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Post Exercise Hypotension Following Concurrent Exercise: Does Order of Exercise Modality Matter?

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ABSTRACT

International Journal of Exercise Science 13(2): 36-48, 2020. Cardiovascular (CV) and resistance training (RT) can moderate negative effects of aging, disease, and inactivity. Post-exercise hypotension (PEH) has been used as a non-pharmacological means to control and reduce BP. Few have evaluated PEH response following a bout of exercise combining CV and RT, whether or not there is an order effect, or if PEH continues when activities of daily living (ADLs) are resumed. Participants ($N = 10$) completed a non-exercise control, a graded exercise test (GXT), and two concurrent sessions (CVRT and RTCV). Each session was followed by a 60-minute laboratory and 3-hour ADLs PEH assessment, respectively. Two-way and Welch-one-way repeated measures ANOVAs were used to determine differences between among conditions in PEH. There was a significant interaction between BP and condition following the 60-minute laboratory measure ($p = .030$, $\eta_P^2 = .166$) and the ADLs BP assessments ($p = .008$, $\eta_P^2 = .993$), respectively. PEH occurred following concurrent exercise conditions at minute 45 for RTCV (118 ± 8, $p = .041$; 95% CI [0.223, 17.443]) and minutes 50 (117 ± 9; $p = .036$ 95% CI [0.441, 21.097]) and 55 (118 ± 8; $p < .001$; 95% CI [5.884, 14.731]) following CVRT. BP was elevated during ADLs following the control session compared to the GXT, RTCV, and CVRT. Regardless of the order, concurrent exercise is effective in potentiating PEH. Elevation in BP associated with ADLs can be mitigated if exercise is performed previously.

KEY WORDS: Exercise prescription, resistance training, cardiovascular health, accelerometry, physical activity

INTRODUCTION

Hypertension (HTN) is a major public health concern associated with both acute and chronic conditions such as myocardial infarction, stroke, and kidney failure (11). While historically perceived as an adult onset condition, young adults attending institutions of higher education are exposed to many psychological stresses that could predispose them to risk for transient HTN (15). Despite vast technological and pharmaceutical breakthroughs in the treatment of HTN, lifestyle modification, such as exercise, remains a lower cost alternative with a lack of negative side effects (21). It is well known that physical activity lowers systolic blood pressure (BP) acutely and chronically. The acute post-exercise response following a bout of exercise or activity is termed post-exercise hypotension (PEH). This clinically relevant phenomenon is generalizable to a variety of populations (normo-, pre-, and hypertensive) and is observed in the first several hours after exercise (3). PEH is evident following cardiovascular (CV) training (4-5), resistance training (RT; 23), and when these modalities are combined in a single session termed concurrent

exercise (13-14). Pairing these modes into a single exercise bout allows the individual to simultaneously train both the CV and musculoskeletal systems. Moreover, this style of training may better reflect the physiological demand experienced by athletes who are required to exert themselves aerobically while generating substantial muscular force.

While numerous reports of PEH following CV or RT exercise are available, few have investigated an order effect of concurrent exercise and PEH (13-14). Evidence of PEH is noted following concurrent exercise ordered CV then RT (14) and RT followed by CV (13-14). Unfortunately, no known studies are available comparing the two versions of concurrent exercise within a given sample or continued the PEH assessment after participants left the laboratory environment. Beyond the acute response, clinical and sport professionals may benefit from knowing the most effective exercise intervention to stimulate PEH both immediately and once the individual continues with activities of daily living (ADLs). Therefore, the purpose of this study was to determine if the order of exercise prescription would affect the immediate BP response in university going individuals following concurrent exercise and to track BP response after the participant left a controlled environment. The authors hypothesized that there would be no differences between the protocols both in the immediate time following exercise (60 minutes) or once participants returned to ADLs.

METHODS

Participants
A sample of convenience consisting of 13 men (*n*= 6) and women (*n*= 7) volunteered for this study. Participants were students and classified as low risk for cardiovascular disease, free from any acute illnesses or orthopedic injuries, non-smokers, and considered physically active according to the guidelines presented by the American College of Sports Medicine (1). Furthermore, participants were excluded from participation if resting BP measurements were greater than 140 / 90 mmHg. The study protocol was approved by the university Institutional Review and participants signed an informed consent. All data collection occurred in the Exercise Physiology and Biomechanics Laboratories at Western Kentucky University.

