UNIVERSITY OF WISCONSIN-LA CROSSE

Graduate Studies

THE EFFECTS OF A PROPER COOL DOWN ON POTENTIAL DETRIMENTS FROM THE HIGH-INTENSITY RESISTANCE SESSIONS

A Manuscript Style Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Clinical Exercise Physiology

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THE EFFECTS OF A PROPER COOL DOWN ON POTENTIAL DETRIMENTS

FROM THE HIGH-INTENSITY RESISTANCE SESSIONS

By Elizabeth M. Schwab

We recommend acceptance of this thesis in partial fulfillment of the candidate's requirements for the degree of Master of Science in Clinical Exercise Physiology.

The candidate has completed the oral defense of the thesis.

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ABSTRACT

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Purpose: High-intensity resistance exercise (HIRE) is effective to improve muscular function, however its effects on arterial stiffness (pulse wave velocity, PWV) have been controversial. Therefore, the purpose of this study is to examine the effects of common cool down protocols on vascular function following a bout of HIRE. **Methods:** Eight (n=8) recreationally active males completed four different trials following two sessions of familiarization. Participants were measured for body composition, blood pressure (BP) in the brachial and aortic arteries, arterial stiffness parameters, and one-repetition maximum (1RM). After each exercise session, vascular changes were measured for 60 minutes. An analysis of variance with repeated measures was used to determine differences within and between interventions at baseline, immediate post, and in the subsequent timepoints. **Results:** Systolic BP immediately following aerobic training were not significantly different between the cooldown and non-cooldown protocols ($p>0.05$). PWV was significantly lower in the sprint interval compared to the other two ($p<0.05$). **Conclusion:** As expected, HIRE elicited a significant detriment to vascular function. Although BP returned to baseline levels relatively quickly following HIRE, regardless of cooldown, arterial stiffness remained elevated. Sprint intervals following HIRE seems to reduce the PWV responses following HIRE, which may highlight its practical use to attenuate arterial stiffening.

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INTRODUCTION

Cardiovascular disease, metabolic disease, and other risk factors can be controlled with physical activity. Primarily, physical activity in the form of regular aerobic and resistance exercise (RE) can reduce the risk of cardiovascular and all-cause mortality via the reduction of arterial stiffness (Montero, Vinet, and Roberts, 2015). Arterial stiffness, measured as pulse wave velocity (PWV), is characterized by the hardening of the arteries due to structural changes in the arterial wall (Shirwany and Zou, 2010) or functional changes in vasodilatory capacity (Alex et al., 2013; Marti et al., 2012). Habitual AE improves PWV (Okamoto, Masuhara, and Ikuta, 2008), aerobic capacity (Ramirez-Velez et al., 2019), and vascular function (Ashor 2014); however, has little effect on muscular hypertrophy. Although high-intensity RE (HIRE) is the most efficacious mode to induce muscular hypertrophy in all populations (Okamoto, Masuhara, and Ikuta, 2013), whether or not this increases PWV remains debatable. Previous evidence suggests RE may have a wide-range of effects on arterial stiffness, typically depending on the intensity and modality of training (Okamoto, Masuhara, and Ikuta, 2013). Previously, Okamoto, Masuhara, and Ikuta (2008) reported that both low-intensity muscular contractions and moderate-intensity continuous AE following HIRE attenuates these acute increases in arterial stiffness following the exercise sessions. Studies have reported decreases in central arterial pressure, despite increased peripheral arterial pressure during the recovery stage following sprint interval exercise (Rakobowchuk, Stuckey, Millar, Gurr, and MacDonald, 2009). Currently, post exercise outcomes during the cool-down phase has been studied to underpin vascular changes that occur immediately following the exercise session for up to 40 min (Yoon et al., 2010). However, more research is needed to determine the vascular response (e.g., arterial stiffness) using different modalities during the phase of an exercise session in order to prescribe exercises that help prevent any cardiovascular diseases. Identifying exercise modes that attenuate the stiffening of the central arteries is an ongoing goal of practitioners due to the impact of increased pulse pressure and stress on overall cardiovascular health (Burr et al., 2016).

This study aims to determine the potential effects of a cool-down on possible detriments on vascular function from high-intensity resistance sessions. It was hypothesized that between each of the exercise sessions, the combined resistance training with aerobic training would have the most beneficial results on vascular function. It was hypothesized that resistance training session alone, would have negative effects on the vascular function, specifically arterial stiffness. Furthermore, it was hypothesized that the control session (no exercise) would result in no changes from on arterial stiffness during that session.

METHODS

Participants

Eight recreationally active males participated in this study (see Table 1). They were apparently healthy, without any known cardiovascular or metabolic diseases. Recreationally active was defined as participation in outdoor activities, resistance and aerobic training for more than 150 min/week but were not consistently or intensely participating in any specific form of physical exercise (i.e. power lifters, runners, cyclists, etc.). Health history questionnaires were completed for each participant to ensure they were healthy and safe to perform exercises before beginning the study. Participants were recruited for this research study through fliers, word of mouth, social media, and classroom participation from undergraduate classes. All participants were provided with an informed consent and the protocols that were followed throughout the study. Participants were excluded from engaging in the study if they meet the following criteria: musculoskeletal injuries and/or restricting cardiovascular impairments. The research study protocol was approved by the University Institutional Review Board.

Procedures and Protocols

All data collection was completed at the University of Wisconsin – La Crosse's Human Performance Laboratory. Demographical information was taken during the two familiarization sessions: height, weight, maximal oxygen consumption, maximal muscular strength, body composition, and aerobic capacity. Trials were randomly assigned to each participant at the beginning of each session by drawing a number 1-4 that was linked to the different exercise sessions. Each participant completed all four trials within a month timeframe. The trials were as follows: high-intensity resistance exercise with no aerobic component (RE), RE followed by continuous AE at 90% of the participants ventilatory threshold (RE+VT), RE follow by sprint intervals (RE+SI), and a non-exercise control trial (CON).

A study by Okamoto, Masuhara, and Ikuta (2007) found there to be an increase in flow mediated dilation (FMD) when the aerobic training was performed immediately following the resistance training compared to the aerobic exercise being completed before the resistance training, hence the format having HIRE completed prior to continuous AE for each exercise session. Measurements of cardiovascular function were taken during each session at baseline (rest), following the bout of RE (or non-exercise control) and following the prescribed aerobic component (or non-exercise control). Specifically, measurements were taken immediately post-exercise, 10-, 20-, 30-, 45-, and 60- time points (see Figure 2). All measurements were matched for time.

Measurements

Measurements taken for the maximal oxygen consumption ($\dot{V}O_2max$) were done using an electrically braked cycle ergometer (Lode, Excalibur Sport) utilizing a previously established ramp protocol of 25 w/min (Boone, Koppo, Barstow, and Bouckaert, 2009). A calibration on the $\dot{V}O_2max$ machine was performed prior to each test in accordance to the manufacture guidelines. Maximal muscular strength was measured on the leg press, bench press, seated row, leg extension, shoulder press, lateral pull down, leg curl, triceps extension, and bicep curl using the one-repetition maximum (1-RM) as previously described (Verdijk, Van Loon, Meijer, and Savelberg, 2009). Seven of the nine exercises were performed on a cable machine to help prevent improper technique. Leg and bench press were not performed on a cable machine but were spotted with proper form to keep the participants safe. Avoidance of alcohol, caffeine, and high-intensity vigorous exercise was done 24 hrs prior to testing. Participants underwent a six-hr fast prior to baseline vascular measurements, and were given an identical meal (Clif Bar, 260 kcal) at the end of each baseline vascular measurement. Each session of exercise was completed with a minimum of 48-72 hr recovery period to compensate for soreness and/or fatigue.

Body Composition & Anthropometric Measurements

Body weight measurements were collected using a calibrated electrical scale (Rice Lake, Weighing Systems) at the beginning of every visit, and height was measured using a standardized measuring tape that was attached to a flat wall. Body composition was estimated using air displacement plethysmography (BODPOD, COSMED, The Metabolic Company) to analyze fat mass (FM) and fat-free mass (FFM).

Table 1. Descriptive characteristics of participants (*n*=8)	
Variable	
Age (yrs)	21.8 ± 2.37
Weight (kg)	78.0 ± 6.64
Height (m)	1.8 ± 0.04
BMI (kg/m^2)	25.2 ± 1.56
FM (kg)	12.1 ± 5.34
FFM (kg)	65.7 ± 6.21
BFperc (%)	15.4 ± 6.30
$\dot{V}O_2$max (ml/kg/min)	50.4 ± 4.90

Values Represent mean ± SD.
Abbreviations: BMI, body mass index; FM, fat mass; FFM, fat free mass; BFperc, percent body fat; $\dot{V}O_2$max, maximal oxygen consumption.

Cardiovascular Function

Vascular measurements were taken at baseline between 5:00-7:00am and post-exercise for each session to see if there were any changes from the different exercise sessions. The measurements taken were: heart rate (HR), brachial systolic blood pressure (bSBP), brachial diastolic blood pressure (bDBP), aortic systolic blood pressure (aSBP), aortic diastolic blood pressure (aDBP), carotid femoral pulse wave velocity (cfPWV), pulse pressure (PP), and mean arterial pressure (MAP). All measurements were captured using a high-fidelity tonometer (SphygmoCor Xcel, AtCor Medical, Sydney, Australia). In the immediate cool-down phase, all vascular measurements were taken for both the resistance and aerobic components of each session. The timeline for our protocol is appropriately described in Figure 1 and Figure 2.

