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Original Research

The Influence of a Total Body Resistance Training Program on Autonomic Modulation and Strength Variables in Young Adults

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ABSTRACT

International Journal of Exercise Science 14(2): 802-814, 2021. The purpose of this study was to examine autonomic modulation using multiple quantitative measures before and after a resistance training (RT) intervention. Seventeen young adults (age 18-35 years) were tested for body composition, muscular strength, and autonomic activity. The RT protocol targeted total-body large muscle groups, which were performed three days a week for eight-weeks. Autonomic assessments included respiratory sinus arrhythmia (RSA), static handgrip exercise, Valsalva maneuver, heart rate variability (HRV), and tilt-table testing. The main finding was that tilt-table duration increased by 68 seconds ($p = 0.05$) after RT. Upper body strength increased by 11.2 kg ($p = 0.001$) and lower body strength increased by 68.3 kg ($p < 0.001$) following completion of the RT intervention. The average total lean mass increased by 1.5 kg ($p < 0.01$), while total fat mass was unchanged ($\Delta = 0.5$ kg, $p = 0.23$). RSA ($\Delta = 0.4$, $p = 0.89$), Valsalva ratio ($\Delta = -0.09$, $p = 0.48$), static handgrip ($\Delta = 8$ mm Hg, $p = 0.07$), and HRV ($\Delta = -0.4$, $p = 0.53$) were not affected by RT. The results from this study suggest that RT improves tilt-table tolerance in a young healthy population as evidence by improved tilt-table duration. However, RT seemed to have no effect on cardio-vagal or adrenergic function.

KEY WORDS: Autonomic nervous system, heart rate, orthostatic tolerance, tilt-table testing

INTRODUCTION

Resistance training (RT) includes dynamic and static exercises that target large muscle groups and is currently recommended by the American College of Sports Medicine for improving muscular health and fitness (2). When performed regularly, RT may increase muscle strength and mass, increase bone mineral density, and raise basal metabolic rate (45). Moreover, RT has shown to maintain or lower arterial blood pressure and increase lean body mass (6, 28), both of which have been associated with decreased cardiovascular risk later in life (13).

It is well known that the autonomic nervous system greatly influences cardiovascular tone and hemodynamics through the modulation of sympathetic and parasympathetic (vagal) activity. Imbalances of this system have been reported as symptoms for disease and disorders (35, 43).

Autonomic imbalances have been indicated in hypertension (7), tachycardia (31), and orthostatic hypotension (13). In contrast to disorders that primarily affect the autonomic nerves, a variety of cardiac pathologies, such as myocardial infarction, heart failure, and cardiomyopathy result in secondary acute and chronic changes within the ANS (16). Moreover, assumption of upright posture imposes significant stress on the body and produces a sudden downward shift in volume, with pooling of blood in the lower abdomen and lower limbs (40). An effective autonomic nervous system causes the body to be able to compensate quickly for this relative volume loss by increasing heart rate, cardiac output, and vascular tone. The critical importance of these compensatory mechanisms is particularly apparent when they fail, as happens in patients with orthostatic intolerance or autonomic dysfunction. Additionally, chronic exposure of unfavorable sympatho-vagal balance, could lead to long-term cardiovascular impairments that are associated with decrements in quality of life (4, 20, 24).

Despite the well-known musculoskeletal benefits that are associated with RT, the associations with autonomic modulation (AM) tend to be controversial (27). Previously it has been shown that an acute bout of resistance exercise may improve cardiac AM assessed via heart rate variability (HRV) (21, 22). While others found no change in sympathetic activity at rest following RT (6, 10). The large amount of "irregularity" in the signal spectrum for HRV may be, at least in part, responsible for these inconsistencies (33). As others have suggested HRV may be losing information regarding sympatho-vagal balance (18). Thus, sole reliance on HRV measures as an indicator of AM may conceal subtle changes in the autonomic nervous system and, in doing so, could lead to erroneous interference concerning autonomic nervous system function.