Upon arrival, participants were briefed on the study protocols and completed the approved informed consent form. Individuals were then assigned to a counterbalanced exercise order as described in Figure 1. Participants exercised at the same time of day as their respective control session. Participants completed a medical history and Physical Activity Readiness Questionnaire (1) prior to commencement of data collection. Height was assessed to the nearest 0.5 cm, facing forward, nose parallel to the ground, without shoes on a Seca 222 full length stadiometer (Hamburg, Germany). Mass was then measured on a Detecto DR400 digital scale (Webb City, MO) to the nearest 0.1kg. Body composition was measured by the same trained technician using a Lange caliper and the seven-site skin fold procedure (1).
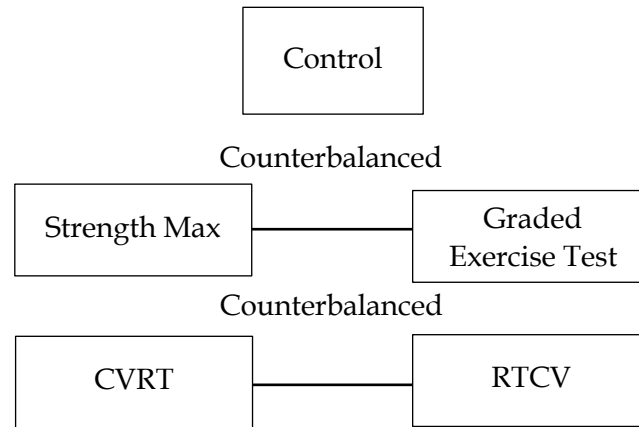
Figure 1. Participants completed the control session on the first day. Then, individuals were assigned to a counter balance where strength and maximal aerobic fitness were assessed to provide information to prescribe exercise for subsequent CVRT and RTCV sessions.

Blood Pressure: To alleviate the potential of affecting BP through human interaction during the PEH assessment period, an ambulatory BP monitor (ABPM) was used to quantify all BP assessments. The SunTech Medical Oscar 2 device (SunTech Medical, Morrisville, NC, US) was validated per the International Protocol for the validation of blood pressure monitoring devices (6). The ABPM cuff was affixed securely to the participant's non-dominant arm, above the antecubital fossa according to manufacturer's guidelines. The ABPM was integrated into a belt which was fastened to his or her waist. The same trained technician fitted each participant. Resting BP was taken and averaged after 10 and 15 minutes of rest prior to each session. All BP assessments were taken while the participant sat upright in a private room with his or her feet flat on the floor and back supported.

Procedures
Participants completed a total of 4 sessions separated by a minimum of 48 hours. A counterbalanced experimental design was used to assess the BP response following maximal CV exercise, two concurrent exercise sessions, and a non-exercise control session (see Figure 1). Session 1 served as a non-exercise control. Participants sat in the laboratory for a total of 60 minutes to collect BP. Following the two exercise conditions and the control condition, participants remained in the Exercise Physiology lab for 60 minutes. During this time, participants sat while BP was assessed every 5 minutes with the ABPM. After the 60-minute laboratory assessment, participants were then asked to return to their free-living activities (class, work, studying, etc.) The ABPM remained on the participant for 3 hours after each session, reading BP once every hour. During the 3-hour period, participants were advised to continue with typical ADLs, omitting structured exercise and the ingestion of vasoconstrictive agents (medications, caffeine, etc.). Step activity was monitored using a validated waist worn Actigraph GT3X accelerometer (17, 22). The accelerometer sampled in 60 second epochs.

Maximal aerobic capacity: Participants performed a maximal graded exercise test (GXT) on a treadmill using the Bruce protocol (10, 20). Data gathered from the GXT reflected maximal intensity exercise for PEH assessment and as a means to prescribe CV exercise during the concurrent sessions. Gas analysis was measured using open circuit spirometry (Hans Rudolph 2700, Shawnee, KS) and a metabolic cart (Parvo Medics, TrueOne 2400, Sandy, UT). Tests were considered a maximal effort test if the participant reached three of the following four criteria: oxygen consumption plateau with a change in stage (VO_{2max}), heart rate within 10 beats per minute (bpm) of age-predicted max, respiratory exchange ratio (RER) $\geq$ 1.1, and/or an OMNI rating of perceived exertion (RPE) $\geq$ 8 (12). Participants received standardized encouragement (i.e., informing participant as to how much time is left in each stage, encouragement to finish the stage, reinforcing the participant's ability to continue).