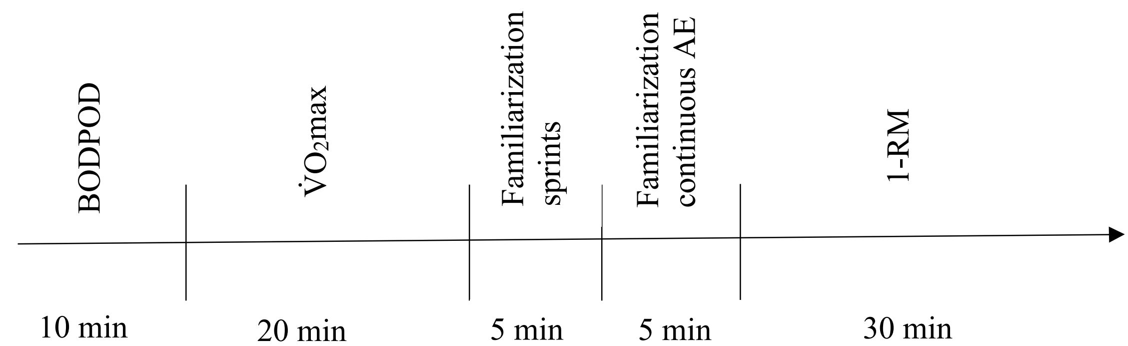

Figure 1. Familiarization Trials

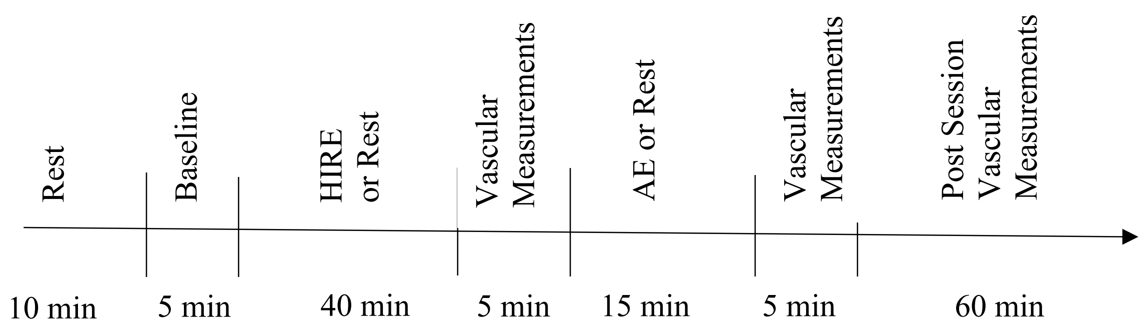

Figure 2. The Four Experimental Trials – Experimental protocol timeline for human experiment

Exercise Sessions

High-Intensity Resistance Exercise

Participants were given 5-10 min of a self-selected low intensity warm up that was kept consistent with each session. The HIRE protocol utilized a relative load of 80% of 1-RM; similar to previous research using HIRE (Okamoto et al., 2013). Briefly, participants completed 3 sets of 6-10 repetitions at 80% of 1-RM for all the exercises in the following order: leg press, bench press, seated row, leg extension, shoulder press, lateral pull down, leg curl, triceps extension, and bicep curl. Immediately following resistance exercise, participants were directed back to the laboratory to complete another set of cardiovascular measurements. Participants' cardiovascular measurements were consistently taken two min and fifteen sec after their last resistance training lift following every session.

Continuous Aerobic Exercise

The continuous AE at 90% VT was completed as a 15 min cool-down session. Participants had an individual set protocol that was 90% of their VT which was identified during the $\dot{V}O_{2max}$ test. Ventilatory threshold was identified as the point where high levels of ventilatory control becomes necessary for the increase in ventilatory frequency to go above VT resulting in the highest ventilatory control (Dehart-Beverly, 2000). Additionally, explaining that if individuals were no longer comfortable to talk while exercising, they have reached past VT. Furthermore, 90% of VT had participants exercising at an average of 13-15 on the RPE6-20 scale (Borg, 1982).

Sprint Interval Exercise

The sprints AE was performed for 15 min at an individualized intensity level based on the percent of body mass (7.5%) that was collected from total body weight during the familiarization sessions. The warm-up for SIE was for 3:20 min set at 100 W. The sprint intervals were completed at maximal exertion for 10 sec at 7.5% of their body mass, and a 1-min active recovery periods, set at 50 W, was allotted between 10 sec sprints. This was done to keep consistency of workload in relation to the moderate continuous aerobic exercise session that was completed. Figure 3 represents a participant performing the session to illustrate typical power production during the sprints.

Control Session

During the control session, participants arrived to the laboratory and baseline cardiovascular measurements taken. Following baseline measurements, participants completed the 5-10 min self-selected warm up at a light intensity and then watched a 45 min educational show, *Our Planet* (Sophie Lanfear, Writer & Director), in a seated position. The 45 min represented the time required to complete the resistance training session. Following the 45 min, another set of measurements was taken, then participants watched another 15 min of the educational show to fulfill the time required to complete the aerobic exercise component performed during the experimental trials. Subsequently, the immediate post cardiovascular measurements along with the 60 min of post session measurements, were collected in the same fashion as experimental trials.

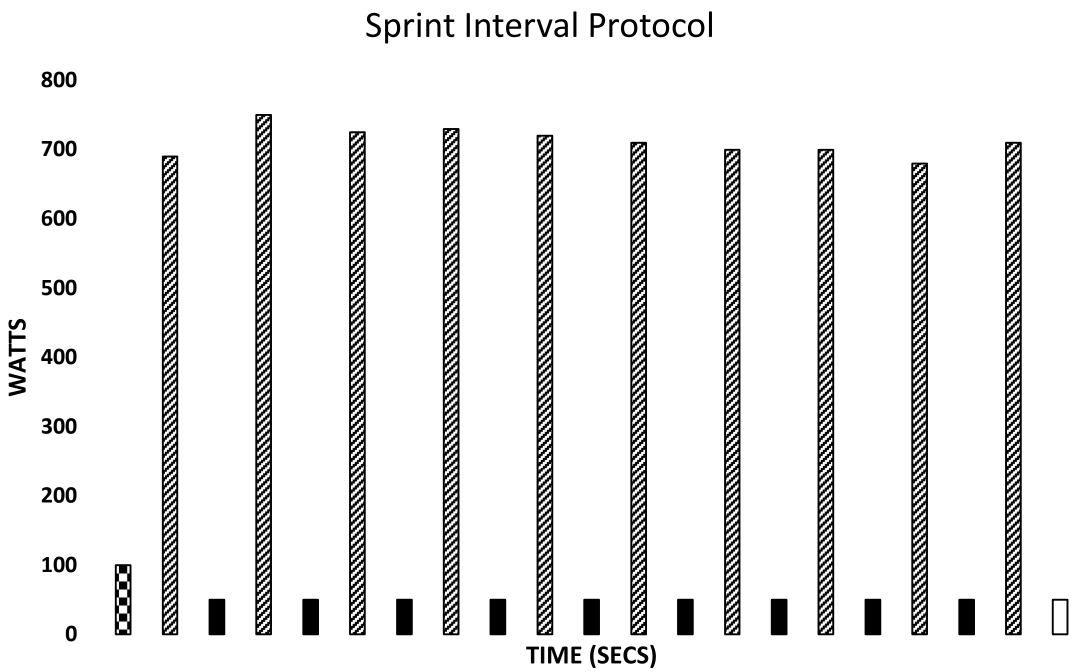

Figure 3. Checkered – 200 sec warm up at 100 W; Slanted Strips – 10 sec sprint interval 7.5% body mass; Solid black – 60 sec recovery stage 50 W; White – 120 sec recovery 50 W cool-down.

STATISTICAL ANALYSIS

Data was analyzed using a two-way (Protocol x Time) repeated measures ANOVA to assess the interaction and main effects of exercise trial and time on cardiovascular responses. An estimation of an appropriate sample size was conducted using previous research investigating the effects of continuous vs interval aerobic exercise on arterial stiffness in adult men (Tordi, 2010). With an effect size of 0.53, 12 subjects would enable us to observe a significant difference (8-9%) between trials with a power of 95%. In the event of a significant F ratio, post hoc analysis for multiple comparisons were performed using a Bonferroni adjustment. Shapiro Wilks normality test assessed the normality and was analyzed for all eight participants and found to be not violated for all demographics. An α-level of 0.05 was utilized to determine statistical significance and data are presented as mean ± significance deviation (SD).

RESULTS

Demographics such as age, weight, height, BMI, $\dot{V}O_{2max}$, indices of body composition, and 1-RM values for all nine resistance exercises, total RE, and AE volume are presented in Table 2. There were no significant differences among the volume of each resistance or aerobic exercises between trials with the exception of designed volume differences between the exercise and control sessions.

Table 2. Values for one-repetition maximum and total volume for resistance and aerobic exercise sessions.