Given that autonomic outflow to one organ or vascular bed may not be the same as other organs or vascular beds, performing a series of quantitative maneuvers that expose the cardio-vagal and adrenergic domains of the autonomic nervous system may provide a more robust representation of overall AM (31, 44). While the importance of healthy autonomic function is well known, there is little information regarding the effects of RT on AM in young adults using multiple assessments. Therefore, the purpose of this study was to examine if changes in AM could be detected following an eight-week RT program in a younger population.

METHODS

Participants

A power analysis was conducted with G*POWER 3.1 (Universitat Kiel, Germany). A sample size of 14 participants was estimated to detect a difference in our primary outcome variable, low frequency/ high frequency ratio, based on means and standard deviations from the available literature (21), at an alpha level of 0.05 with 80% power. Therefore, seventeen healthy subjects (seven males and ten females) completed the intervention and all the testing procedures. Participant characteristics are presented in Table 1. All females were tested during their early follicular phase of the menstrual cycle (37). Exclusion criteria included known metabolic or cardiovascular disease, current adherence to a resistance training program, and taking prescription medication other than oral contraceptives. None of the participants had a history of musculoskeletal injury that could affect exercise training. All participants were naïve to RT and completed at least 19 sessions throughout the eight-weeks of RT and completed two autonomic testing sessions. Written informed consent was provided by all participants prior to participation, and the study was approved by The International Review Board at Ball State University. This research was carried out fully in accordance with the ethical standards of the International Journal of Exercise Science (30).

Table 1. Participant characteristics (n = 17).

Variable	Overall
Age (y)	22 ± 4
Height (cm)	172 ± 9
Weight (kg)	75.7 ± 20.5
Body mass index (kg/m^2)	25.4 ± 4.9

Protocol

Participants reported to the laboratory on two separate occasions. All participants were asked to refrain from caffeine, alcohol, and food ingestion 12 hours prior to data collection as well as exercise for 24 hours prior to data collection sessions. Body composition was assessed during the first visit prior to our autonomic testing protocol. All autonomic tests were performed with subjects in the supine position. Participants were instrumented with a three-lead ECG and a finger photoplethysmography cuff (model 2300, Finapres, Ohmeda, Englewood, CO) to record beat-to-beat arterial pressure. Transcranial Doppler ultrasound (2 MHz; Multigon Industries, Elmsford, NY) was used to assess cerebral blood flow velocity, in the left middle cerebral artery, as an index of cerebral blood flow. A nasal canula was placed on participants upper lip in order to record end tidal CO_2 ($ETCO_2$). After instrumentation, participants were undisturbed for 15 minutes and quietly rested until autonomic testing began. Resting blood pressures were measured with an automated sphygmomanometer and heart rate (HR) was obtained using the three-lead ECG. Following the autonomic and body composition visit, participants went through estimated and actual 1-Repetition Maximum (1-RM) testing for the associated exercises (2). All measures were then repeated following eight-weeks of exercise training.

Autonomic Testing: Selected autonomic testing maneuvers were done as previously described by Novak (30). With a minimum of three minutes of quiet rest in between each measure, testing began with paced breathing exercises, instructing the participant to inhale for five seconds and exhale for five seconds which was repeated six times, for a total of 60 seconds. Next, to help understand the sympathetic reflex pathways we examined the autonomic response to handgrip exercise as measured by use of a dynamometer exerting maximal effort handgrip (26, 47). Static handgrip was then held at one-third the maximum handgrip and recorded for two minutes. Following handgrip, the Valsalva maneuver was performed three times and consisted of 15 seconds of forceful breathing against a resistance of at least 40 mm Hg. Lastly, we initiated an orthostatic assessment by using a tilt-table positioned to 70°. Participants stood in this tilted position for up to 15 minutes or until indications of pre-syncope were noted in the combination of preceding physiological monitoring parameters (i.e., blood pressure decreasing, HR increasing, $ETCO_2$ decreasing, and significant change in the cerebral blood flow wave form from its triangular wedge shape tracing). The frequency domain of HRV data was analysed during time of tilt (in periods of 15 minutes unless pre-syncope symptoms occurred). All recordings were measured with ADInstruments LabChart Pro software.