Maximal strength (6 and 10RM tests): On a separate day, participants completed a 6-repetition maximum (RM) test on back squat and bench press and 10RM for bicep curl, triceps push-down, leg curl, and lat pull-down. These repetition maximum schemes were deemed appropriate for recreationally active individuals and a safer alternative to 1RM testing (6RM for core lifts and 10RM for assistance lifts; 18). These tests followed National Strength and Conditioning Association testing procedures (18) and were selected as a safer alternative to 1RM testing. Data from these assessments were used to predict each participant's 1RM and subsequently prescribe exercise for the RT training session. Strength assessments followed this order: back squat, bench press, leg curl, lat pull-down, bicep curl, and triceps push-down.

For maximal testing, the participant warmed up with a light resistance that easily allowed for 8-10 repetitions for back squat and bench press and 15-20 repetitions for the single joint lifts. Participants were given 2 to 4 minutes of rest before each 1RM attempt. If the participant performed greater than 6 or 10 repetitions on the attempt, the load was increased and another effort was given following a 2 to 4-minute break. If the participant performed $\leq$ 6 or $\leq$ 10 repetitions, the protocol was considered complete and the estimations were concluded. The participants' 6 or 10RM were identified within five attempts to avoid fatigue. The weight lifting OMNI RPE scale was used after each lift to evaluate the individual's perceived level of exertion during the testing session.

Concurrent exercise sessions: Participants completed a concurrent exercise session with CV exercise prior to RT (CVRT) and the inverse (RTCV) to compare the potentiation of PEH. The concurrent sessions were designed to allow the participant to complete all exercise activities within a 60-minute period to reflect other PEH investigations (14). The submaximal CV exercise protocol consisted of running for 20 minutes at 65% of the individual's VO_{2max}. This time included a 5-minute warm up and 5-minute active cool down as prescribed by ACSM. Exercise intensity was monitored by oxygen consumption response via open circuit spirometry. Resistance exercise consisted of 2 sets of 6-8 repetitions on back squat, bench press, leg curl, lat pull-down, bicep curl then triceps push-down (in that order) at 80% of the participant's calculated 1RM. This session was repeated, in the inverse order, to evaluate the presence of PEH following RTCV. There was a 3-5-minute rest interval allowed between the RT and CV portions of each concurrent session.

Statistical analyses

An a priori power analysis indicated a needed sample of 10 to attain 80% power in the statistical tests assuming a small effect of 0.2 and a statistical alpha of .05 (G*Power, Version 3.1). A two-way repeated measure analysis of variance (RM ANOVA) was conducted to determine the within subjects BP effect of the condition across time during the 60-minute and 3-hour post-session periods. A similar analysis was used to evaluate the participants' step activity during the 3-hour period after leaving the lab. When appropriate, post hoc one-way Welch RM ANOVAs were conducted to determine if PEH occurred following each session. Hypotension was defined as a significantly reduced systolic BP compared to control BP, respectively (21). When needed, post hoc analyses were conducted using one-way ANOVAs, corrected with the Sidak factor to protect the familywise alpha of $p < .05$. Data were analyzed using IBM Statistics for Windows, Version 23.0 (Aramonk, NY: IBM Corp). Data are presented as means and standard deviations and measures of effect were calculated by SPSS and reported as η_p^2.

RESULTS

All participants who agreed to participate in the study completed the testing sessions, however, three participants were excluded from the analyses because of equipment malfunction leading to the loss of at least one data point throughout the assessment period. As such, the analyses included 10 individuals. Participant demographics are presented in Table 1. PEH data were normally distributed with the exception of two time points; CON minute 35 (p = .047) and CVWT minute 40 (p = .004). Noting the normality of the rest of the data, the analysis continued as planned.