Leg Press (kg)	367.5 ± 91.78
Bench Press (kg)	92.6 ± 14.51
Seated Row (kg)	89.5 ± 17.38
Leg Extension (kg)	104.6 ± 27.30
Lateral Pulldown (kg)	80.9 ± 9.94
Shoulder Press (kg)	66.1 ± 13.26
Leg Curl (kg)	60.3 ± 13.21
Triceps Pulldown (kg)	76.1 ± 9.64
Biceps Curl (kg)	78.1 ± 14.73
Total Volume Load (kg)	7289.6 ± 1217.36
Sprints Workload (KJ)	122.3 ± 4.59
Continuous Cycle Workload (W)	134.4 ± 10.29

Values Represent mean ± SD.
1-RM: 1-repetition maximum.

The hemodynamics of the participants are presented in Table 3. The cardiovascular indices can be viewed in Table 4 and represent the measurements obtained across all time points during the four sessions.

PWV was significantly higher in the three sessions for all time points from baseline to immediate post resistance training (IPRT). PWV was significantly lower in the RE+SI compared to the HIRE and VT groups. PWV was significantly lower during RE+SI until 10 min into the time point measurements where it then increased, whereas RE and RE+VT remained elevated until 30 min following the bout of aerobic exercise and then decreased and went back to the baseline measurements. PWV from baseline to IPRT had a significant increase in the RE, RE+SI, and RE+VT, however, RE+SI was the only session to have a significant reduction from IPRT to immediate post aerobic training (IPAT).

There were no differences in HR at rest between sessions. HR was significantly lower in RE compared to RE+SI and RE+VT in the cool-down measurements. HR had a significant difference in RE and RE+SI, having an increase from baseline to IPRT, IPAT, and the cool-down phase. However, following the baseline measurements, all time points remained higher in the RE+SI session compared to RE and RE+VT.

Resting bSBP, bDBP, aSBP, bDBP, PP, and MAP had no significant difference between all sessions. All exercise trials had a significant increase in bSBP, aSBP, and MAP from baseline to IPRT in response to the RE session. It was found that bSBP immediately following aerobic training was not significantly different between the cool-down and non-cool-down protocols. bSBP was significantly higher during RE+VT cool-down phase compared to RE and RE+SI. However, bSBP was significantly decreased from IPRT to IPAT in both RE and RE+SI sessions compared to RE+VT. A significant decrease was found in aSBP from IPRT to IPAT in RE, RE+SI, and RE+VT. PP was significantly higher in RE+SI from baseline to IPRT compared to RE and RE+VT. However, RE was significantly higher from baseline to IPRT compared to RE+SI and RE+VT. MAP was significantly higher from IPRT to IPAT in both RE and RE+SI compared to RE+VT.

Table 3. Brachial and aortic hemodynamics at rest, following resistance and aerobic exercises, and time course analysis for 60 min following four different exercise sessions.

	CON	*RE*	*RE+SI*	*RE+VT*
PWV				
Baseline	5.0 ± 0.21	5.0 ± 0.16	5.1 ± 0.19	5.1 ± 0.25
IPRT	5.2 ± 0.32[ac]	6.0 ± 0.41[†]	5.8 ± 0.43	6.0 ± 0.70
IPAT	5.1 ± 0.32	5.9 ± 1.07	5.0 ± 0.38	5.9 ± 0.78
10 min	4.9 ± 0.23[ac]	5.8 ± 0.87	5.0 ± 0.44[a]	5.9 ± 0.75[b]
20 min	4.9 ± 0.21	5.5 ± 0.66	5.2 ± 0.92	5.6 ± 0.67
30 min	4.8 ± 0.19	5.1 ± 0.39	5.4 ± 0.83	5.3 ± 0.53
45 min	4.9 ± 0.13[b]	5.0 ± 0.40	5.8 ± 0.94[a]	5.3 ± 0.41
60 min	5.0 ± 0.21	5.0 ± 0.40	5.6 ± 1.31	5.1 ± 0.27
HR				
Baseline	53.1 ± 3.31	49.6 ± 4.60	52.6 ± 2.77	51.5 ± 4.19
IPRT	51.9 ± 6.01[abc]	99.6 ± 11.17[‡]	98.5 ± 6.99[‡]	99.0 ± 6.14[‡]
IPAT	51.0 ± 4.38[abc]	80.1 ± 9.55[†]	103.1 ± 7.95[a‡]	96.5 ± 4.96[a‡]
10 min	50.3 ± 4.68[abc]	70.9 ± 7.16[‡]	94.3 ± 10.32[a†]	80.5 ± 7.09[b‡]
20 min	50.0 ± 3.55[abc]	67.1 ± 4.55[‡]	89.6 ± 9.38[a†]	74.9 ± 7.59[b‡]
30 min	50.0 ± 5.95[abc]	64.6 ± 6.86[†]	83.5 ± 6.97[a‡]	68.3 ± 5.44[b‡]
45 min	49.9 ± 5.96[abc]	60.4 ± 2.72[‡]	74.5 ± 4.44[a‡]	65.1 ± 7.47[b†]
60 min	54.9 ± 9.86[b]	59.8 ± 6.88[†]	75.0 ± 10.82[a*]	63.4 ± 7.27[†]
bSBP				
Baseline	117.7 ± 5.93	121.6 ± 5.69	120.4 ± 3.85	125.2 ± 8.04
IPRT	134.4 ± 5.73[†]	145.9 ± 9.09[†]	145.5 ± 10.84[†]	142.5 ± 8.28[*]
IPAT	124.9 ± 10.75	124.3 ± 3.77	133.4 ± 13.42	138.0 ± 8.25[a]
10 min	117.9 ± 2.53	119.3 ± 6.36	119.5 ± 10.52	123.4 ± 6.30
20 min	118.9 ± 4.52	118.0 ± 4.47	118.3 ± 10.0	124.1 ± 8.20
30 min	117.0 ± 3.74	118.0 ± 4.21	118.1 ± 6.56	120.3 ± 5.90
45 min	121.0 ± 4.96	118.1 ± 6.75	116.8 ± 6.36	121.0 ± 9.93
60 min	121.0 ± 6.55	120.9 ± 8.84	121.0 ± 7.75	121.8 ± 7.52

bDBP				
Baseline	64.5 ± 5.69	68.9 ± 4.49	66.5 ± 4.83	68.0 ± 6.73
IPRT	69.1 ± 5.11	76.1 ± 3.64	71.5 ± 4.28	74.0 ± 8.18
IPAT	68.5 ± 4.34	66.5 ± 5.68	67.6 ± 9.40	73.9 ± 5.51
10 min	63.3 ± 3.45	62.0 ± 6.93	63.9 ± 9.49	67.4 ± 6.67
20 min	62.0 ± 2.14	62.0 ± 5.95	63.5 ± 10.20	68.3 ± 4.59
30 min	64.3 ± 3.99	65.9 ± 5.87	63.3 ± 7.70	64.8 ± 4.53
45 min	64.3 ± 2.05	63.6 ± 4.00	62.9 ± 5.19	67.6 ± 6.44
60 min	67.0 ± 7.82	65.0 ± 5.37	65.4 ± 3.54	66.8 ± 4.92
aSBP				
Baseline	102.2 ± 4.33	106.4 ± 3.22	105.4 ± 4.42	108.8 ± 5.55
IPRT	112.4 ± 5.40[abc†]	127.4 ± 7.23[†]	127.3 ± 9.77[†]	123.4 ± 8.12[*]
IPAT	107.4 ± 8.72	107.8 ± 3.01	111.3 ± 10.38	116.8 ± 6.41
10 min	102.3 ± 3.81	103.0 ± 3.66	104.4 ± 8.60	106.6 ± 5.48
20 min	102.1 ± 4.12	102.0 ± 4.04	103.8 ± 9.13	107.5 ± 8.19
30 min	101.9 ± 4.12	103.3 ± 3.77	103.8 ± 5.70	104.4 ± 6.41
45 min	104.4 ± 4.44	102.5 ± 6.07	102.8 ± 6.61	105.6 ± 9.32
60 min	104.8 ± 7.25	105.6 ± 5.80	105.9 ± 6.42	105.0 ± 7.93
aDBP				
Baseline	65.5 ± 5.48	69.8 ± 4.22	67.8 ± 4.61	69.0 ± 6.44
IPRT	70.5 ± 5.21[a]	79.0 ± 4.14	74.3 ± 3.77[†]	76.3 ± 7.76
IPAT	69.6 ± 4.66	68.0 ± 5.55	70.1 ± 9.76	75.9 ± 6.49
10 min	64.6 ± 3.54	63.9 ± 6.92	67.5 ± 10.73	69.4 ± 7.44
20 min	63.3 ± 1.67	63.0 ± 5.24	67.8 ± 10.99	69.8 ± 5.34
30 min	64.8 ± 4.53	66.8 ± 6.20	67.3 ± 8.31	65.8 ± 4.92
45 min	66.0 ± 2.39	64.8 ± 4.71	65.4 ± 4.60	68.8 ± 6.23
60 min	67.9 ± 7.61	67.0 ± 4.75	69.0 ± 3.63	67.5 ± 4.63
PP				
Baseline	36.7 ± 4.89	36.6 ± 3.62	37.7 ± 4.81	39.8 ± 5.70
IPRT	41.9 ± 6.20	48.4 ± 8.37	53.0 ± 10.52[†]	47.1 ± 7.49
IPAT	37.8 ± 5.75	39.8 ± 7.55	41.1 ± 7.20	40.9 ± 7.85
10 min	37.6 ± 3.02	39.1 ± 7.55	36.9 ± 7.79	37.3 ± 7.59
20 min	38.9 ± 4.00	39.0 ± 5.66	36.0 ± 9.64	37.8 ± 6.78
30 min	37.1 ± 5.49	36.5 ± 4.69	36.5 ± 10.68	38.6 ± 5.34
45 min	38.4 ± 4.14	37.8 ± 5.80	37.4 ± 8.05	36.9 ± 6.88
60 min	36.9 ± 3.76	38.6 ± 5.73	36.9 ± 8.06	37.5 ± 6.44
MAP				
Baseline	78.1 ± 4.42	82.1 ± 3.44	80.8 ± 4.50	82.6 ± 5.34
IPRT	84.4 ± 4.17[abc*]	103.8 ± 5.55[‡]	100.8 ± 5.99[†]	99.4 ± 7.29[†]
IPAT	82.3 ± 6.25[c]	83.6 ± 2.92	88.9 ± 9.31	93.5 ± 4.99[a]