Body Composition: Height and weight were measured to the nearest 0.25 cm and 0.1 kg using a balance beam scale and stadiometer, respectively. Body composition was assessed by means of air displacement plethysmography (BODPOD). Prior to each measurement, the BODPOD was calibrated per manufactures instructions. Participants were instructed to wear minimal form-fitting clothing (i.e., bike-style shorts, sports bra, or swimsuit) and a swim cap. In the case that the participant did not have appropriate clothing, the clothing was provided for them by the researchers.

Muscular Strength testing: 1-RM tests for the chest and leg press exercises were performed. Prior to 1-RM, participants were educated on proper form for both exercises. ACSM guidelines were followed for 1-RM testing (1, 2). Briefly, after a warm-up and familiarization period, each participant performed a single repetition lift equal to 50-70% of the participant's predicted maximum capacity. Resistance was progressively increased per repetition until the participant was unable to complete the selected repetition. The final weight lifted successfully was recorded as the absolute 1-RM.

Training Sessions: All exercise training sessions were performed in the Adult Physical Fitness Center facility at Ball State University. Each training session began with a five-minute aerobic warm-up at a self-selected pace. Each participant was supervised through all exercises to ensure safety and proper form. In agreement with the American College of Sports Medicine guidelines for untrained adults, participants' initial intensity for the total exercises was aimed at 60-80% of their recorded 1-RM. Each training session involved eight resistance exercises that target all major muscle groups (Table 2). Each exercise was performed at 8-12 repetitions for two sets with a two-minute rest between for the first two weeks and three sets of 8-12 repetitions for the remaining six weeks, in order to progressively increase the training stimulus. The weight was progressed by study personnel per exercise set or session if needed to maintain 8-12 repetitions until volitional fatigue, which corresponds with 60-80% of 1-RM (2). Each training session lasted approximately 60 minutes.

Table 2. Eight-week total body resistance training protocol.

Exercise#	Weeks 1-3*	Weeks 4-8*	Machine
Chest Press	2 sets of 8-12 repetitions	3 sets of 8-12 repetitions	Seated Pulley
Leg Press	2 sets of 8-12 repetitions	3 sets of 8-12 repetitions	Seated Pulley
Lat Pull Down	2 sets of 8-12 repetitions	3 sets of 8-12 repetitions	Seated Pulley
Leg Curl	2 sets of 8-12 repetitions	3 sets of 8-12 repetitions	Seated Pulley
Triceps Extension	2 sets of 8-12 repetitions	3 sets of 8-12 repetitions	Standing Pulley
Bicep Curl	2 sets of 8-12 repetitions	3 sets of 8-12 repetitions	Dumbbells
Lateral Row	2 sets of 8-12 repetitions	3 sets of 8-12 repetitions	Seated Pulley
Shoulder Press	2 sets of 8-12 repetitions	3 sets of 8-12 repetitions	Seated Pulley

#Exercises were performed at 60-85% 1-repetition maximum. *Exercises were performed to volitional exhaustion.

Statistical Analysis

All data is presented as means ± SD unless otherwise noted. Participant characteristics were interpreted using descriptive statistics. A paired t-test was used to compare significant differences between baseline and post-training. Deltas (Δ) were determined for variables of interest (i.e., tilt-table duration, RSA, LF/HF, static handgrip exercise, and Valsalva ratio) by calculating the difference between post RT and baseline data. A two-tailed, bivariate correlation was used to determine the relationship amongst selected variables (i.e., fat mass and resting systolic blood pressure). All data were analyzed using the Statistical Package for the Social Science (SPSS version 24.0; IBM, Armonk, NY). Substantive differences were determined with Cohen's d (d) as a measure of effect size: 0.1 as trivial; 0.2 as small; 0.5 as moderate; and 0.8 as large (42). Statistical significance was set at a probability level of p value ≤ 0.05.