There were no differences in the resting systolic BP assessed prior to each session [$F(1,36)$ = 1.16, H-F p = .34]. There was an interaction between BP and condition. Follow up analyses found no differences among conditions. However, post hoc comparisons indicated hypotension at minute 45 following RTCV (118 $\pm$ 8 mmHg, p = .041; 95% CI [0.223, 17.443]) and minutes 50 and 55 following CVRT, respectively (117 $\pm$ 9 mmHg; p = .036 95% CI [0.441, 21.097]) and 55 (118 $\pm$ 8 mmHg; p < .001; 95% CI [5.884, 14.731]). No PEH was noted subsequent the control or GXT sessions. Mean BP values for each condition across the 60 minutes are presented in Figure 2. Statistical values are presented in Table 2.

Table 1. Sample descriptive statistics (N = 10)

	Frequency	Mean	SD
Sex	Men = 5		
	Women = 5		
Age (years)		21.5	1.3
Height (cms)		170.9	9.1
Mass (kgs)		70.8	14.3
Body Fat (%)		18.6	8.7
Systolic blood pressure (mmHg)		124	9
Diastolic blood pressure (mmHg)		75	10

Note. cms = centimeters; kgs = kilograms; % = percent; mmHg = millimeters of mercury. Blood pressures are the average of the resting 10- and 15-minute assessments before the control session.

Figure 2 depicts the average systolic BP for each session at baseline and each hour for 3 hours. The two-way RM ANOVA identified a significant interaction between BP and condition in the hours after returning to ADLs. Pairwise comparisons did not indicate differences among conditions, however, a difference was noted between baseline BP and the first hour after the participants returned to free-living activities. Simple effect analyses indicated that the BP 1 hour after the individuals returned to ADLs was significantly higher after the control session compared to the baseline BP average and the other conditions. There were no differences in step activity between conditions, $F(2.0, 14.0) = 0.034$, H-F $p = .96$. See Figure 3 for a graphical representation of percent change in systolic BP and Figure 4 for the respective step activity. See Table 3 for session averages and standard deviations for the study's independent variables.

Table 2. Results from statistical analyses.

	Statistical Test	Variables	Statistical Value	Significance	Effect size
60 Mins	2wRM-ANOVA	BP x Condition Interaction	$F(30.00, 240.00) = 1.20$	.030*	.166
		BP across Time	$F(10.00, 63.21) = 2.36$	.028*	.228
		Condition across Time	$F(2.16, 17.28) = 2.91$	.078	.267
	Welch ANOVAs	Control	$F(9.38, 75.11) = 0.58$	.813	.068
	BP according to condition	GXT	$F(10.00, 90.00) = 1.41$	.187	.136
		RTCV	$F(10.00, 90.00) = 1.96$	.047*	.179
		CVRT	$F(10.00, 90.00) = 2.81$	.005*	.238
3 Hours	2wRM-ANOVA	BP x Condition Interaction	$F(7.64, 68.78) = 2.90$	.008*	.993
		BP across Time	$F(3.00, 24.66) = 6.86$	.002*	.767
		Condition across Time	$F(3.00, 27.00) = 0.69$	.564	.272
	Welch ANOVAs	Control	$F(2.61, 23.50) = 7.18$	.002*	.444
	BP according to condition	GXT	$F(2.51, 22.57) = 3.95$	.026*	.305
		RTCV	$F(3.00, 27.00) = 2.74$	.063	.233
		CVRT	$F(3.00, 27.00) = 1.26$	.306	.123