10 min	77.0 ± 2.83	78.5 ± 5.10	82.9 ± 8.98	83.8 ± 5.85
20 min	76.3 ± 1.98	77.5 ± 4.41	82.5 ± 8.96	83.8 ± 6.04
30 min	77.5 ± 3.51	80.1 ± 4.79	81.9 ± 4.73	80.1 ± 5.54
45 min	78.4 ± 2.50	78.4 ± 4.00	79.6 ± 3.93	82.6 ± 7.67
60 min	81.1 ± 7.79	81.1 ± 3.98	82.6 ± 3.11	82.0 ± 5.55

Values Represent mean ± SD

[a]Significantly different than the HIRE trial ($p<0.05$).

[b]Significantly different than the SIE trial ($p<0.05$).

[c]Significantly different than the CAE trial ($p<0.05$).

Significant change from baseline $^{*}p<0.05$; $^{\dagger}p<0.01$; $^{\ddagger}p<0.001$.

Abbreviations: PWV, pulse wave velocity; bSBP, brachial systolic blood pressure; bDBP, brachial diastolic blood pressure; aSBP, aortic systolic blood pressure; aDBP, aortic diastolic blood pressure; PP, pulse pressure; MAP, mean arterial pressure; IPRT, immediate post resistance training; IPAT, immediate post aerobic training; Control, control trial; HIRE; high-intensity resistance exercise alone; Sprints; high-intensity resistance training with sprints on cycle trial; Continuous, high-intensity resistance exercise with moderate continuous cycle trial.

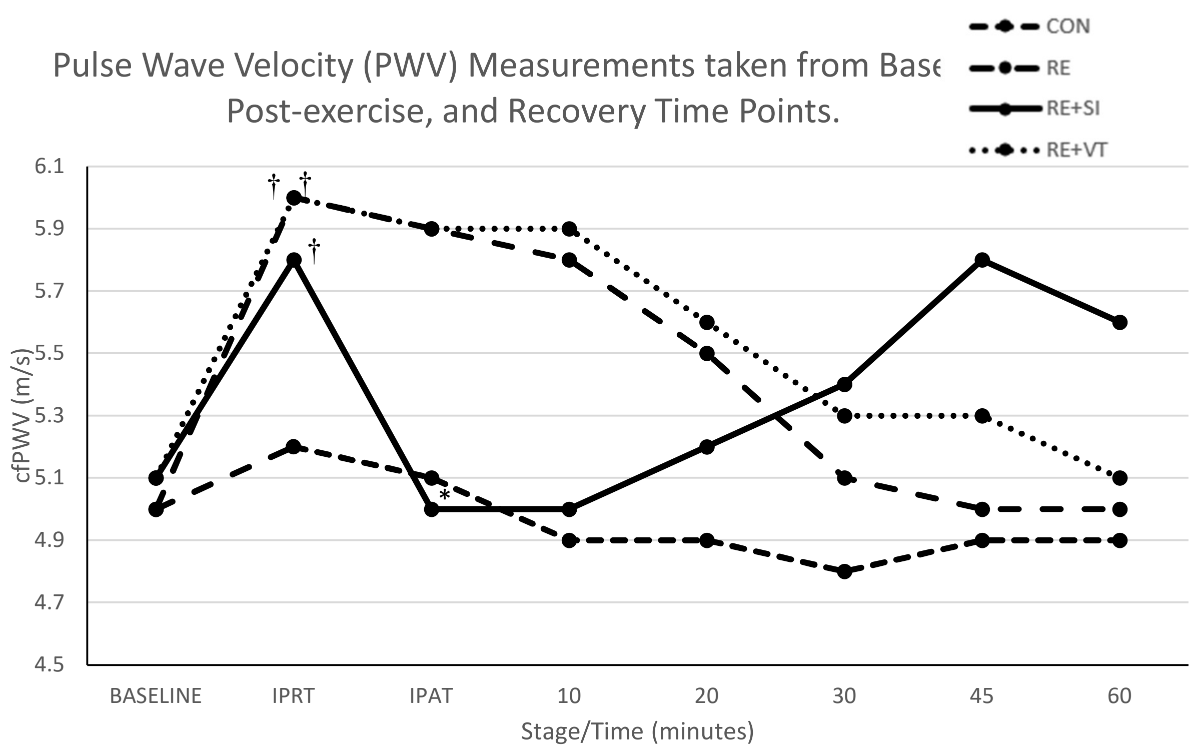

Figure 4. *Significant difference between IPRT and IPAT ($p<0.05$).
†Significant difference between Baseline and IPRT ($p<0.05$).

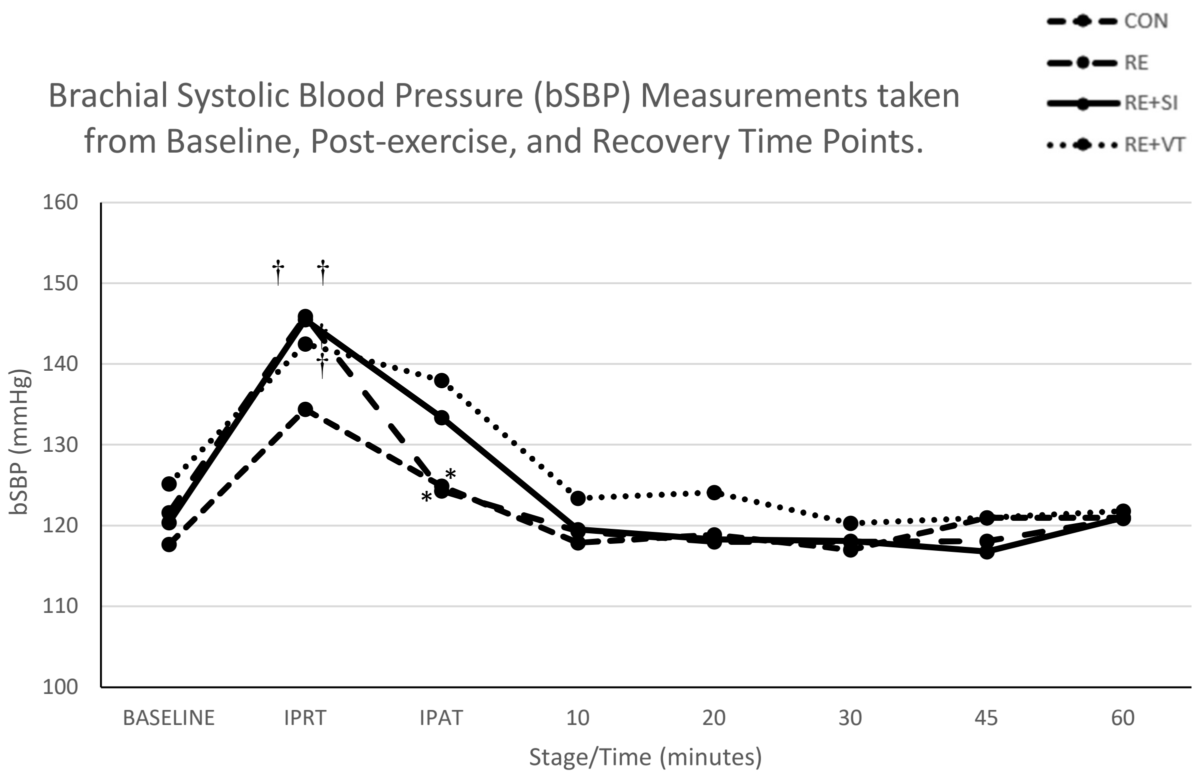

Figure 5. *Significant difference between IPRT and IPAT ($p<0.05$).
†Significant difference between Baseline and IPRT ($p<0.05$).