RESULTS

Autonomic variables: There were significant differences in total tilt-table duration ($p = 0.05$) in participants following the RT intervention, represented by an overall mean tilt-table time increase of 68 seconds. RT had a moderate effect on tilt-table duration ($d = 0.58$) and handgrip exercise ($d = 0.53$). However, static handgrip remained unchanged ($p = 0.07$). HRV was not different post exercise ($p = 0.53$) and there were no differences between RSA ($p = 0.82$) or Valsalva maneuver ($p = 0.49$) (Table 3).

Table 3. The change in autonomic modulation after 8-weeks of resistance training.

	n	Baseline	Post-Training	Δ	*p* value	Cohen's *d*
RSA (bpm)	17	20.1 ± 7.8	20.5 ± 7.2	0.4	0.82	0.05
Static handgrip (mm Hg)	16	33 ± 16	41 ± 14	8	0.07	0.53
Valsalva ratio	17	2.0 ± 0.5	1.9 ± 0.4	-0.1	0.48	0.22
LF/HF ratio	17	1.4 ± 2.2	1.0 ± 0.8	-0.4	0.53	0.24
Total tilt time (seconds)	17	517 ± 150	585 ± 72	68	0.05*	0.58

Values described as mean ± SD. RSA: respiratory sinus arrhythmia, LF/HF: low frequency/high frequency ratio, bpm: beats per minute, kg: kilograms, Δ delta, *d:* Cohen's effect size. *Denotes significance $p \leq .05$

Strength Assessment and Body Composition: There were significant increases in maximal strength such that there was a 14.6% ($p = 0.001$) increase in 1-RM chest press (Figure 1) and 25.3% increase in 1-RM leg press (Figure 2). Average lean mass increased by 1.5 kg ($p = 0.005$). However, there was no differences in %Fat ($p = 0.23$) or fat mass ($p = 0.67$) following RT. BMI was greater following the RT program ($p = 0.04$), and total weight increased overall ($p = 0.03$) (Table 4).

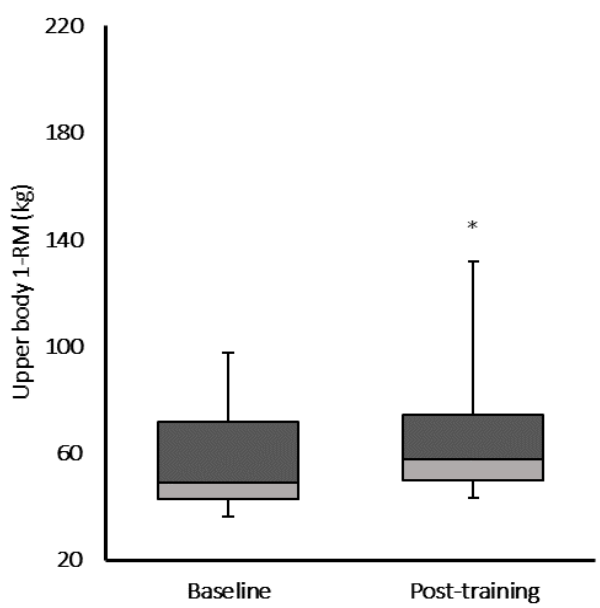

Figure 1. Box-and-whisker plots of the distribution of upper body 1-repitition maximum (1-RM) assessment before (65 ± 37 kg) and after (76 ± 43 kg) 8-weeks of resistance training. Exercise assessments included seated chest press. The square dots represent outliers. *Significant within group differences in the change in upper body 1-RM (p = 0.001) (n = 17).