Note: Statistical test = Two-way repeated measures ANOVA and Welch one-way ANOVA. F values for ANOVAs were based on Huynh-Feldt tests and effect sizes represent η_p^2 values. * represents statistical significance at $p < .05$. BP = systolic BP.
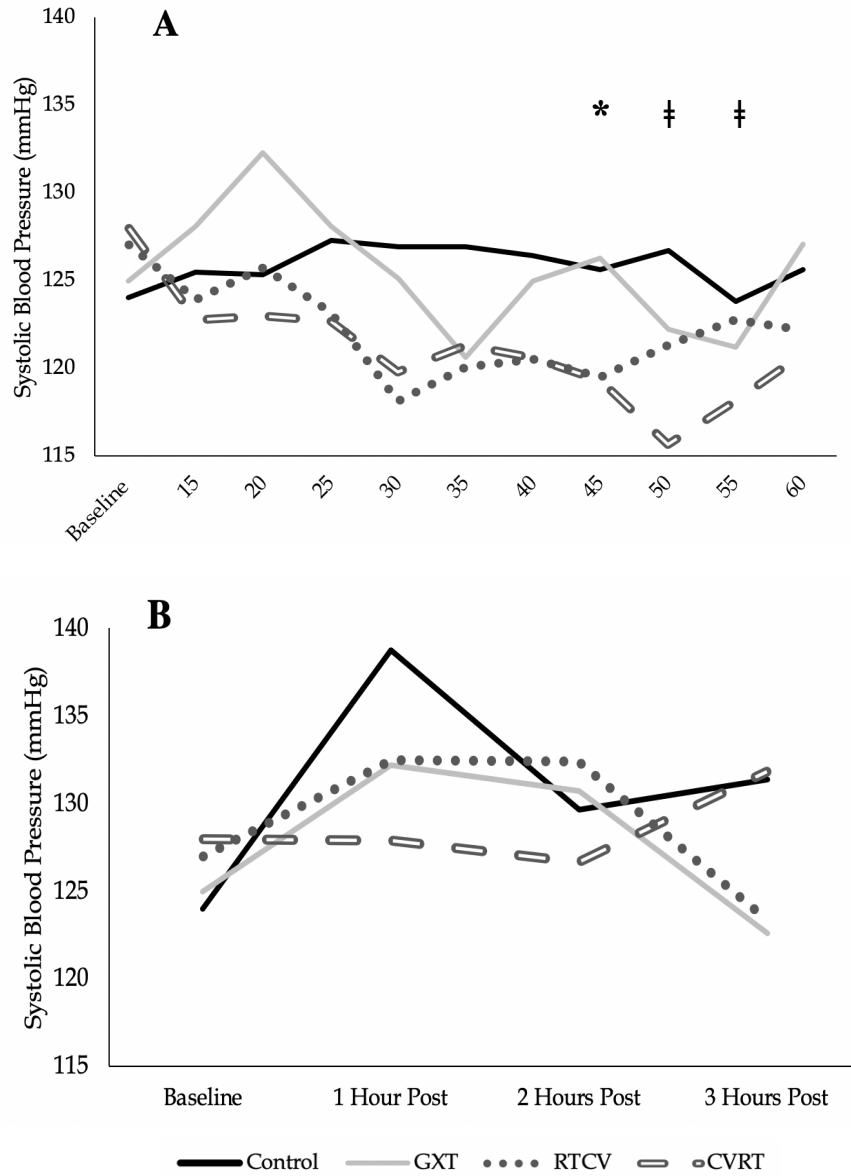
Figure 2. Sample means for systolic BP following the control and experimental conditions. Baseline = average systolic BP of all sessions. * = significant PEH following RTCV. ǂ = significant PEH following CVRT. A: No PEH was noted after GXT or control sessions. B: No PEH noted after returning to ADLs.
