THE EFFECTS OF A 4-WEEK RESISTANCE TRAINING INTERVENTION ON CARDIOVASCULAR AND AUTONOMIC FUNCTION IN YOUNG WOMEN

A Thesis

by

SAREAN HARMONI A GAYNOR-METZINGER

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Abstract

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PURPOSE: Cardiovascular disease is growing in prevalence, and the cardiovascular and autonomic protective properties of estrogen in women are no longer keeping up with the lifestyle habits and risk factors increasing this disease risk. While aerobic training has been shown to promote increased cardiovascular health and autonomic function, little is known about the effects of resistance training. METHODS: Nine women were recruited to participate in a 4-week strength-based resistance training intervention following a 4-week wait period. Subjects arrived to the lab for baseline measurements of anthropometrics, body composition, cardiovascular function, and autonomic function. Subjects were asked to attend baseline measurements, familiarization, and maximal effort strength test pre-wait period, post-wait period/pre-intervention, and post-intervention. RESULTS: There was a significant increase in strength gains for squat, bench, and deadlift, pre- to post-intervention (p=0.000, p=0.002, and p=0.000, respectively). There was a significant increase in resting heart rate pre- to post-intervention (p=0.017). A significant decrease was observed in both baroreceptor sensitivity and total peripheral resistance pre- to post-intervention (p=0.018 and p=0.002, respectively). CONCLUSION: Four weeks of a strength-based resistance training intervention promoted strength gains in young women without eliciting deleterious effects in cardiovascular and autonomic function.

Keywords: weight training, lifting, heart, vessel, female, nervous system, strength

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First, I would like to take a moment and thank my wonderful committee for all of the support and guidance. I would also like to thank Appalachian State University Office of Student Research for providing funding for this project.

Dedication

I would like to dedicate this project and all of its efforts to my mom and dad. Thank you for supporting me on this path that differed from our 'norm.'

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Foreword

Chapters from this thesis will be submitted to *Medicine & Science in Sports & Exercise,* the official peer-reviewed journal of the American College of Sports Medicine, published by Lippincott, Williams, and Wilkins publishers. This manuscript has been formatted according to the style guide for that journal.

Chapter 1 – Introduction

The increasing prevalence of cardiovascular disease and other systemic diseases is a growing concern in the United States, and this trend is escalating in women as they age. Women are generally considered to be "cardiovascular protected" due to increased levels of 17β-estradiol (the primary estrogen). Estrogen, a sex hormone, has been shown to increase cardioprotection in premenopausal women by increasing compliance through means of enhanced endothelial function, modulated blood pressures, and better lipid profiles and cholesterol metabolism (1, 2). Estrogen has also been shown to modulate autonomic nervous system function thus preventing pathology-induced sympathovagal imbalance, a known cause for autonomic dysfunction and subsequent cause for cardiac arrhythmias in premenopausal women (3, 4). A tightly modulated cardiovascular system and responsive autonomic system decrease risk for cardiovascular disease; thus, it is pertinent to address the growing prevalence of cardiovascular disease seen in women, believed to be a result of their estrogen levels being adversely impacted by lifestyle factors (5-9). Previous literature has established that aerobic training can decrease risk of cardiovascular disease by improving cardiovascular and autonomic function; however, studies observing the effects following resistance training have been less conclusive and findings varied partially due to wide-ranging training protocols and populations (10-14).

Strength-based resistance training is a type of resistance training that incorporates heavier loads with light-to-moderate volume (sets and repetitions) (15). National Strength and Conditioning Association (NSCA) guidelines for strength-based resistance training include 2 to 6 sets of 6 or fewer repetitions with loads between 80-95% of a 1-repetition maximum using movements that recruit larger muscle groups (e.g., squat, bench press, and deadlift) (15). Strength-based resistance training provides a wide range of benefits including increased strength, which can enhance function in daily activities, and decreased risk of injury (e.g., strains, fractures) through factors such as increased bone mineral density and stronger connective tissue (16, 17). Movements that correspond with these strength guidelines typically necessitate the use of the Valsalva Maneuver in order to successfully perform them due to the heavier loads and larger movement patterns (15). The Valsalva Maneuver is a breathing mechanism that incorporates an increase in intrathoracic pressure through a deep inhalation and brief holding of breath to stabilize and brace against the weight in order to correctly and safely perform the movement (15, 18). Unfortunately, there is little known about the cardiovascular and autonomic adaptations to strength-based resistance training specifically in women (8, 9, 19, 20). American College of Sports Medicine (ACSM) guidelines currently recommend resistance training using similar higher volume and light-to-moderate loads 2 to 3 days per week, which disregards the possible benefits from strength-based training (30). Consequently, previous resistance training research with cardiovascular and autonomic variables has typically employed resistance training protocols utilizing higher volume, lighter loads, and movements that isolated muscle groups (e.g., machines) (11-13, 21). The results from these previous studies demonstrated beneficial results specifically in female populations, while results were less conclusive in male populations (4, 11-13, 17, 20-29).

Previous research investigating other methods of resistance training observed an increase in central arterial stiffness and sympathetic outflow in men (11-13, 20, 23, 24, 28, 29, 31). However, results in women with similar training protocols observed no significant increase in arterial stiffening or change to autonomic function, with no results available on strength-based resistance training in women (11-13, 20, 29, 32). Understanding the cardiovascular and autonomic responses to strength-based resistance training in young women by assessing central arterial stiffness, peripheral blood flow, and innervation of the heart and vessels might provide some insight on the beneficial effects of this training method (8, 33).

Purpose and Hypothesis

Current research supports the health benefits of resistance training at higher volumes with lighter loads in women; however, little is known about the possible benefits of training with a lower volume with heavier loads (30). The adaptations that follow training at lower volumes with heavier loads need further evaluation. This study examined the cardiovascular and autonomic adaptations after 4 weeks of a strength-based resistance training program in young women. We hypothesized that lower volumes and heavier loads would elicit no significant change in arterial stiffness. Our second hypothesis was that this intervention would elicit no significant change to autonomic function. Our third hypothesis was that we would see a decrease in total peripheral resistance, thus indicating an increase peripheral blood flow.