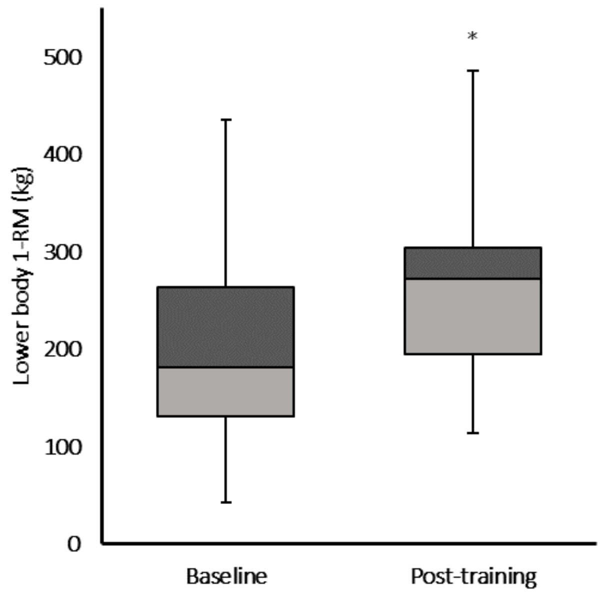

Figure 2. Box-and-whisker plots of the distribution of lower body 1-repitition maximum (1-RM) assessment before (203 ± 100 kg) and after (271 ± 94 kg) 8-weeks of resistance training. Exercise assessments included seated leg press. *Significant within group differences in the change in lower body 1-RM ($p < 0.001$) ($n = 17$).

Table 4. Body composition variables following eight weeks of resistance training ($n = 17$).

	Baseline	Post-Training	*p* value	Cohen's *d*
Total weight (kg)	75.7 ± 20.5	77.0 ± 21.1	0.03*	0.06
Body Fat (%)	26.8 ± 9.5	26.1 ± 8.8	0.23	0.07
Fat mass (kg)	21.2 ± 12.2	20.9 ± 12.2	0.67	0.02
Lean mass (kg)	54.5 ± 11.8	56.0 ± 12.2	0.005*	0.12

Values described as mean ± SD. *Denotes significance $p < 0.05$.

Cardiovascular Responses: Resting cardiovascular responses following the exercise intervention are listed in Table 5. HR responses to the tilt-table test were captured following three minutes of rest before the tilt-table test, the maximum HR during 70° tilt, and following three minutes rest post tilt-table test. Prior to RT, average HR responses increased from resting (62 ± 8 bpm) to 70° tilt (107 ± 14 bpm) ($p < 0.001$). Once the tilt-table test concluded, HR responses significantly decreased from 70° tilt to post tilt-test (60 ± 10 bpm) ($p < 0.001$). There was no difference in the magnitude of HR change from pre-tilt to 70° tilt following RT (baseline Δ 45 bpm, post-training Δ 45 bpm, $p = 0.40$). Exercise training did not change resting systolic ($p = 0.32$) or diastolic ($p = 0.10$) blood pressure. However, RT did have a small-moderate effect on diastolic blood pressure ($d = 0.49$). Fat weight was directly related to resting systolic blood pressure before RT ($r = 0.60$, $p = 0.01$) and after RT ($r = 0.69$, $p = 0.002$) (Figure 3A-B). Resting HR remained unchanged ($p = 0.26$) post exercise intervention.

Table 5. Cardiovascular variables following 8-weeks of resistance training (n = 17).

	Baseline	Post-Training	p value	Cohen's d
SBP (mm Hg)	125 ± 8	127 ± 10	0.32	0.22
DBP (mm Hg)	77 ± 5	74 ± 7	0.10	0.49
RHR (bpm)	61 ± 6	58 ± 9	0.26	0.39
Maximal HR during TTT (bpm)	107 ±11	106 ± 14	0.35	0.08

Values described as mean ± SD. SBP: systolic blood pressure, DBP: diastolic blood pressure, RHR: resting heart rate, TTT: tilt-table test. *Denotes significance $p < 0.05$