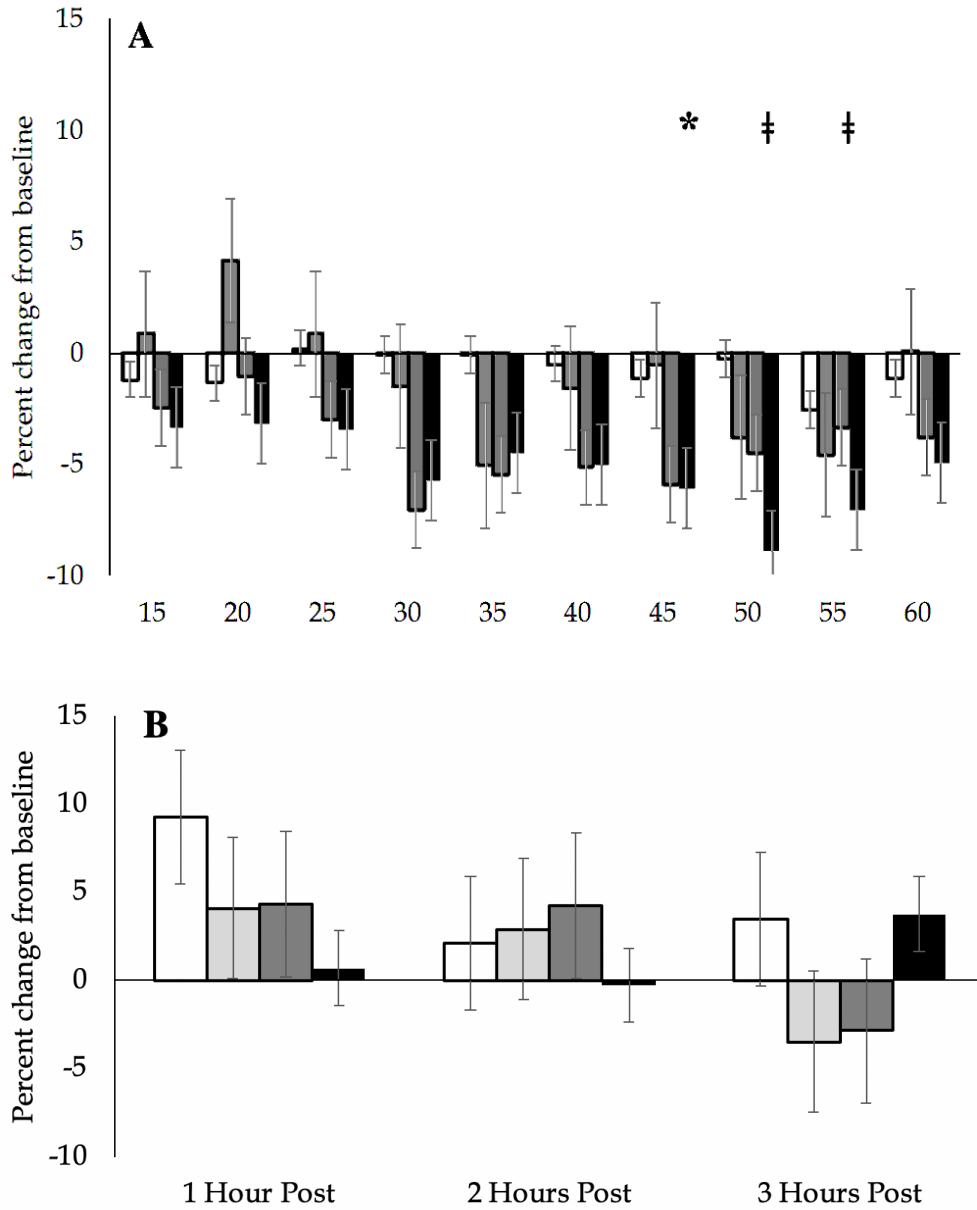
Figure 3. Graphical representation of percent change in BP from baseline to each time interval, respectively. Baseline was the average resting systolic BP from all conditions. * = significant PEH following RTCV. ǂ = significant PEH following CVRT. A: Time is measured in minutes post activity. No PEH was noted after GXT or control sessions. B: No PEH noted after returning to ADLs.
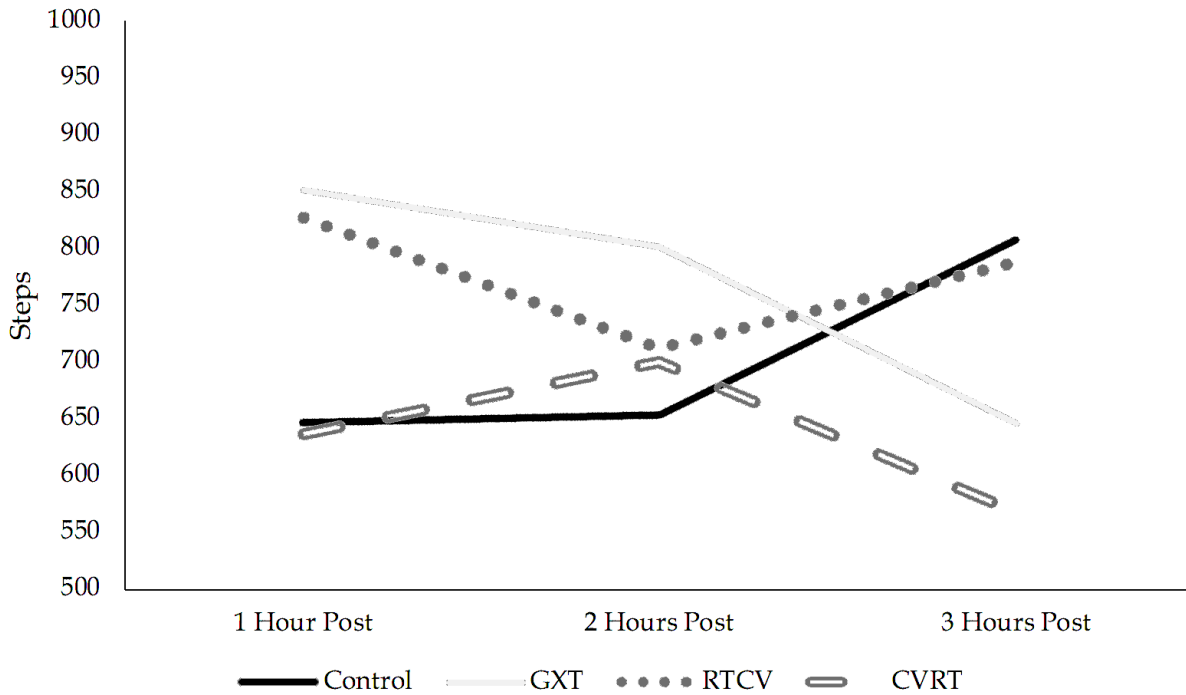
Figure 4. Hourly step activity between conditions. No statistical differences were found.