Chapter 2 – Review of Literature

Normal Cardiovascular and Autonomic Function

The cardiovascular system is a combination of a pump (the heart) and an intricate network of elastic vessels (i.e., arteries, capillaries, and veins) that work together to transport oxygen and nutrients to the tissue while simultaneously shuttling metabolic waste (e.g., carbon dioxide) out (33). This network communicates with the cardiovascular control center to regulate blood pressure globally by means of dilatory and constricting mechanisms, and it dilates locally by means of nitric oxide (NO) signaling through endothelial function (8, 33). Essentially, the vessels are able to relax or increase in diameter (vasodilation) to decrease resistance in the event of increased pressures and blood flow, and they are able to contract or decrease in diameter (vasoconstrict) to increase resistance (8, 33). Together, the heart and vessels can modulate blood pressure both during systole (ejection of blood to the system via myocardial contraction) and diastole (filling of the heart chambers during relaxation).

Modulation of cardiovascular function is done via the autonomic nervous system, which is composed of the sympathetic nervous system and parasympathetic nervous system. Sympathetic tone heavily influences the increase in cardiac output needed by means of increased heart rate and myocardial contractile force (stroke volume) during a high-stress situation or during prolonged exercise (33). Parasympathetic tone is responsible for the maintenance of resting heart rate and vasodilation of vessels to tissue and organs for proper perfusion of blood (33). These mechanisms, together with the cardiovascular system, are fundamental for adequate transport of oxygen and nutrients to the working muscle and tissue while shunting blood away from inactive vascular beds during various circumstances (33).

Some of these circumstances include bouts of exercise. For instance, during strength-based resistance training, autonomic function and the cardiovascular system work together to increase cardiac output and transport oxygen and nutrients to the working muscle while maintaining mean arterial pressure throughout the system (33). Specifically, parasympathetic withdrawal along with sympathetic outflow increase heart rate, and through sympathetic outflow, stroke volume increases by increasing the force of myocardial contraction (33). Blood pressure rises to increase perfusion to the working muscle and tissue while being shunted away from inactive tissue (33). This increase in perfusion is explained by both the vasodilatory response in the active vascular beds and by vasoconstriction in the inactive beds (8, 33).

Dysfunction and Maladaptation of Cardiovascular and Autonomic Function

Cardiovascular and autonomic function can, however, be hindered through mechanisms such as stiffening of the vessels, increased sympathetic outflow leading to a subsequent lack of efficient modulation of cardiovascular control, and decreased endothelial function (5, 8). During the aging process or if insult to the vascular walls occurs (e.g., through chronic high blood pressure or atherosclerosis), both endothelial dysfunction and collagenous build-up of the vessels can occur (5). This build-up of collagenous connective tissue and dysfunction of the endothelium is what stiffens arteries, creating a lack of compliance and distensibility (5, 8).

As central and peripheral arteries become stiffer, resistance to blood flow increases throughout the system causing the heart to work harder to receive and forcefully eject blood into the vessels. For instance, increased central arterial stiffness will increase the workload on the heart to fight against the resistance during ejection into the aorta and will cause myocardial hypertrophy and remodeling, which increases the risk for cardiovascular disease (6, 7). Over time, this can cause deleterious effects on cardiovascular function through a negative feedback loop, which in turn also increases risk for cardiovascular disease and all-cause mortality (7).

Autonomic function plays a substantial role in effectively maintaining homeostasis, and if hindered, causes the heart and vessels to work harder to respond to changes in pressure (33). If there is an influx of sympathetic outflow and a subsequent decrease in parasympathetic outflow, autonomic control of the heart and its vascular network is no longer modulating changes in pressure and flow as efficiently causing more effort and time to produce the needed responses. Sustained sympathetic outflow has also been linked with increased risk of cardiovascular disease and all-cause mortality (3).

Influence of Resistance Training on Cardiovascular and Autonomic Function

Previous literature has demonstrated varying cardiovascular and autonomic adaptations to forms of exercise including resistance training and further examination is needed. Adequate cardiovascular and autonomic function is essential in modulating heart and vessel function; therefore, it is important to understand the possible varying effects from exercise modalities such as resistance training. Less is understood about the effects of strength-based resistance training using larger free-weight movements, as hypertrophy-based resistance training using machines or other muscle-isolating movements has been the main focus previously (11, 12, 21).

Training methods from previous studies often implemented hypertrophy-based resistance training protocols, which specifically meant increased repetitions and sets with more muscle-specific movements that required the use of machines or smaller movement patterns (11-13, 20, 24-26, 28, 29). In some studies, hypertrophy-based training demonstrated either no change or an increase in arterial stiffness in men without increases in blood pressure (13, 24). For instance, after a 12-week whole-body resistance training program progressing from high volume to lower volume with an increase in load, Rakobowchuk et al. (24) demonstrated a significant decrease in pulse pressure and a nonsignificant decrease in resting heart rate among a group of young men while there were no significant changes to arterial compliance. Results were contradictory to previous studies that demonstrated a decrease in arterial compliance following resistance training (23).

In another study, Collier et al. (12) compared vascular responses pre- and post-aerobic training to hypertrophy-based resistance training in men. Aerobic exercise has been recommended as the “cardiovascular protective” modality of exercise, and Collier et al. (12) took it a step further to compare these known effects from aerobic training to the unknown responses to hypertrophy-based resistance training. The results showed that after the acute bout of aerobic or resistance exercises, the resistance group and aerobic group had varying adaptations to the modes of exercise. Following resistance training, peripheral blood flow increased due to a decrease in total peripheral resistance and subsequently an increase in calf and forearm vasodilatory capacity. The aerobic group also demonstrated an increase in forearm vasodilatory capacity, however, the highlight of the study was the increase in peripheral blood flow with resistance training. This is a key finding because many studies have seen an increase in pulse wave velocity following resistance training, which is indicative of arterial stiffening; however, the lack of a subsequent increase in blood pressure shows there must be compensatory factors, which was confirmed by the decrease in total peripheral resistance and subsequent maintenance of systemic pressures (5, 13).