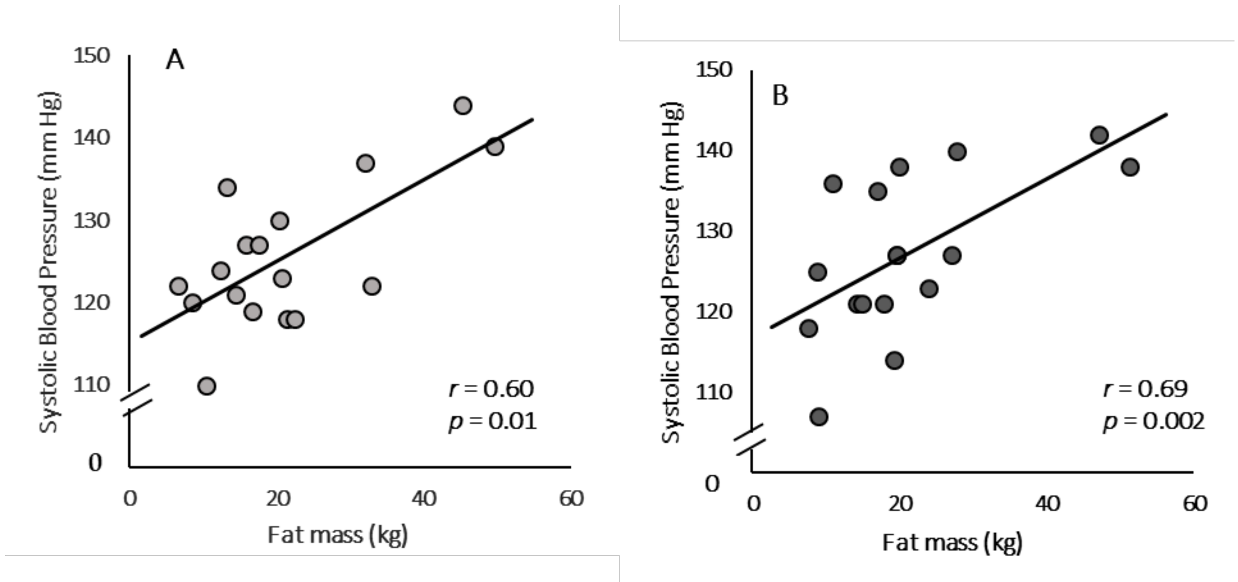

Figure 3. The relationship between total fat mass and resting systolic blood pressure (A) before and (B) after exercise training (n = 17).

DISCUSSION

The primary purpose of this study was to detect changes in AM using multiple autonomic assessments following an eight-week RT program in young adults. To our knowledge, this was the first study to measure AM using multiple quantitative measures that expose the cardio-vagal (i.e., HRV, Valsalva ratio, RSA) and adrenergic (i.e., handgrip exercise, tilt-table testing) domains of the autonomic nervous system. Our resistance training protocol elicited significant increases in lean mass which corresponded with increases in upper- and lower- body strength. The main finding of this study was that tilt-table duration significantly increased following the RT intervention. Interestingly, AM was unchanged in all tests after RT. Thus, our results appear to suggest that eight-weeks of RT may improve orthostatic tolerance (i.e., evidenced by tilt-table duration) despite no change in AM.

Previously, it has been documented that endurance training has a beneficial effect on orthostatic tolerance by improving heart pump performance (46). This may be evident through directly effecting the myocardium by increasing contractility (38), strengthening the muscles in the legs, which may improve muscle pump and venous return to the heart (29), and by reducing vasomotor tone allowing for decreased total peripheral resistance (23). While endurance exercise imposes a volume load on the cardiovascular system, resistance exercise exerts intermittent marked pressor responses on the cardiovascular system and is therefore characterized primarily as a pressure load response. As such, it has been shown that isolated muscle RT in a clinical population is associated with improvements in cardiac filling and cardiac output at rest (11). Furthermore, total body RT tends to result in increased vascularization of targeted muscle-groups, which corresponds to greater blood flow from exercising muscles with each movement (3, 36). Based on these findings, we can reasonably infer that improved , orthostatic tolerance may be due to the increase in muscle mass and improvements in skeletal muscle pump (39). For these reasons, our research suggests that RT is safe and may have important benefits for cardiac function.