Table 3. Means and standard deviations of independent variables

	Mean	SD
Post Session 60min BP		
CON	125	11
GXT	127	13
RTCV	123	10
CVRT	122	10
Post Session BP 3hrs ADLs		
CON	133	13
GXT	129	12
RTCV	129	10
CVRT	129	11
Post Session Steps 3hrs ADLs		
CON	703	620
GXT	770	730
RTCV	776	596
CVRT	635	642

DISCUSSION

The aim of the present study was to investigate PEH following concurrent exercise (60 minutes and 3 hours) when the order of exercise modality varied (CV then RT and RT then CV). The main findings show that both concurrent exercise sessions were potent enough to stimulate PEH in normotensive, healthy university attending adults. While there was no difference between

conditions in the RM ANOVA, PEH was only noted at minute 45 following RTCV and at minutes 50 and 55 following CVRT. Failure to identify PEH during the control session solidifies that the attenuated BP observed after concurrent exercise was not resultant from diurnal variations. Finally, BP remained low for the first hour following the exercise sessions, despite returning to ADLs. The picture of PEH after one hour of ADLs is less clear. Future investigations might consider noting the exact ADLs participants return to rather than relying on step activity to appraise activity level. PEH might be dictated more by the environment the individual returns to rather than the quantity of activity.

Potential mechanisms for PEH: A meta-analysis presented several potential mechanisms for PEH following CV exercise, such as, decreased peripheral resistance and cardiac output (related to age, body mass index, and BP status, not sex or training history; 3). As such, a mixed-gender sample with similar anthropometrics and BP status were recruited. Although speculative and beyond the scope of this article, it is presumable that the PEH following concurrent exercise resulted from decreased vascular resistance, attenuated cardiac output, histamine receptor activation, prolonged muscle afferent activation, the "resetting of baroreflexes", and/or the release of vasogenic agents such as nitric oxide or prostaglandins (2-3, 9). It is likely that the PEH observed in the current sample originated from activation of histamine H_1 and H_2 receptors from mast cell degranulation and reductions in peripheral resistance more so than cardiac output or nitric oxide release (9). Brito et al. (2014) identified that decreases in cardiac output are most often seen in older, hypertensive, and overweight adults (3). Despite records demonstrating elevated nitric oxide concentrations in the blood for at least 2 hours post-GXT (12), no PEH was observed in the current sample. Based on the current state of the literature, nitric oxide is not considered a major contributor to PEH (8). This purported drop in peripheral resistance via sustained postexercise vasodilation may be the reason BP was reduced during the 60-minute period following concurrent exercise and remained low in the hour following the exercise sessions. This systemic drop in vascular resistance may have not been adequately stimulated from the GXT due to its short duration. Further, mechanistic investigations are warranted.