In a different study, Collier et al. (11) investigated the autonomic and cardiovascular effects of a 4-week hypertrophy-based resistance training protocol versus an aerobic training protocol in pre-hypertensive men and women. The specific focus was on the effects of elevated blood pressure on heart rate and blood pressure variability as well as baroreflex sensitivity. These mechanisms are known to modulate homeostatic control of blood flow throughout the system, and therefore understanding the adaptations within these systems is important in understanding the possible effects of the respective exercise protocol. The results showed that even though resting blood pressure decreased significantly for both exercise modalities, sympathetic tone increased and parasympathetic tone decreased in the resistance group (11). However, resistance training elicited a decrease in sympathetic tone to the periphery, which would compensate for the decreased parasympathetic modulation of the heart. These findings highlight the complexity of responses from resistance training.

Resistance training and its influences on the cardiovascular and autonomic systems have also been reviewed across several studies to determine any commonalities. Bhati et al. (21) conducted a systematic review of 28 studies from recent years to determine the effects of resistance training on cardiac autonomic function. With this review, results suggested that heart rate variability improved after resistance training. This improvement specifically extended to a greater control of parasympathetic tone (which was measured using root mean square standard deviation and high frequency) and the overall low frequency:high frequency ratio. Several studies within this review observed different results due to sex and age differences, pre-menopause vs. post-menopause in women, clinical health status, training age, and training protocol (21, 23, 27, 28). These results make it pertinent to distinguish the effects of resistance training by focusing specifically on strength-based resistance training and its influence on cardiovascular and autonomic function in the female population.

Training Adaptations with Respect to Women

Women tend to adapt differently to resistance training with respect to cardiovascular and autonomic function. Pulse wave velocity has been shown to have no significant change or an increase after resistance training in men, while women have seen no change or a decrease. For instance, the aforementioned study conducted by Rakobowchuk et al. (24) observed the cardiovascular adaptations of 12 weeks of resistance training on young, healthy, recreationally active men. Conversely, Rossow et al. (20) observed the effects of 8 weeks of resistance training on arterial stiffness and hemodynamics in young and old women. An increase in both systolic and diastolic blood pressures was demonstrated in both groups, while pulse wave velocity differed significantly between groups, and carotid-femoral pulse wave velocity had a nonsignificant decrease in both groups. The main result included the significant increase in peak forearm blood flow and reactive hyperemia for both groups, which was also demonstrated in a study conducted by Teixeira et al. (19) focusing on endothelial and muscular function after 16 weeks of resistance training in post-menopausal women. Following the intervention, the resistance-training group saw a significant increase in forearm blood flow following exercise, while the control group did not, thus indicative of an improvement in endothelial function following resistance training (19, 20, 24).

Collier et al. (13) compared sex differences in pre-hypertensive and hypertensive I males and females. Men showed to a significant increase in pulse wave velocity while women did not, and both men and women saw an increased basal and peak blood flow. It is known that peripheral blood flow works together with central blood flow to maintain adequate mean arterial pressure throughout the system, and seeing an increased peak blood flow in the periphery within these studies shows that resistance training can enhance blood perfusion and endothelial function even if central arteries stiffen (13).

It is pertinent to observe the cardiovascular and autonomic adaptations following strength-based resistance training in women, due to the paucity of evidence from previous literature. If we understand the cardiovascular and autonomic adaptations from this training protocol in women, we can appropriately prescribe more effective exercises to increase overall quality of life (2, 17, 19).

Chapter 3 – Methodology

Subjects

Nine healthy, college-aged females (18-30 years old) were recruited from a mid-sized state university in the southeastern region of the United States and the surrounding community. Inclusion criteria were previous recreational weight training experience (experience with the movements for the intervention) without consistent weight training (3 days or more per week for 4 weeks or more) in > 6 months. Exclusion criteria consisted of a history of cardiovascular, renal, or metabolic disease, or taking any medications that would influence measurements or results (other than contraceptives that allow for cyclic and regular menstrual cycles as measurements were taken during the follicular phase). All subjects read and signed an Informed Consent, which was approved prior to the investigation by the Institutional Review Board for the Protection of Human Subjects, and was provided during recruitment.

Following recruitment, subjects were asked to visit the lab 3 consecutive days for baseline measurements, a familiarization session to assess technique for the exercises that were used in the intervention, and a maximal effort strength test to determine 1-repetition maximal effort attempts (1RM) on the squat, bench press, and deadlift. The results from the maximal effort strength tests were used to create a percentage-based prescription for the resistance intervention.

First Visit

Anthropometrics

Upon arrival, height (cm) and weight (kg) were measured using a stadiometer and a scale, then body mass index (BMI) was calculated by squaring height in meters and dividing it into weight in kilograms (kg/m^2). Body composition was measured using dual-energy x-ray absorptiometry (DEXA) (DEXA Horizon, Hologic Inc., Marlborough, MA, USA) to determine fat mass (FM), fat-free mass (FFM), body fat percentage (%BF), and bone mineral density (BMD). These measurements were used to control for any body composition changes that occurred during the intervention period.

