS. Evaluating the methodological quality of postexercise hypotension aerobic exercise interventions. Front Physiol 13: 851950, 2022.

17. del Valle Soto M, Manonelles Marqueta P, de Teresa Galván C, Franco Bonafonte L, Luengo Fernández E, Gaztañaga Aurrekoetxea T. Prescription of exercise in the prevention and treatment of hypertension. Document of consensus of the Spanish society of sports medicine. Arch Med Deporte 32(5): 281-312, 2015.

18. Edwards JJ, Deenmamode AHP, Griffiths M, Arnold O, Cooper NJ, Wiles JD, O'Driscoll JM. Exercise training and resting blood pressure: A large-scale pairwise and network meta-analysis of randomised controlled trials. Br J Sports Med 57(20): 1317-1326, 2023.

19. Fagard RH. Dipping pattern of nocturnal blood pressure in patients with hypertension. Expert Rev Cardiovasc Ther 7(6): 599-605, 2009.

20. Fairbrother K, Cartner B, Alley JR, Curry CD, Dickinson DL, Morris DM, Collier SR. Effects of exercise timing on sleep architecture and nocturnal blood pressure in prehypertensives. Vasc Health Risk Manag 10: 691-698, 2014.

21. García-Ortiz L, Recio-Rodríguez JI, Puig-Ribera A, Lema-Bartolomé J, Ibáñez-Jalón E, González-Viejo N, Guenaga-Saenz N, Agudo-Conde C, Patino-Alonso MC, Gomez-Marcos MA. Blood pressure circadian pattern and physical exercise assessment by accelerometer and 7-day physical activity recall scale. Am J Hypertens 27(5): 665-673, 2014.

22. Hopkins WG. Measures of reliability in sports medicine and science. Sports Med 30(1): 1-15, 2000.

23. Lagally KM, Robertson RJ. Construct validity of the Omni resistance exercise scale. J Strength Cond Res 20(2): 252-256, 2006.

24. Lee EK, Zhang DD, Yip BH, Cheng J, Hui SS, Yu EYT, Leung M, Chu WCW, Mihailidou AS, Wong SY. Exercise intervention to normalize blood pressure and nocturnal dipping in hypertensive patients (END-HT): Protocol of a randomized controlled trial. Am J Hypertens 34(7): 753-759, 2021.

25. Ling C, Diaz KM, Kretzschmar J, Feairheller DL, Sturgeon KM, Perkins A, Veerabhadrappa P, Williamson ST, Lee H, Grimm H, Babbitt DM, Brown MD. Chronic aerobic exercise improves blood pressure dipping status in African American nondippers. Blood Press Monit 19(6): 353-358, 2014.

26. Lovato NS, Anunciação PG, Polito MD. Blood pressure and heart rate variability after aerobic and weight exercises performed in the same session. Rev Bras Med Esporte 18(1): 22-25, 2012.

27. Lucius K. Integrative medicine in the management of hypertension. Integr Complement Ther 28(5): 240-250, 2022.

28. Morais PK, Campbell CS, Sales MM, Motta DF, Moreira SR, Cunha VN, Benford RE, Simões HG. Acute resistance exercise is more effective than aerobic exercise for 24h blood pressure control in type 2 diabetics. Diabetes Metab 37(2): 112-117, 2011.

29. Morais PK, Sales MM, Alves de Almeida J, Motta-Santos D, Victor de Sousa C, Simões HG. Effects of aerobic exercise intensity on 24-h ambulatory blood pressure in individuals with type 2 diabetes and prehypertension. J Phys Ther Sci 27(1): 51-56, 2015.

30. Navalta JW, Stone WJ, Lyons TS. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12(1): 1-8, 2019.

31. O'Brien E. Dipping comes of age: The importance of nocturnal blood pressure. Hypertension 53(3): 446-447, 2009.

32. Ohkubo T, Imai Y, Tsuji I, Nagai K, Watanabe N, Minami N, Kato J, Kikuchi N, Nishiyama A, Aihara A, Sekino M, Satoh H, Hisamichi S. Relation between nocturnal decline in blood pressure and mortality. The Ohasama study. Am J Hypertens 10(11): 1201-1207, 1997.

33. Park S, Jastremski CA, Wallace JP. Time of day for exercise on blood pressure reduction in dipping and nondipping hypertension. J Hum Hypertens 19(8): 597-605, 2005.