Comparison of PEH following concurrent exercise: Although limited for direct comparisons, investigations evaluating PEH following concurrent exercise support the data currently presented. Teixeira (2011) noted a decrease in cardiac output and stroke volume paired with a slight increase in vascular resistance following concurrent exercise. Normotensive adults completed 30 minutes of cycling at 75% VO_{2peak} followed by 3 sets of 20 repetitions on 6 exercises at 50% 1RM (25). These investigators found the potentiation of hypotension only after concurrent exercise when compared to the CV session alone, thus echoing the presented data, despite the difference in RT intervention (25). Ruiz and colleagues (2011) measured PEH following a 40 minute session of moderate intensity cycling, a whole body RT session scheduled at three sets of 12RM, and a concurrent session combining the two with CV before RT. Without a CON condition, the researchers compared post exercise BP to that session's resting value. All exercise sessions resulted in PEH after 15 minutes of recovery (24). While the divergent interventions make direct comparisons difficult, it appears that the combination of RT with CV does not limit PEH response immediately after exercise. The current investigation builds upon previous literature by following the PEH response into ADLs and including a true CON session.

These students often returned to a classroom setting, studying, or work-related activities. The notation of prolonged attenuated BP in spite of returning to potential stress inducing situations is a significant finding. Future investigations might consider evaluating PEH throughout the course of the semester.

The observation of PEH further into recovery (minute 45 after RTCV and minutes 50 and 55 after CVRT) is reflective of other concurrent exercise investigations. Keese et al. (2011) noted approximately a 5.6% decrease in BP when assessed at minute 60 after CVRT. Moreover, PEH lasted from minutes 90 to 120 following concurrent exercise identical to the current RTCV session (13). A faster (from minute 15 to minute 60) and slightly greater magnitude of PEH was noted following a concurrent exercise prescription with greater total exercise volume (-10.5% at minute 45 to -8.6% at minute 30, respectively; 24).

In support of past investigations, the present study is the first known to evaluate the effectiveness of changing the order of exercise modality when evaluating PEH. With an average BP reduction of 11.5%, the CVRT session was responsible for the greatest magnitude of PEH (although not statistically different from the RTCV session). These data indicate that the order of exercise modality did not impede a PEH response in normotensive adults. Further investigations may consider determining the translational capacity of this information to other populations with characteristics known to influence BP (i.e., those with disease, those who are obese, those who smoke).

Blood pressure remained low for several hours following exercise, even after participants returned to ADLs. This was not true following the control condition. These data push the current body of PEH literature towards evaluation of hemodynamic exercise response in free living conditions using ABPMs. Further, information from this work solidifies the positive effect of RT on PEH, regardless of when the training occurs in an exercise session.

While the novelty and value of the information gained from this investigation is clear, the following modifications in future research are suggested to address potential limitations to the current investigation: [1] increase the duration and/or intensity of RT or CV exercise to potentially increase the PEH response; [2] disperse CV exercise between RT movements to be more applicable to sport; [3] evaluate the effects of power style RT within concurrent training; [4] shorten rest intervals between RT exercises; [5] change the recovery position from sitting to supine during PEH assessment.

Moreover, investigators wishing to build upon these data may amend the limitations that arose during the data collection and analysis of this project. While participants performed the four sessions at the same time of day as their initial control session, there was some interparticipant variability in regard to session time (roughly half we conducted before lunch and the other after lunch). Noting the potential variability in postprandial BP, future studies should consider testing all participants at the same time of day. Assessment of BP during ADLs may be explained better with more frequent measurements than once per hour. However, increasing the frequency of assessments may result in higher participant burden and discomfort. Lastly, the discrepancy

of total exercise duration between the GXT and concurrent sessions may have limited the ability for the investigators to detect PEH following the maximal exercise.

The main findings from this investigation are that [1] PEH occurs in concurrent exercise despite the order of modality prescription and [2] that BP can be maintained at near resting values following exercise, despite returning to potentially stress inducing ADLs. This information can be applied to students who are looking to use exercise as a non-pharmacological mean to regulate BP. Future research is warranted to determine the appropriateness of this intervention in clinical and sport settings. If the findings hold true, coaches, trainers, or clinicians might not fear mitigating positive BP effects of CV exercise by concurrently weight training with athletes or clients with suboptimal BP.

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