Central Arterial Stiffness

Arterial stiffness was indirectly measured using pulse wave analysis (PWA) and pulse wave velocity (PWV) via an inflatable brachial cuff, applanation tonometry on the left carotid artery, and an inflatable cuff on the left femoral artery (Sphygmocor XCEL, AtCor Medical, Sydney, Australia). PWA and PWV are valid measurements to determine central arterial health (e.g., central arterial stiffness) through estimating aortic blood pressure, determining the amount of augmentation to the initial pulse wave (augmentation index (AIx) and augmentation index corrected to 75 beats per minute (AIx75)), and by measuring the speed at which blood travels from the carotid to the femoral artery (5).

Subjects were asked to rest supine in a dimly lit room for 5 minutes prior to measurement. Using an inflatable cuff on the left arm, brachial blood pressure (BP) was determined after averaging the last 2 measurements of a 3-measurement process providing a 1-minute rest between each measurement. After inputting the final averaged blood pressure measurement into the system, the distance was measured between the hip crease to the top edge of the femoral cuff, the left carotid artery to the suprasternal notch, and the suprasternal notch to the femoral cuff. These values were used to determine the distance between the carotid artery and the femoral artery via an algorithm within the system. Then two measurements of PWV were taken and averaged for statistical analysis. If the measurements differed greater than the standard deviation of ±0.3 m/s, then a third measurement was taken.

Blood Pressure

With the subjects in a supine position, beat-to-beat BP was recorded for a 10-minute epoch via finger plethysmography (NOVA Finometer; FMS, Amsterdam, the Netherlands) and averages of the last three minutes of each epoch were used in the statistical analyses. Validity and reliability of this non-invasive technique has been demonstrated against invasive methods and has been shown to provide accurate measurement of BP changes when compared with intra-arterial BP (13).

Heart Rate Variability

Autonomic function was measured using heart rate variability (HRV) with a Valsalva maneuver to induce a physiological stress such as one undergone with strength training. Subjects followed the Valsalva maneuver protocol standardized by gated autonomic software while continuing measurements of beat-to-beat changes. The protocol consisted of a 1-minute epoch of normal resting breaths followed by an exhalation of roughly 40 mmHg into a mouth piece for 15 seconds. Following, subjects then performed another 3 minutes of normal resting breaths as HRV was measured (9).

Second Visit

Familiarization

Subjects arrived the following day after the first visit to attend a familiarization session. During this time, the subjects were shown a demonstration of the various exercises that were implemented for the intervention. After the demonstration, subjects reenacted the movements and were provided feedback to refine the mechanics of each movement prior to maximal effort strength testing and the intervention. The movements that were performed for this session and utilized for the intervention included the back squat, Romanian deadlift (RDL), weighted lunge, bench press, push press, barbell high-pull (high-pull), deadlift, bent-over row, and glute-hamstring raise (GHR). These movements were chosen based on the experimental design's need for strenuous compound movements to promote recruitment of greater motor units and stability using the Valsalva maneuver to coincide with the strength-based approach.

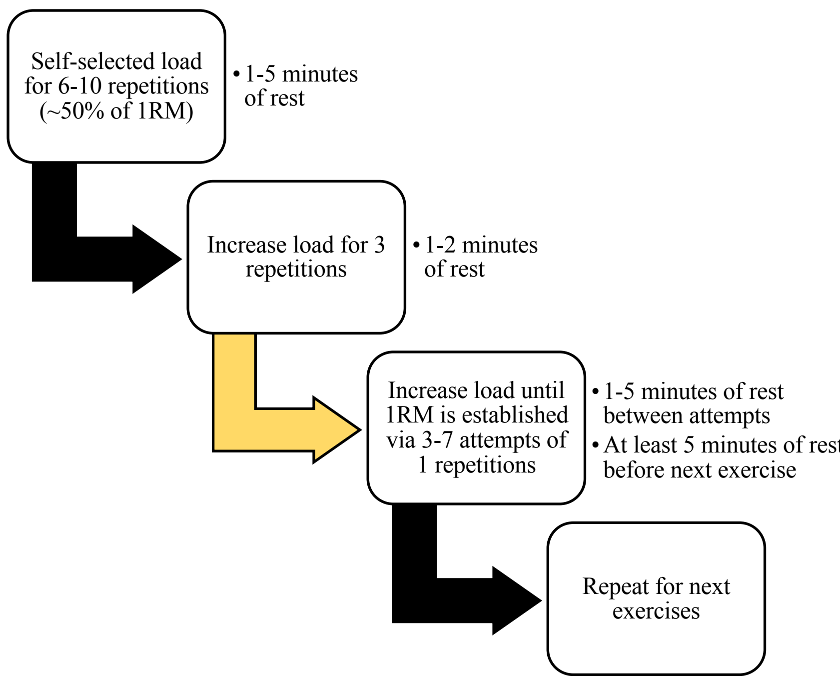
Third Visit

Maximal Effort Strength Testing

The final visit prior to the intervention consisted of a maximal effort strength testing protocol to safely reach a 1-repetition maximal attempt (1RM) on 3 compound movements that were used during the intervention (squat, bench press, deadlift) (see Figure 2) (34).

A 1RM test was terminated if the subject was unable to fully perform the movement from start to finish at the given load. The last load attempted and completed prior to failure was used for the exercise prescription during the intervention. Percentages of the 1RM for each respective lift were used to determine the load for the given exercise, and the auxiliary exercises were also based on percentages of the analogous movements' 1RMs tested during this session. Following the third visit, subjects underwent a 4-week wait period, where they continued daily life activities followed by a physical activity log recording activity levels for that respective week. Subjects returned to the lab for retesting, another familiarization session, and a pre-intervention maximal effort strength test, and then underwent the 4-week strength-based resistance training intervention.