34. Pescatello LS, Parducci P, Livingston J, Taylor BA. A systematically assembled signature of genes to be deep-sequenced for their associations with the blood pressure response to exercise. Genes (Basel) 10(4): 295, 2019.

35. Pescatello LS, Schifano ED, Ash GI, Panza GA, Corso LML, Chen MH, Deshpande V, Zaleski A, Cilhoroz B, Farinatti P, Taylor BA, O'Neill RJ, Thompson PD. Deep-targeted sequencing of endothelial nitric oxide synthase gene exons uncovers exercise intensity and ethnicity-dependent associations with post-exercise hypotension. Physiol Rep 5(22): e13510, 2017.

36. Ramirez-Jimenez M, Morales-Palomo F, Moreno-Cabañas A, Alvarez-Jimenez L, Ortega JF, Mora-Rodriguez R. Aerobic exercise training improves nocturnal blood pressure dipping in medicated hypertensive individuals. Blood Press Monit 27(4): 272-275, 2022.

37. Ratamess NA, Alvar BA, Evetoch TE, Housh TJ, Kibler WB, Kraemer WJ, Triplett NT. American college of sports medicine position stand. Progression models in resistance training for healthy adults. Med Sci Sports Exerc 41(3): 687-708, 2009.

38. Rocha J, Cunha FA, Cordeiro R, Monteiro W, Pescatello LS, Farinatti P. Acute effect of a single session of pilates on blood pressure and cardiac autonomic control in middle-aged adults with hypertension. J Strength Cond Res 34(1): 114-123, 2020.

39. Saco-Ledo G, Valenzuela PL, Ruiz-Hurtado G, Ruilope LM, Lucia A. Exercise reduces ambulatory blood pressure in patients with hypertension: A systematic review and meta-analysis of randomized controlled trials. J Am Heart Assoc 9(24): e018487, 2020.

40. Scher LM, Ferriolli E, Moriguti JC, Scher R, Lima NK. The effect of different volumes of acute resistance exercise on elderly individuals with treated hypertension. J Strength Cond Res 25(4): 1016-1023, 2011.

41. Sherwood A, Smith PJ, Hinderliter AL, Georgiades A, Blumenthal JA. Effects of exercise and stress management training on nighttime blood pressure dipping in patients with coronary heart disease: A randomized, controlled trial. Am Heart J 183: 85-90, 2017.

42. Sherwood A, Steffen PR, Blumenthal JA, Kuhn C, Hinderliter AL. Nighttime blood pressure dipping: The role of the sympathetic nervous system. Am J Hypertens 15(2): 111-118, 2002.

43. Stamler R. Implications of the Intersalt study. Hypertension 17(1 Suppl.): I16-I20, 1991.

44. Tanaka H, Monahan KD, Seals DR. Age-predicted maximal heart rate revisited. J Am Coll Cardiol 37(1): 153-156, 2001.

45. Theodorakopoulou M, Dipla K, Zafeiridis A, Sarafidis P. Nocturnal dipping profile in chronic kidney disease: Searching for underlying mechanisms in order to prevent adverse events. Physiol Rep 8(24): e14665, 2021.

46. Wu Y, Johnson BT, Chen S, Chen Y, Livingston J, Pescatello LS. Tai ji quan as antihypertensive lifestyle therapy: A systematic review and meta-analysis. J Sport Health Sci 10(2): 211-221, 2021.

47. Wuerzner G, Bochud M, Zweiacker C, Tremblay S, Pruijm M, Burnier M. Step count is associated with lower nighttime systolic blood pressure and increased dipping. Am J Hypertens 26(4): 527-534, 2013.

48. Yamagami Y, Saeki K, Tai Y, Maegawa T, Iwamoto J, Kataoka H, Kurumatani N, Obayashi K. Objectively measured physical activity relates to night-time blood pressure in older adults: Cross-sectional analysis in the Heijo-Kyo cohort. J Hypertens 38(4): 649-655, 2020.

49. Zhou B, Carrillo-Larco RM, Danaei G, Riley LM, Paciorek CJ, Stevens GA, Gregg EW, Bennett JE, Solomon B, Singleton RK, Sophiea MK, Iurilli MLC, Lhoste VPF, Cowan MJ, Savin S, Woodward M, Balanova Y, Cifkova R, Damasceno A, Elliott P, et al. Worldwide trends in hypertension prevalence and progress in treatment and control from 1990 to 2019: A pooled analysis of 1201 population-representative studies with 104 million participants. Lancet 398(10304): 957-980, 2021.