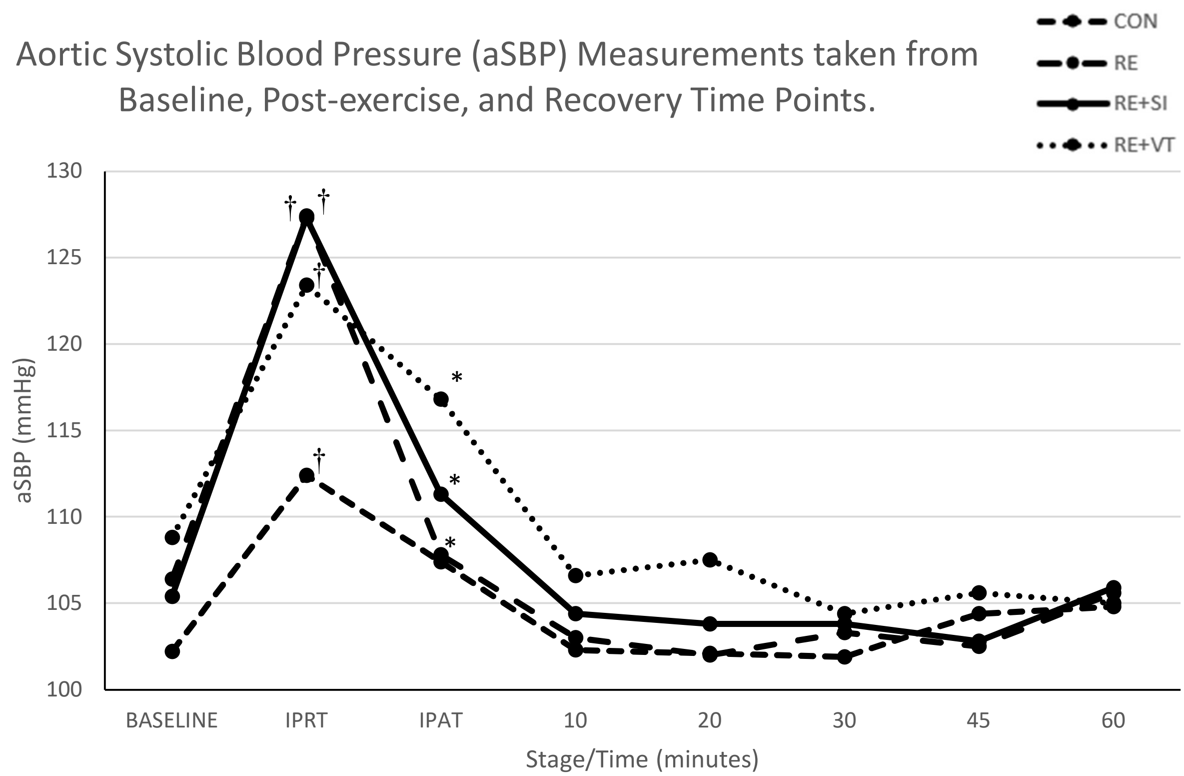

Figure 6. *Significant difference between IPRT and IPAT ($p<0.05$).
†Significant difference between Baseline and IPRT ($p<0.05$).

DISCUSSION

The purpose of this study was to compare vascular function in the recovery period following the three different high intensity resistance exercise sessions combined with an aerobic or no aerobic components. The main finding was that PWV was initially reduced in the RE+SI session and PWV remained elevated in the RE and RE+VT sessions. This could be because of the physiological changes that develop with a high increase in vasodilation that release catecholamines into the system to help the tissues have adequate amounts of blood to the working muscles. Previous evidence found there to be significant changes with high-intensity interval training (HIIT) and moderate continuous training that helped to improved cfPWV and FMD but there was a higher percentage in the HIIT group (Ramirez-Velez et al., 2019). Similarly, our research backs up these findings showing that acutely, the SIE session found a greater decrease in cfPWV than any other sessions. However, a previous study found there to be an increase in cfPWV in women that completed resistance training programs (Cortez-Cooper et al., 2005). This study's findings were in response to a training effect over a period of a few weeks whereas our study was focusing on the acute effects of each combination of exercises.

Another study found SIE to increase central artery PWV immediately after training but returned to resting measurements 20 min into recovery (Rakobowchuk et al., 2009). The same study by Rakobowchuk et al. (2009) found a reduction in PWV in the lower limbs immediately post exercise, however PWV also went back to baseline resting measurements 44 min into recovery. Similarly, our study observed a significant reduction in cfPWV following SIE and remained lower until approximately 10 min post where it then went back to baseline. Our hypothesis as to why this resulted in the SIE but not any of the other sessions was because there was such an increase in metabolic by-product result in vasodilation (e.g., adenosine, decreased pH, increased CO_2, etc.) (Currie, McKelvie, and MacDonald, 2012). From this hypothesis, it would be concluded that the cardiovascular system, specifically referring to vasodilation, may have resulted in a prolonged period of the vessels staying dilated following the exercise and cool-down measurements. Another study found there to be a significant increase in cfPWV 20 min after the resistance exercise group compared to the control group (Yoon et al., 2010). Our study did not have the same initial effects with cfPWV within the RE session, however there were overall elevated cfPWV changes in the recovery phase for the RE session. A meta-analysis of training studies from 8-11 weeks showed HIRT to have an increase in arterial stiffness whereas moderate resistance training had no changes within arterial stiffness (Miyachi, 2013). Having adherence to both aerobic and resistance training can help prevent not only cardiovascular disease, but also other known metabolic diseases and obesity (Okamoto, Masuhara and Ikuta, 2008).

Brachial SBP was increased in all three exercise sessions from the resting values, however the RE and RE+SI sessions had a lower bSBP in the IPAT compared to the IPRT. Other research found an increase in cSBP, cDBP, and PP from baseline to 90 min post both moderate and high intensity aerobic exercises that were performed (Perissiou et al., 2018). When the aerobic component was added into the exercise session, bSBP had an overall increase from the resting values. The results also showed there to be an elevated increase throughout all measurements in bSBP in the RE+VT session rather than the other two exercise sessions. However, based off other studies, it would be presumed that the RE+VT session should have had lower bSBP than the RE session which was not the case. A hypothesis for this was that the rest period for the RE session was too long due to the 15 min of watching *Our Planet* that was in place of the aerobic portion. Since this study was focused on the acute changes, it may have not affected the bSBP as much as it did in the training studies. As shown in Figure 5, the CON session had an increase in bSBP. This may seem odd since CON groups are supposed to show no changes, however since the cardiovascular measurements were taking at a fixed time point and participants had to walk from the gym into the lab, which involved walking up a set of stairs, this activity along with the lack of rest likely raised bSBP. A rise in SBP during exercise, such as walking up a set of stairs, shows that there was a proper hemodynamic response to the increase in physical stress that was not obtained when participants baseline measurements were collected (Sheikhvatan, Nejatian, and Sardari, 2010).

Aortic SBP was higher as a result of both the RE and RE+SI sessions from the initial measurements. Similarly, Devan et al. (2005) reported an increase in carotid artery systolic blood pressure immediately following resistance exercise. This supports the hypothesis that RE would remain higher than the groups that had the aerobic component incorporated in the exercise session. It was no surprise that the most detrimental effects were found in the exercise session of RE where there was no aerobic exercise to follow the resistance training. These findings were consistent with previous data from a meta-analysis that found an increase in arterial stiffness with HIRT and no change in arterial stiffness with moderate intensity resistance training (Miyachi, 2013).

These results demonstrated the effects of combining the proper aerobic training portion with HIRT with overall vascular health. RE+SI had the most vascular benefits found among the other exercise sessions, though after 10 min of recovery the vascular changes went back to normal. These findings suggest that RE followed by 15 min of SI had the most positive effects on overall vascular health within recreationally active males ages 18-30. This study can be addressed towards those who are trying to achieve muscular hypertrophy while potentially improving vascular health.

Further research is needed to evaluate sedentary compared to recreationally active individuals and see the possible vascular changes among the two groups in response to RE. Likewise, more research is needed on the acute vascular response following moderate intensity resistance exercise proceeded with aerobic exercise. Additionally, future research should be conducted on women to see if acute vascular changes in response to RE combined with AE differ from the results found in men within this study.

Some limitations to this study were the participants did not maintain a dietary log. It was known that each participant was fasting for 6 hrs before any of the testing, but to make sure that there was consistency on their diet before each session could have been helpful with a log. A limitation that caused significant changes within this study were the locations of the gym that was utilized and the exercise science lab. The participants did the resistance training portion in a gym that was on the first floor of the building and were required to walk down a hallway, up a flight of stairs, and down another long hallway to reach the entrance of the lab within a small time frame. This potentially resulted in increases in post IPRT measurement. There may have been different results if the two facilities utilized would have been closer together. Lastly, having more participants for the study would have helped improve statistical power and reduce the likelihood of type II error.

The results from this study can be applied to help increase both resistance and aerobic training. It is known that the order of combining these types of exercises has significant effect on vascular health.

CONCLUSION

In conclusion, the results of this study show there to be an important relevance on the impacts of different types and combinations of exercise within the recovery phases. Having a SIE portion incorporated within the exercise session has more benefits immediately post exercise and following 30 min on the cfPWV, bSBP, and aSBP. As studied previously, the HIRE session had the most detrimental effects with cfPWV, remained elevated in post bSBP and aSBP. For the best outcomes for cardiovascular health when completing a HIRE session, incorporating an interval type of aerobic exercise will have favorable acute outcomes for the recovery phase of vascular health, specifically PWV.