Figure 2. Maximal Effort Strength Test Protocol



Strength-Based Resistance Training Intervention

A 4-week strength-based resistance training intervention was implemented the following week after the last pre-intervention visit. The subjects came in 3 days per week with at least 24 hours of rest between each session, and conducted the respective day's prescribed exercises. Squat, bench press, and deadlift loads were prescribed using percentages of the respective 1RM, while auxiliary exercises were prescribed using percentages of the analogous movement's 1RM determined during the strength test (see Figure 1). The program included a progression of load over the 4-week intervention with minimal increase in volume to account for any neural adaptations made after the first 2 weeks (see Figure 1). The intervention was considered complete after the third day of the fourth week, and post-intervention measurements and a final maximal effort strength test were taken at least 48 hours after the last training session.

Figure 1. Training Intervention Protocol

Week One

Day	Exercise	Set	Reps	Load
Day 1	Back Squat	3	5	75%
	RDLs	3	6	60%
	Weighted Lunges	3	6	30%
Day 2	Bench Press	3	5	75%
	Push Press	3	6	40%
	High Pull	3	6	20%
Day 3	Deadlift	3	5	75%
	Bent-Over Row	3	6	25%
	GHR	3	6	BW

Week Two

Day	Exercise	Set	Reps	Load
Day 4	Back Squat	3	5	78%
	RDLs	3	6	63%
	Weighted Lunges	3	6	33%
Day 5	Bench Press	3	5	78%
	Push Press	3	6	43%
	High Pull	3	6	23%
Day 6	Deadlift	3	5	78%
	Bent-Over Row	3	6	28%
	GHR	3	6	BW

Week Three

Day	Exercise	Set	Reps	Load
Day 7	Back Squat	4	5	80%
	RDLs	4	6	65%
	Weighted Lunges	4	6	35%
Day 8	Bench Press	4	5	80%
	Push Press	4	6	45%
	High Pull	4	6	25%
Day 9	Deadlift	4	5	80%
	Bent-Over Row	4	6	30%
	GHR	4	6	BW

Week Four

Day	Exercise	Set	Reps	Load
Day 10	Back Squat	4	5	83%
	RDLs	4	6	68%
	Weighted Lunges	4	6	38%
Day 11	Bench Press	4	5	83%
	Push Press	4	6	48%
	High Pull	4	6	28%
Day 12	Deadlift	4	5	83%
	Bent-Over Row	4	6	33%
	GHR	4	6	BW

Exercise prescription for each day based on exercise, sets, repetitions (reps), and the load to use as the prescribed weight. Romanian deadlift (RDL) percentage was based on the

1RM of the deadlift. Weighted lunge percentage was based on the 1RM of the squat. Push press percentage was based on the 1RM of the bench press. High pull percentage was based on 1RM of deadlift. Bent-over row percentage was based on 1RM of deadlift. Gluteal hamstring raise (GHR) was based on body weight (BW).

Treatment of the Data

A repeated measure analysis of variance (ANOVA) (time (pre-wait period, post-wait period/pre-intervention, and post-intervention)) was used with SPSS software (version 23; SPSS Inc. Chicago IL, USA) on all dependent variables. If a significant interaction was detected, an appropriate *post hoc* test was conducted. The *a priori* significance was set at $\alpha < 0.05$, and all data are reported as means ± SEM. Eta square values were listed to accommodate for effect size with a sample size of 9.

Sample size for the present study was based on previous data from our laboratory gathered under similar conditions. For these calculations, the STATA statistical software package was used (College Station, TX), and 15 subjects were required to give us adequate statistical power at a $P < 0.05$. With the relatively small sample size, rather large differences may not reach statistical significance and result in type II error with other secondary variables. Therefore, effect sizes (partial η^2, which represents the proportion of total variation attributable to the factor, partialing out other factors from the total nonerror variation) for deconvolution analysis variables are reported as an additional statistical parameter to aid the reader in interpretation of the findings.

Chapter 4 – Results

Anthropometrics and Body Composition

Subject demographics are presented in Table 1. No significant differences were found between pre- and post-intervention anthropometrics or body composition. There was 100% adherence to the training intervention and successful completion of all exercises at their prescribed loads, repetitions, and sets.

Strength Gains

Subject strength gains are presented in Table 1. For squat, bench press, and deadlift strength gains, there was a significant main effect of time ($F[1,8]=57.647$, $p=0.000$, $eta^2=0.878$; $F[1,8]=21.333$, $p=0.002$, $eta^2=0.727$; $F[1,8]=33.333$, $p=0.000$, $eta^2=0.806$). Pairwise comparisons revealed a significant increase in weight lifted during the maximal effort strength test from pre-intervention to post-intervention ($p=0.000$; $p=0.002$; $p=0.000$, respectively).

Cardiovascular Function

Subjects' cardiovascular measurements are presented in Table 2. For heart rate, there was a significant main effect of time ($F[1,8]=9.116$, $p=0.017$, $eta^2=0.533$). Pairwise comparisons revealed resting heart rate significantly increased from pre-intervention to post-intervention ($p=0.017$). For pulse wave velocity, there was not a significant main effect of time pre-intervention to post-intervention. There were also no other significant effects of time for other arterial stiffness measures.

Subject hemodynamics are presented in Table 2. For cardiac output, there was a main effect of time for both pre-Valsalva Maneuver and post-Valsalva Maneuver ($F[1,8]=6.084$, $p=0.039$, $eta^2=0.432$; $F[1,8]=9.143$, $p=0.016$, $eta^2=0.533$, respectively). Pairwise comparisons showed there was a significant increase in cardiac output pre-intervention to post-intervention for both pre-Valsalva Maneuver and post-Valsalva Maneuver ($p=0.039$ and $p=0.016$, respectively). For baroreceptor sensitivity, there was a significant main effect of time ($F[1,7]=9.484$, $p=0.018$, $eta^2=0.575$). Pairwise comparisons showed a significant decrease in baroreceptor sensitivity from pre-intervention to post-intervention ($p=0.017$). For total peripheral resistance, there was a significant main effect of time ($F[1,8]=21.836$, $p=0.002$, $eta^2=0.732$). Pairwise comparisons showed a significant decrease in total peripheral resistance from pre-intervention to post-intervention ($p=0.002$).