AM did not significantly change in our younger population. These results are similar to other studies that have demonstrated no effects of RT on AM in young adults (6, 10, 21). Carter et al. (6) demonstrated that RT had no effect on muscle sympathetic nerve activity and HR in young adults. Participants underwent thrice weekly exercise training for eight-weeks consisting of three sets of each exercise, performing ten repetitions during sets one and two, and as many repetitions as possible before concentric failure during set three. In a similar age group and exercise training protocol, Cooke et al. (10) found that RT did not affect vagal-cardiac control and cardio-vagal baroreflex sensitivity as evidence by R-R variations in respiratory frequency and HRV. However, in a group of healthy young men, Heffernan et al. (20) reported that while six-weeks of exercise training did not change indices of HRV, it did increase sample entropy. This suggests that RT may be beneficial for increasing vagal tone in healthy young men; however, when sample entropy was examined in older women there was no change (17). Together, these data would suggest that the sole usage of HRV may not be sensitive enough to detect changes in AM.

The present study demonstrated no changes in blood pressure, namely systolic blood pressure, after a RT program, which is contrary to previous reports (6, 8). Collier et al. (10) demonstrated a decrease in brachial systolic and diastolic blood pressure with RT consisting of nine exercises performed for three days a week over a period of four weeks. However, the women were classified as Pre- and Stage-1 hypertensives. Additionally, Carter et al. (6) has shown that eight-weeks of RT effectively lowers arterial blood pressure in younger men and women despite no change in sympathetic activity. One possibility of our controversial findings could be, in part, by non-significant changes in fat mass. It is well known that an intimate link exists between weight, adiposity, and blood pressure responses (25). Our results confirm these findings, wherein a moderate relationship between systolic blood pressure and fat mass was seen before and after (Figure 3A & 3B) RT. This suggests that adiposity could be a significant contributor in blood pressure responses. Given that fat mass was unchanged ($p = 0.23$) and total mass increased ($p = 0.03$), then it seems reasonable to conclude that heavier body composition may be responsible for our contrary blood pressure findings.

The results of the present study should be considered in light of several limitations. First, during participant recruitment, it was difficult to obtain equal numbers of males and females willing to participate in high-intensity RT. This is a concern given that autonomic regulatory mechanisms may differ in men and women at rest (15) or during hemodynamic challenges (10). However, we feel this is acceptable given that all women were tested in the early-follicular phase of the menstrual cycle. Second, we did not control for lifestyle habits (i.e., caloric intake or adequate hydration) only asking that they maintain their normal life patterns. Of note, dietary intake was also not assessed before baseline and post BOD POD assessments, potentially influencing body composition measures. Third, we acknowledge that the effect sizes for our body composition variables were low ($d < 0.2$). Our p-values do not reveal how much of a difference was observed. Thus, the low effect sizes demonstrate the magnitude of change for our body composition variables (i.e., total weight, body fat %, fat mass, and lean mass) are trivial at best. Lastly, although the literature suggests resistance training programs similar to the one utilized in the present study induce skeletal muscle hypertrophy, the two-compartment model of body composition used in the present study does not allow us to definitively state that changes in lean mass were the result of increased muscle volume or fiber hypertrophy (5, 12, 19, 34, 41). We cannot exclude the possible influence of increased muscle water and glycogen storage on the body composition results reported here.

In conclusion, the results of this study demonstrate that RT may improve orthostatic tolerance in a young healthy population. In addition, these data also suggest that eight-weeks of RT was not sufficient to influence blood pressure or AM as measured by RSA, Valsalva ratio, handgrip exercise, or HRV. Future studies are warranted to examine the effects of RT in an orthostatic intolerant population to see if training can offset the symptoms associated with orthostatic stress.

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