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Clif Bar & Company. White chocolate macadamia nut flavor.

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APPENDIX A
INFORMED CONSENT

ATTACHMENT A - APPLICATION FOR UNIVERSITY IRB REVIEW

(All submissions must be typewritten) Date 07/26/2019

1. a. Principal Investigator/Project Director (if thesis or undergraduate research project, student's name):

   Elizabeth Schwab

   b. Applicant Status: (Check all that apply)

   ☐ Faculty
   ☐ Academic Staff
   ☒ Graduate Student
   ☐ Undergraduate Student

   c. Investigator/Project Director Local Address:
   1022 Vine Street La Crosse, WI 54601

   d. Investigator/Project Director Local Telephone # 763-913-9129 E-mail: schwab4939@uwlax.edu

2. a. Title of Proposed Project: The Effects of Proper Cooldown on Potential Detriments from the High-Intensity Resistance Sessions

   b. Project Period: Begin Date: 10/2019 End Date: 05/2020

   c. If a student project of any type, Faculty Advisor's Name, Department, and Phone:

   Name: Salvador Jaime Signature: ______________________

   Department: ESS Phone #: 6518 E-Mail: SJAIME@UWLAX.EDU

   *Names and Signatures of Thesis Committee Members:

______________________	______________________
Name	Signature
______________________	______________________
Name	Signature

3. If the researcher believes his/her project may be reviewed under expedited procedures (p. 6-9) and/or falls within the exemptible category, (p.4-5) please check the appropriate box(es) below

   ☒ Expedited
   ☐ Exemptible

   a. If expedited, please indicate the number(s) of the categories listed on pages (6-9) 4

b. If exemptible, please indicate the number(s) of the categories listed on pages (4-5)

___

___

4. By signing this application, I agree to comply with any decisions made by the University of Wisconsin-La Crosse IRB in regard to the above named research project, and or the standards of professional ethics in my field of study.

____

____

____

_____ _____

Signature

Date

The IRB has reviewed the above research project and has determined that:

1. _____ APPROVAL IS GRANTED -as submitted or as modified per attached (check one)

☐ a. the protocol does not contain procedures which place human subjects at risk, or

☐ b. the protocol contains procedures which place human subjects at minimal but acceptable risk, or

☐ c. the protocol contains or is likely to contain procedures that may place human subjects at greater than minimal risk; however, the risk(s) are outweighed by the sum of the anticipated benefits of the research.

2. _____ APPROVAL NOT GRANTED

The following IRB members participated in this review:

_____ _____ _____

On behalf of the board:

IRB Chairperson or Coordinator Signature Date

Narrative Statement

Project:

1. All subjects will be provided with an informed consent before beginning participation within data collection, procedures, protocols, and after the University of Wisconsin – La Crosse Institutional Review Board for the Protection of Human Subjects grant approval.

   Subjects (recreationally active males) will be reporting cardiovascular measurements taken within six sessions of different types of exercises. The first two sessions will be familiarization sessions as well as performing 1-repetition maximum (1 RM), maximal oxygen consumption test (VO_2max), and a body composition (BODPOD) testing. The 1RM testing will be done by giving the participants a warm up then having them start performing 10 repetitions at 50% of their max, then 5 repetitions at 70%, 3 repetitions at 80%, and then 1 repetitions at 90% of their predicted 1RM. Each high-intensity resistance session training will be run by the same person to keep consistency. The following four sessions will be done in a randomized order (participants will pick from four numbered cards without knowing the exercise they are choosing) and completed post familiarization testing. The sessions are high-intensity resistance training with aerobic training, high-intensity resistance training with sprint-interval training, high-intensity resistance training alone, and a control session. Each session will be separated by three-four days of a rest period. Statistical analysis will then be conducted to analyze the effect of proper cool-down on potential detriments of arterial stiffness from high-intensity resistance sessions.
2. A total of 15 males subjects aged 18-30 will be recruited from the University of Wisconsin – La Crosse and the city of La Crosse. Subjects will be from exercise backgrounds of recreationally active (> 150 min/week). Race and ethnicity are unknown at this point, and not

relevant to the study. The subjects were chosen because they are sedentary and recreationally active, but in good health standings.

3. Not applicable.
4. The familiarization meetings will be held to assimilate their understanding of the order of each session and how they will be administered. Subjects will participate based on their willingness to participate and if they meet the standards of recreationally active lifestyles.
5. All personal information will be kept separate from data collection, and will be done by using numbered codes. No personal information will be used in the scientific literature or results.
6. Possible inconveniences for participants within the study are the time frame that the study will take to complete. Between the time from the familiarization and four other sessions the total time of participation will be approximately 12 hours.
7. The inherent risk of low. Data will be stored by coded numbers and on computers of faculty members and graduate students. None of the information is inherently sensitive.
8. Subjects will gain a better understanding of the effects of different types of exercises on arterial stiffness and the effects that happen within the cool-down phase post exercise session. Knowledge gained from participation will be beneficial to individuals discovering the proper exercises to perform to have the best cardiovascular effects.

<u>Informed Consent</u>

Project: The Effects of Proper Cooldown on Potential Detriments from the High-Intensity Resistance Sessions

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Faculty Advisor: Salvador Jaime
138 Mitchell Hall
University of Wisconsin
– La Crosse
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Purpose and Procedures

- The purpose of this study is to determine the effects of a proper cool-down on potential detriments of arterial stiffness from high-intensity resistance sessions.
- My participation will involve six sessions of different exercise testing, which will all be different forms of exercise.
- The time requirements per session is approximately 160 minutes over one 6 session period with each 72-96 hours of rest between sessions.
- Resistance training will take place in 101 Mitchell Hall, UW-L.
- Cardiovascular, body composition, and aerobic testing will take place in 225 Mitchell Hall, UW-L.
- During the aerobic testing a heart rate monitor will be worn to monitor the level at which I will stay at.
- During the cardiovascular measurements I will have two blood pressure cuffs on, one on the thigh and another on the arm. I will also have a small pen like device set on my neck while testing is taking place.

Potential Risks

- I may experience muscle soreness and fatigue after each session.
- Individuals trained in CPR, Advanced Cardiac Life Support, and First Aid will be in the laboratory, and all testing will be terminated if any complications occur.
- The risk of any serious life-threatening complications for healthy individuals like myself, is near zero.

Rights and Confidentiality

- My participation is voluntary. At any time of the study I am able to withdraw and discontinue without any punishments.
- I can refuse to answer any questions at which I do not feel answering at any time during the study.

- The results of this study may be published within scientific literature with using grouped data only.
- All information will be kept confidential through the use of numbers having no names attached to them or any other personal identification.

Benefits of this Study

- I and the other participants may benefit by understanding the effects that cool down have on the cardiovascular system post exercise sessions.

Questions regarding study may be directed to Elizabeth Schwab (763-913-9129), the principal investigator, or the study advisor Dr. Salvador Jaime, Department of Exercise and Sports Science, UW-L (608-785-6518). Questions regarding the protection of human subjects may be addressed to the UW-La Crosse Institutional Review Board for the Protection of Human Subjects, (608-785-8044 or irb@uwlax.edu).

Participant ____
Date______________

Researcher ____ Date ______________

APPENDIX B
HEALTH HISTORY QUESTIONNAIRE

HEALTH HISTORY QUESTIONNAIRE

Name____________________________ Date___/___/___ Phone (H)

____

Date of Birth ___/___/___ Age_____ Gender_____ Ethnicity ______

(W)____________

Address

(home)____zip____________

UWL faculty/staff____ UWL student____ Community____ Other_____

Primary health care provider and health insurance

____

(*Only for information/emergency contact)*
How did you hear of our services?

____

♦♦

MEDICAL HISTORY

Self-reported: Height ______ Weight ______

Physical injuries:

____

Limitations

____

Have you ever had any of the following cardiovascular problems? Please check all that apply.

Heart attack/Myocardial Infarction	____	Heart surgery	____
Chest pain or pressure	____	Swollen ankles	____
Arrhythmias/Palpitations	____	Heart murmur	____

Valve problems	____	Dizziness	____
Shortness of breath	____	Congestive heart failure	____

Have you ever had any of the following? Please check all that apply.

Hepatitis/HIV	_____	Cancer (specify type)	____
Rheumatic fever	_____	High blood pressure	____
Kidney/liver disease	_____	Obesity	____
Diabetes (specify type)	_____	Asthma	____
Emphysema	_____	Stroke	____
Depression	_____	Thyroid problems	____
Total cholesterol >200 mg/dl	_____	HDL cholesterol <35 mg/dl	____
LDL cholesterol >130 mg/dl	_____	Trigylcerides >150 mg/dl	____

Do immediate blood relatives (biological parents & siblings **only**) have any of the conditions listed above? If yes, list the problem, and family member age at diagnosis.
____
_____

Is your mother living? Y N Age at death ______ Cause ___________________

Is your father living? Y N Age at death ______ Cause ___________________

Do you currently have any condition not listed that may influence test results? Y N

Details____
______

Indicate level of your overall health. Excellent _____ Good _____ Fair _____ Poor _____

Are you taking any medications, vitamins or dietary supplements now? Y N
If yes, what are they?