Autonomic Function

Subject autonomic data are presented in Table 2. There were no significant main effects of time for autonomic function pre-intervention to post-intervention.

Table 1 Characteristics and Strength

Characteristics	Pre-Intervention	Post-Intervention
Height (cm)	164.1 ± 5.6	163.9 ± 6.1
Weight (kg)	65.7 ± 10.3	66.9 10.7
Body Mass Index (BMI)	24.3 ± 2.8	24.8 ± 2.8
Fat-Free Mass (kg)	45.5 ± 5.4	46.6 ± 5.6
Fat Mass (kg)	20.8 ± 6.2	21.0 ± 6.6
Body Fat (%)	30.9 ± 5.0	30.5 ± 5.6
Bone Mineral Density (g/cm^3)	1.070 ± 0.110	1.075 ± 0.109
Strength	**Pre-Intervention**	**Post-Intervention**
Squat (kg)	62 ± 11	$71 \pm 9^{**}$ p=0.000
Bench (kg)	37 ± 7	$40 \pm 7^{**}$ P=0.002
Deadlift (kg)	76 ± 19	$84 \pm 19^{**}$ P=0.000
Total (kg)	174 ± 32	$196 \pm 31^{**}$ P=0.000

All data are expressed as mean ± SE; Abbreviations: RMSSD – Root mean square differences of successive R-R (heartbeat) intervals; Asterisk (*) denotes significance (P ≤ 0.05) and (**) denotes significance (P≤ 0.01).

Table 2. Cardiovascular and Autonomic Function

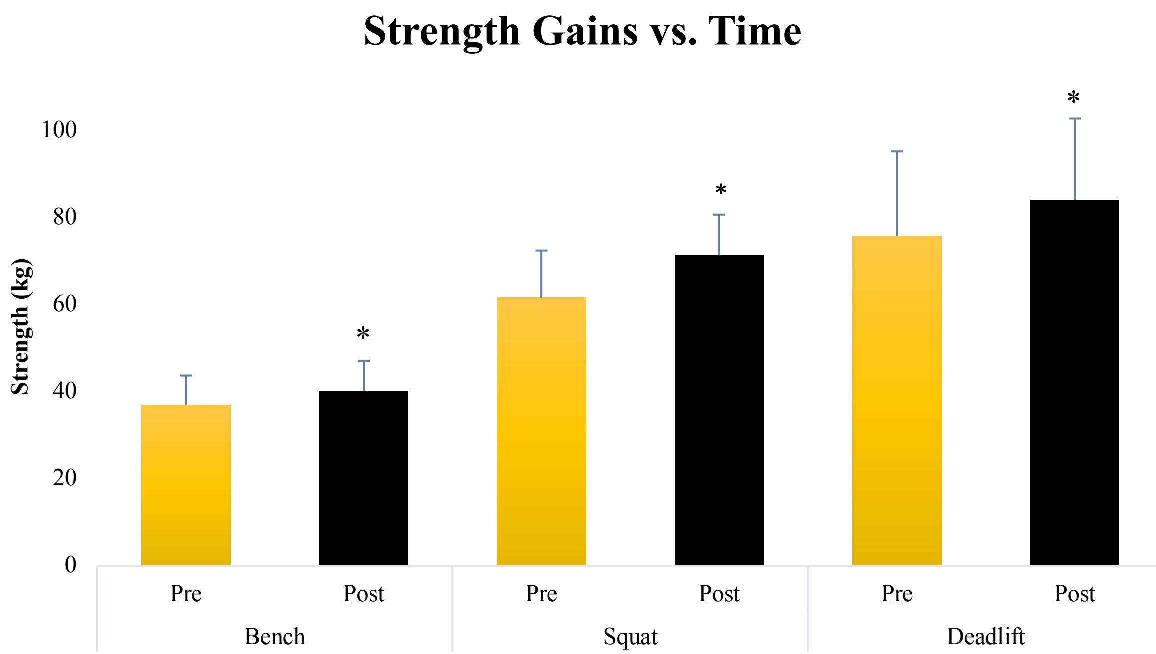
Cardiovascular Function	**Pre-Intervention**	**Post-Intervention**
Systolic Blood Pressure (mmHg)	110 ± 4	111 ± 3
Diastolic Blood Pressure (mmHg)	68 ± 4	68 ± 4
Pulse Pressure (mmHg)	30 ± 3	30 ± 2
Resting Heart Rate (bpm)	62 ± 7	66 ± 10* P=0.017
Brachial SBP (mmHg)	37 ± 7	40 ± 7
Mean Arterial Pressure (mmHg)	80 ± 5	80 ± 6
Pulse Wave Velocity (m/s)	5.12 ± 0.46	5.22 ± 0.65
Baroreceptor Sensitivity	30 ± 7	21 ± 7* P=0.018
Total Peripheral Resistance (mmHg)	1.076 ± 0.281	0.916 ± 0.250** P=0.002

Autonomic Function	Pre-Intervention		Post-Intervention	
	Pre-Valsalva	**Post-Valsalva**	**Pre-Valsalva**	**Post-Valsalva**
Heart Rate (bpm)	62 ± 8	75 ± 9	68 ± 13	72 ± 31
Low Frequency (ms^2)	1745.57 ± 956.89	1580.75 ± 980.27	1209.99 ± 712.57	1616.88 ± 394.39
High Frequency (ms^2)	1454.22 ± 1033.44	341.50 ± 206.56	1354.99 ± 1187.79	346.38 ± 185.91
Low Frequency: High Frequency	2.340 ± 3.114	5.606 ± 3.421	1.461 ± 1.151	5.273 ± 1.607
RMSSD	78.98 ± 33.38	43.00 ± 8.04	64.43 ± 32.22	41.00 ± 12.11

All data are expressed as mean ± SE; Abbreviations: RMSSD – Root mean square differences of successive R-R (heartbeat) intervals; Asterisk (*) denotes significance ($P \leq 0.05$) and (**) denotes significance ($P \leq 0.01$).

Figure 3. Strength Adaptations

A



B

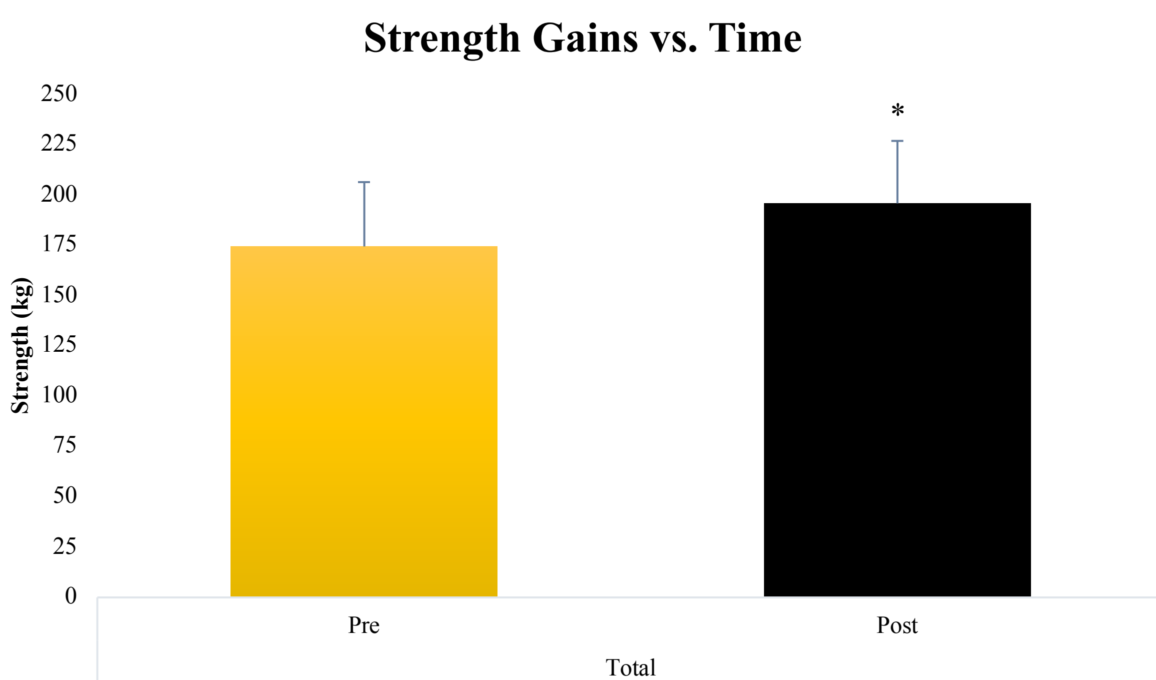
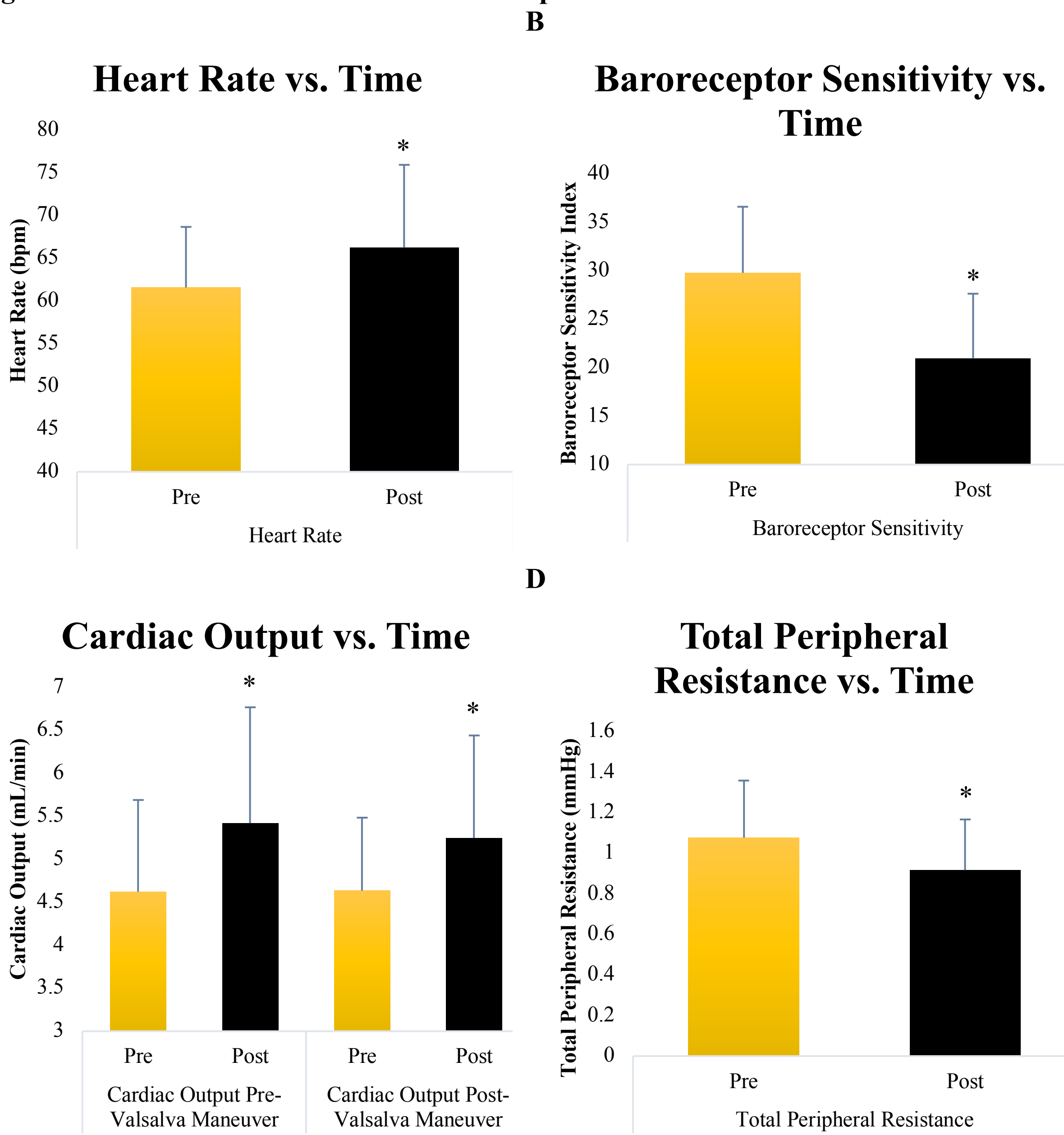