____

Do you have allergies to any medications? If yes, what are they?

____

Have you been seen by a health care provider in the past year? Y N

If yes, elaborate

____

Have you had a prior treadmill test? Y N If yes, when?_______ What were the results?

____

Have you ever experienced any adverse effects during or after exercise (fainting, vomiting, shock, palpitations, hyperventilation)? Y N If yes, elaborate._____________

____

♦♦

LIFESTYLE FACTORS

Do you now or have you ever used tobacco? Y N If yes: type ___________________ How long? _____________ Quantity ______/day Years since quitting ____________

How often do you drink the following?

Caffeinated coffee, tea, or soda _____oz/day Hard liquor _____oz/wk

Wine _____oz/week Beer ____oz/wk

What do you do for physical activity/exercise now?____________________________

How often do you exercise? ____________ How long per session?________

Estimate your exercise intensity level or exercise heart rate.________________

Indicate your current level of emotional stress. High____ Moderate ____ Low____

♦♦

WOMEN ONLY

Please check the response that most closely describes your menstrual status:

_____ Post-menopausal (surgical or absence of normal menstrual periods for 12 months)

_____ Eumenorrheic – Normal menstrual periods (~every 28 days)

_____ Amenorrheic – Absence of normal menstrual periods for at least 3 months

_____ Oligomenorrheic – Irregular menstrual periods with occasional missed cycles.

APPENDIX C

REVIEW OF LITERATURE

Review of Literature: The Effects of a Proper Cooldown in Potential Detriments from the High-Intensity Resistance Sessions

Elizabeth Schwab

ESS 730: Research Methods for ESS

July 25, 2019

Introduction

Nearly half of adults in the United States have some severity of cardiovascular disease (CVD) (American Heart Association News). It is known that CVD is the leading cause of mortality in the United States. Sedentary lifestyles may augment the rate of development for atherosclerosis, metabolic disease, and elevated blood pressure (BP). Aerobic training and resistance training are examples of exercises that can improve or worsen vascular function, in particular. Individuals that aerobically train, resistance train, or combine both types of exercise together, are trying to improve their overall health. Research has shown there to be negative effects when only performing resistance training in relation to the vascular function (Okamoto, Masuhara, and Ikuta, 2011). Other studies have demonstrated positive effects following aerobic training on vascular function (Alex et al., 2013). Combining both aerobic and resistance training have been studied to see the effects they have on cardiovascular function and improvements finding both positive and negative effects (Montero, Vinet, and Roberts, 2015). The order and correct combination of resistance training with the correct type of aerobic training and the vascular effects that occur post exercise has yet to be elucidated.

Vascular Physiology

Vascular health is crucial in maintaining a well-adapted healthy lifestyle based on exercise and diet. If a healthy lifestyle is not maintained, many detrimental vascular dysfunctions can occur. Increasing arterial stiffness is indicative of vascular dysfunction, which can be a predetermining factor for stroke and many other cardiovascular disease

(Chen, Shen, Liu, and Yang, 2016). When the arteries become stiffer, their elasticity and compliance decrease, which increases pressure making it difficult for the blood to flow through the vessels. Indices of arterial stiffness can be measured via pulse wave velocity (PWV) and pulse wave analysis (PWA) using a high-fidelity tonometer to measure arterial pulsations. Pulse wave velocity (PWV) is the rate at which the pressure in the arteries move down throughout the vessel (Data Science International, 2019). The lower the PWV score an individual receives, the greater compliance that the arteries and vessels have, which results in a more rapid flow for blood to get administered throughout the body. The velocity of the blood flow gives a measurement of the arterial compliance, which allows the distance it takes to get from one location of the body to another to be measured. The slower the velocity of the blood results in an increase in pressure, making the heart's workload increase overall. The PWV measures waveform peaks that are interpreted as pressure waves within the arterial walls. The peak of the wave form shows the peripheral radial and aortic arterial blood pressure (Butlin and Qasem, 2016). Measuring PWA is a noninvasive method to separation of the wave form as it pertains to the ejection of a stroke volume and consequential return of the reflected wave, which can quantify central BP as well as augmentation index (AIx), a measure of systemic stiffness (Figure 1., Wilkinson et al., 2002). Both PWV and PWA are considered gold standard methods to measure arterial stiffness and wave reflection. There are several segments that are of interest for vascular physiologists, however carotid-femoral PWV (cfPWV) has the most evidence and clinical relevance. Pulse pressure (PP), the difference between systolic and diastolic BP (SBP and DBP, respectively), is another independent predictor of cardiovascular mortality and has its focus on arterial stiffness as a key determining risk factor in relation with each other (Wilkinson et al., 2002).

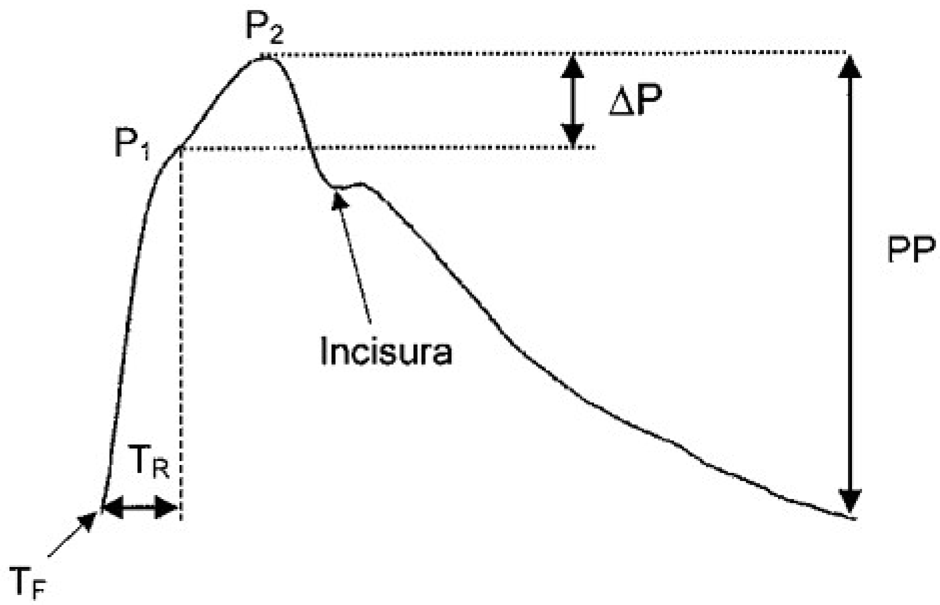

Figure 1. Pulse wave analysis. P1: the first systolic peak; P2: second systolic peak; ΔP: augmented index, PP: pulse pressure, TR: the reflection of time from the bottom of the wave to the first stressed point; TF: the foot of the wave; Ejection Fraction shown from the TF to the Incisura.

Arterial stiffness: history and exercise effects

Arterial stiffness is the hardening of the arterial walls, which significantly reduces its elastic properties (Shirwany & Zou, 2010). This process of arterial stiffness is a normal biological phenomenon as individual's age and is an independent contributing factor to cardiovascular disease. Studies have found that the stiffening of the central arteries are linked to different cardiovascular risk factors because it leads to a greater demand on the heart through the elevation of the pulse pressure and wall stress resulting in possible atherosclerosis and a decrease in coronary artery perfusion (Kass, Saeki, Tunin, & Recchia, 1996; Belz, 1995).

Regular adherence to both aerobic and resistance training are essential to prevent or treat lifestyle-related chronic diseases such as hypertension, obesity, dyslipidemia, and glucose dysregulation (Okamoto, Masuhara, & Ikuta, 2008). These two physical activities have different effects on arterial stiffness depending on if the specific exercises are performed alone, the order they are done when combined in a workout, and the level of intensity. Aerobic training has been shown to have positive cardiovascular results long-term (Miyachi 2013). Aerobic exercise has been shown to reduce arterial stiffness, BP, resting heart rate and sympathetic tone, and increase aerobic capacity and angiogenesis in humans (Ashor et al., 2014). It is known that the sympathetic system, if chronically stimulated, can result in an increase in cardiovascular diseases and many other metabolic diseases. Alex et al. (2013) tested the hypothesis regarding the beneficial effect of aerobic training (70% maximal heart rate) on sympathetic activity at rest to evaluate during the deconditioned state to potentially discover if there would be a reverse effect. The study reported no effect on the low frequency BP variability with aerobic conditioning, though this may have been affected by the limitation of self-selected aerobic modality. While aerobic training has clear benefits, there is little-to-no benefit for muscular hypertrophy, which is particularly important as muscle mass is positively correlated with insulin sensitivity (Ibañez et al., 2005) and negatively associated with arterial stiffness (Cortez-Cooper et al., 2005) and hypertension (Miyachi 2013). Therefore, it makes sense to combine both resistance training and aerobic training to get adequate benefits from both types of training. Previous data supports that participation in high intensity resistance training (HIRT) increases arterial stiffness, and aerobic training decreases arterial stiffness (Okamoto, Masuhara, and Ikuta, 2013). Montero, Vinet, and Roberts (2015) designed a study to determine the effects of combining resistance training and aerobic training to see the impact that the two types of training have on the cardiovascular and musculoskeletal functions. They found a decrease in PWV in the aerobic group, but no changes in the combined training or control groups (Montero et al., 2015). Although the combined training group that included resistance training did not decrease cfPWV, it did not increase it either. Furthermore, resistance training can independently decrease both central and peripheral BP (Montero et al., 2015). More research will need to be done on combined resistance training and aerobic exercise since there are so many beneficial results with body composition and musculoskeletal health overall compared to completing aerobic training alone. Other studies such as Okamoto, Masuhara, and Ikuta (2007) reported a significant increase with flow mediated dilation (FMD), a marker of endothelial function, within a group that performed aerobic training immediately following an acute bout of HIRT, compared to the reduction in FMD when the aerobic training was completed prior to resistance training. The measurements taken in the detraining phase found the brachial-ankle PWV (baPWV) had reversed back to the baseline measurements (Okamoto et al., 2007). This is important to be aware of since the changes reversed back to the subject's baseline measurements after the exercise program was finished. This shows that there was not a negative effect with the arterial compliance as long as aerobic training was performed after resistance training. The aerobic training is the factor within this study that helped lower the baPWV and FMD back to normal after it had been raised from the resistance training portion of the exercise. Aerobic training before resistance training had negative effects on the vascular function showing an increase in baPWV and a decrease in FMD (Okamoto et al., 2007).

High-intensity resistance training (HIIT) is the most efficacious form to induce muscular hypertrophy. Cortez-Cooper et al. (2005) conducted a study to observe the effects of HIIT on cardiovascular function. The vascular function measurements obtained pre-and post-resistance training program were PWV, BP, carotid AIx (Cortez-Cooper et al., 2005). There were findings of an increase within aortic PWV as well as the AIx increased (Cortez-Cooper et al., 2005). The increase with the vascular function shows the negative effects that resistance training had on the body physiologically. Cortez-Cooper et al. (2005) found that continuous moderate-intensity resistance exercise does not reduce central arterial compliance in middle-aged and older adults. Okamoto, Masuhara, and Ikuta (2011) researched the effects of low-intensity resistance training and the effects it had on arterial stiffness. Increase of 1-repetitions maximum (1-RM) was found as well as an increase in baPWV, but only after the training sessions were completed (Okamoto et al., 2011). The level of intensity to perform resistance training has had and been found to have different effects on vascular function. Performing HIRT is beneficial for increasing muscle mass at a faster and higher rate, however enhanced endothelial function does not become improved in HIRT like it does in lower intensities (Okamoto, Masuhara, & Ikuta, 2009). Okamoto et al. (2011) confirmed that HIIT does increase arterial stiffness but lower intensities does not, which supports the hypothesis that lower intensities may be more impactful to help decrease the risk of arterial stiffness while improving muscle quality. Low-intensity was found to have a positive effect in reducing arterial stiffness because of the suppressed sympathetic tone factor (Okamoto et al., 2011). The way of mechanically moving the weights has benefits in relation to arterial stiffness. It was found that there were more benefits while performing eccentric resistance training type exercises in relation to decreasing risk factors for disease and may be an effective type of exercise for middle-aged and older adults (Okamoto et al., 2006). Therefore, there seems to be a clear mechanism for HIRT as it pertains to increases in arterial stiffness. Additionally, post-HIRT modalities that can significantly mitigate these arterial stiffening responses.

Combining both aerobic and resistance training type exercises has been found to have significant changes with vascular health. Aerobic training and resistance training are two types of exercises that can positively affect life-style changes (Okamoto, Masuhara, and Ikuta 2008). Higher blood pressure has been found to decrease the elasticity of the arteries resulting in higher arterial stiffness, which can occur from high-intensity resistance training. The study found a significant increase in FMD, mean blood velocity, and blood flow when comparing the training group performing slow resistance training compared to the sedentary group (Okamoto et al., 2008). Exercise types such as HIRT has been proven to have an increase within arterial stiffness and moderate resistance training had no changes within the arterial compliance (Miyachi, 2013). There was an increase in arterial stiffness due to the type of resistance training that was performed within the multiple different studies collected in this meta-analysis. Within this meta-analysis by Miyachi (2013), five of the studies showed an increase within arterial stiffness in young subjects, and three of the studies had significant findings with middle-aged subjects. From these findings, it could be assumed that HIRT lead to an increase in arterial stiffness, however moderate-intensity resistance training programs within the meta-analysis showed no changes (Miyachi, 2013). From this meta-analysis, it can be concluded that arterial stiffness shows increases with high-intensity interval training in young adults.

Lack of time is often cited as a main obstacle for regular adherence to exercise (Withall, Jago, and Fox, 2011). Sprint interval training (SIT) is a form of exercise that raises heart rate at a high intensity following with a decrease during the lower workload stages for shortened periods of time which can have many benefits of regular moderate-intensity constant aerobic training without the time commitment (Rakobowchuk, Stuckey, Millar, Gurr, and MacDonald, 2009). Acute SIT decreased central artery distensibility and increased peripheral artery distensibility during the recovery phase (Rakobowchuk et al., 2009). Aside from the aforementioned study, little has been done to observe the effects of SIT on arterial stiffness and wave reflection in other populations or following an acute HIRT session. However, HIIT has found an increase in aerobic fitness with no detriment to the cardiac system (Holloway, Roche, and Angell, 2018). High-intensity interval training (HIIT) has been widely accepted by many due to its time-efficient style of exercise rather than other types of aerobic training, as the duration of exercise is lower than moderate-intensity continuous but longer than SIT. Wen et al. (2011) found that fifteen minutes a day of HIIT can reduce the risk of all-cause mortality by 25%, which is equal to 60 minutes of moderate intensity physical activity. Both HIIT and moderate-intensity continuous training are two types of aerobic training with known positive increases in aerobic capacity, however it is imperative to elucidate which is more efficacious for improving vascular function. Ramos et al. (2015) reported improved FMD following HIIT. The HIIT significantly improved endothelial function and therefore improves vascular health function. Ramirez-Velez et al. (2019) found significant changes with both HIIT and moderate continuous training that helped to improve vascular function by improving cfPWV and FMD however these findings of the vascular health were more significant within the HIIT group. Both the moderate-intensity group and the HIIT group increased progression until week 4 and then stayed the same throughout the remaining 12 weeks. Additionally, HIIT elicited greater benefits on vascular parameters, such as endothelial function in physically inactive adults (Ramirez-Velez et al., 2019). Holloway et al. (2018) reported that HIIT elicits no significant detriments with any of the cardiac structural measures. Many specific cardiovascular benefits were discovered by participating in physical activity to help decrease arterial stiffness (Burr, Beck and Durocher, 2016). According to Burr et al. (2016), individuals that participate in high-intensity cross-training (HICT) had significantly better PWV values than sedentary individuals. High-intensity cross-training (HICT) is a form of aerobic exercise, similar to HIIT, with special ordering of the workouts done multiple times without rest in between them and usually performed until failure. The HICT is known to have a constant aerobic stimulus because of the constant movement and training mechanism that are followed by this type of training resulting in being impactful on vascular function. Both the HICT and aerobic training group had positive effects with the training programs that were given to them (Burr et al., 2016). There was a no change in the cfPWV in the HICT. There was no increase with arterial stiffness for the HICT (Burr et al., 2016). Both groups did not show a negative impact on arterial stiffness (Burr et al., 2016). High-intensity cross-training (HICT) may offer higher musculoskeletal and cardiovascular benefits without having the detrimental physiological effects such as arterial stiffness.

There are little data to support acute effects that occur immediately post exercise session as well as during the cool down phase. A study done tested SIT and the effects that occur immediately post as well as 15 minutes post exercise and found that immediate results showed an elevation in systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial pressure (MAP), and PP (Rakobawchuk et al., 2009). However, there were returns of original baseline measurements 15 minutes post the sprint interval session. Future research is needed to see the effects that result in the cool down phase for longer rest periods following exercise sessions.

Conclusion

A wide variety of studies have been done to try and find the correct type(s) of exercise that will decrease the natural physiological increases of arterial stiffness that happen with age. Performing aerobic training after resistance training was shown to have beneficial impacts on arterial stiffness (Okamoto, Masuhara, & Ikuta, 2007). It was discovered that those who participated in HICT had significantly better values within vascular function, specifically pulse wave velocity than those who were sedentary (Burr, Beck, Durocher, 2016). The HIIT reduces the time required to complete an exercise and had beneficial impacts towards the cardiovascular system. Resistance training at a higher level of intensity followed by an aerobic type program seem the most favorable in decreasing arterial stiffness (Montero, Vinet, and Roberts, 2015). These findings show there to be an increase in musculoskeletal strength as well as improvements in vascular function. Studying vascular function pre-and post will help find the proper dose response needed to help decrease negative vascular function that occur post exercise. Further research is needed to discover the underlying combination that will be needed to find the best form of exercise to decrease vascular function in the cooldown phase. Finding the proper intensity of resistance training with the type of aerobic training and the effects it will have on arterial stiffness is not found. Discovering the effects on proper cooldown with the effects of high-intensity resistance training with other aerobic exercises has yet to be determined.

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