Figure 4. Cardiovascular and Autonomic Adaptations



Chapter 5 – Discussion

Four weeks of strength-based resistance training in young women elicited substantial results for subjects within the study. The main findings following the resistance training intervention were as follows: a) no alteration in arterial stiffness, b) an increase in resting heart rate and subsequent decrease in baroreceptor sensitivity, c) a decrease in peripheral resistance thus maintaining blood pressure in a compensatory manner, and d) no alteration in cardiac vagal or sympathetic outflow. Furthermore, significant strength gains were observed pre- to post-intervention, thus validating the effectiveness of the protocol used in the intervention.

The current investigation found no significant changes to arterial stiffness as shown by results from pulse wave analysis and pulse wave velocity. This reaffirms postulations from previous literature that observed either no significant change to arterial stiffness or a decrease in arterial stiffness following resistance training in women (12, 13, 20). Previous studies that observed maladaptive changes to arterial stiffness following resistance training failed to specifically determine the adaptations possible in women (23).

The exercise protocol made it necessary to utilize the Valsalva maneuver, which increases intrathoracic pressures consequentially increasing acute BP values during each repetition. It is known that the Valsalva maneuver independently increases arterial stiffness in men (18). It is then suggested that an exercise protocol demanding use of this breathing mechanism to stabilize and perform the movements at the respective loads for the prescribed repetitions and sets should have elicited an increase in arterial stiffness following the intervention, but this was not observed in the current investigation. This may be due to the cardioprotective properties observed in women (2, 8, 33, 35). Cardioprotective properties seen in women may blunt the effect of the Valsalva maneuver on vascular stiffness (18).

While we observed an increase in resting heart rate and subsequent decrease in baroreceptor sensitivity post-intervention, we did not observe a significant change to blood pressure. It is known that an increase in resting heart rate and a decrease in baroreceptor sensitivity should elicit an increase in blood pressure within the system. This is due to increased frequency of contractions ejecting blood out of the heart causing for a decreased filling time and a diminished amount of blood flow traveling through the vessels, thus causing for vasoconstricting mechanisms to modulate. If modulation is limited when baroreceptor sensitivity decreases, then pressures should increase. However, this was not observed in the current study, which can be explained by the significant decrease in resistance in the periphery allowing for greater blood flow peripherally. This finding is similar to another study's finding which observed the influence on peripheral blood flow following an 8-week resistance training intervention in young and older women (20). It should be noted that our intervention implemented a different training protocol and measured peripheral resistance as opposed to directly measuring peripheral blood flow; however, outcomes were similar in that peripheral blood flow increased following intervention via the subsequent decrease of peripheral resistance.

Another important finding is that cardiovascular autonomic function was not influenced by the resistance training intervention, since none of the parameters of frequency domain or time domain for heart rate variability were altered following the intervention. The results from this study coincide with some previous studies that did not observe maladaptive influence on autonomic function (36-39). Autonomic function through balance in sympathetic outflow and parasympathetic control is key to modulating cardiovascular function, thus maintaining this balance is important for maintaining a decreased risk of cardiovascular diseases later in life (40). This finding is important as it is the first of its kind in young women with this training protocol. Women are known to have more protective autonomic modulation, which may be a reason for these results (3, 33).

Overall, this study successfully induced strength gains following 4 weeks of a strength-based resistance training intervention using free weight movements that incorporated larger muscle groups. This protocol made it necessary to utilize a Valsalva maneuver to perform the exercises correctly; however, there were no observed degradations in cardiovascular and autonomic function following this 4-week intervention. Peripheral blood flow increased due to a decrease in peripheral resistance to blood flow, which mitigated any changes to blood pressures caused by the increase in resting heart rate and decrease in baroreceptor sensitivity. Thus, this protocol may be beneficial for increasing strength gains and daily function without increasing risk for cardiovascular disease or other related diseases later in life.

Limitations

As with all research, this study is not without limitations. The subjects' training status was based on self-evaluation, which might have provided less accurate depictions, thus two familiarization sessions were implemented (pre-wait period and pre-intervention) to control for lack of experience with exercises. Diet and other lifestyle factors were not accounted for; therefore, we implemented physical activity questionnaires used to track wait period activities, and we encouraged maintaining these lifestyles during intervention. We also did not follow-up with our subjects to determine long-term effects of the intervention, therefore it is imperative to study this topic further and determine whether post-intervention results would be sustained following the conclusion of the intervention and thereafter. The study concluded with a small sample size as well, which prevents generalization of results to the population. The age group of the sample also prevents generalizability to other age groups.

Conclusion

Our data suggest that a 4-week strength-based resistance training intervention does not elicit maladaptation in cardiovascular and autonomic function. Strength-based resistance training promotes strength without degradation of cardiovascular function or autonomic function. While strength-based resistance training influenced an increase in resting heart rate and subsequent decrease in baroreceptor sensitivity, it decreased peripheral resistance which compensated and maintained systemic blood pressures.

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Vita

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