Metabolic and cardiovascular adjustments during psychological stress and carotid artery intima-media thickness in youth

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1. Introduction

It is widely accepted that there is individual variation in the cardiovascular response, or reactivity, to acute psychological stress [1]. However, there remains controversy over the reactivity hypothesis, which suggests that heightened cardiovascular responses to psychological stress contribute to the etiology of cardiovascular pathology and disease and that those individuals who have the greatest reactivity are at the most risk [2–5]. Skepticism over the reactivity hypothesis stems from inconsistent and conflicting results in the literature [2] which is likely due, in part, to differences in methodology and analyses employed across studies [4,6–10]. Additionally, an inherent limitation of the reactivity hypothesis is that the direction of the relationship between increased cardiovascular reactivity to psychological stress and future hypertension and cardiovascular disease (CVD) is ambiguous [7,11,12]. Therefore, further investigation into the pathophysiological mechanisms whereby cardiovascular reactivity is associated with an increased risk for CVD and the methods used to analyze this reactivity is needed.

Cardiovascular reactivity is traditionally measured as the stress-induced increase in a cardiovascular variable from a baseline or resting condition. Numerous studies in adults and youth have shown that greater traditionally measured cardiovascular reactivity to psychological stress is correlated with an increased risk for hypertension and CVD [9,13–15]. Studying CVD risk factors in pediatric and adolescent populations is of particular importance because the beginnings of CVD appear in youth, well before the presence of clinical signs or symptoms of CVD [11,16–20]. Advances in non-invasive imaging technology have allowed in vivo study of the structural and functional properties of the arterial system in pediatric and adolescent populations and can identify the risk for CVD at a much earlier stage [17,21–24]. Research using these ultrasound techniques provides initial evidence that thickening of the arterial wall and endothelial dysfunction can occur as early as childhood, thus increasing the risk for cardiovascular complications in adulthood [17,21,25]. Our laboratory was the first to demonstrate that traditionally measured systolic blood pressure (SBP) reactivity to acute psychological stress
The reasons why increases in cardiovascular variables during acute psychological stress may be atherogenic also remain unclear. Similar cardiovascular responses occur during aerobic exercise and acute psychological stress including increases in cardiac output, heart rate (HR), and SBP. However, exercise is protective and beneficial for cardiovascular system health. Studies in adults, although limited in number, show convincingly that HR and cardiac output during psychological stress are in excess of what would be expected based on metabolic demand [4,26,27]. We have also shown (Lambiase et al., unpublished work) that psychological stress-induced increases in HR and SBP are excessive based on metabolic demand in adolescents. It has been proposed that the metabolic appropriateness of cardiovascular responses may be one mechanism whereby increases in HR and SBP produce atherogenic or athero-protective effects [4], but this has not yet been tested. Gender may modify the relationship between cardiovascular stress reactivity and CVD risk. Men and women have different cardiovascular responses to psychological stress which may result in different CVD risk. Lawler et al. [28] determined that men exhibit greater myocardial and DBP reactivity to psychological stress than women. The greater reactivity of men might be one mechanism contributing to gender differences in CVD incidence [28]. However, others have observed greater myocardial reactivity in women [29,30]. Much less work has been completed in children, but Murphy et al. [31] determined that boys had greater cardiovascular reactivity to a video game stressor than girls. Importantly, boys also have greater CIMT than girls of the same age [32]. Thus, more research in youth is needed to determine the metabolic appropriateness of cardiovascular responses to psychological stress in both boys and girls to determine whether differences in cardiovascular reactivity between genders affect cardiovascular health.

The present study had several aims. The first aim was to replicate our previous findings that traditionally measured SBP reactivity to psychological stress was associated with CIMT in healthy adolescents. A second aim was to determine if excess HR and SBP based on metabolic demand was associated with CIMT in youth. A third aim was to identify whether there were gender differences in cardiovascular responses to psychological stress and gender differences in the association of stress-induced cardiovascular reactivity and CVD risk in adolescents.

2. Methods

2.1. Participants

Fifty-four adolescents (27 boys, 27 girls), ages 13–16 served as subjects. Subjects included 47 white, 1 black, 1 Asian, and 5 youth of other or mixed race. Adolescents were lower than the 85th percentile for BMI. Adolescents did not have any conditions or diseases that would affect their ability to be physically active or any psychological conditions and could not be taking any medications that would influence the stress response. Socioeconomic status (SES) was assessed by the parent completing a questionnaire. Parents provided written informed consent for their child’s participation and the adolescent provided written assent. The study was approved by the University at Buffalo Social and Behavioral Sciences Institutional Review Board.

2.2. Procedures

Adolescents were tested in 3 days: an exercise day, a stress day, and an ultrasound measurement day to assess CIMT. The order of the exercise day and stress day was counterbalanced across subjects. CIMT was measured on a separate day after participants completed the exercise and stress protocols. Prior to each meeting adolescents were instructed not to eat anything at least 3 h prior to the visit and not to participate in any intense physical activity or consume any caffeine the day of or the day before the lab visit. The exercise day and stress day were scheduled at least 1 full day apart and at the same time of day.

At the first appointment, adolescents were measured for height and weight. On both the exercise day and the stress day adolescents were fitted with a Polar HR monitor (Port Washington, New York) and the correct sized Suntech Tango BP cuff (Morrisville, North Carolina). Adolescents were also fitted with an appropriate sized face mask attached to a metabolic cart (Vmax Encore Metabolic Cart, Sensormedics) via a sampling line to measure metabolic demand. Adolescents rested for 10 min to collect resting HR, BP, and O2 consumption. HR and O2 consumption were measured continuously during this baseline period. BP was taken twice during the last 2 min of baseline on both days.

In 1 day adolescents completed a graded exercise test on a treadmill. HR and O2 consumption were measured continuously during exercise. SBP was measured twice during the last 2 min of each exercise stage. On the other day adolescents completed measures of psychological stress reactivity. The adolescent participated in two stress reactivity tasks that model stressors adolescents experience during a school day. The order of the stress tasks was randomly counterbalanced across subjects. The adolescent rested for 5 min between the tasks. Adolescents were provided with magazines to read during the rest period. HR and O2 consumption were monitored continuously during the stress tasks and the rest period. SBP was measured twice during each task and the rest period.

2.3. Measurement

2.3.1. Medical history and demographic variables

Current medical problems, including psychiatric diagnoses and conditions or medications that may affect stress reactivity were assessed by phone screen. SES was assessed by the parent completing a questionnaire [33].

2.3.2. Anthropometrics

Body weight was measured to the nearest 0.01 kg with the subjects wearing shorts and a t-shirt. Height was measured with a stadiometer. Body mass index (BMI) was calculated according to the following formula: \(\text{BMI} = \frac{\text{weight}}{\text{height}^2}\). BMI percentile was calculated in relationship to 50th BMI percentile for adolescents based on their sex and age.

2.3.3. Measurement of heart rate and blood pressure

During the exercise and stress protocols, HR was measured using a Polar (Port Washington, NY) HR monitor consisting of a transmitter with an elastic belt that was strapped around the adolescent’s torso, directly over the sternum and just below the chest/pectoral muscles, and a wrist monitor. BP was measured with a Suntech Tango monitor (Morrisville, North Carolina). Adhesive electrodes were attached to the adolescent’s chest (one below each collar bone and one below the right rib area). The Suntech Tango uses the auscultatory method aided by electrocardiographic R-wave gating and an oscillometric transducer and is a valid and reliable measure of BP during rest and exercise [34]. Measurement of BP followed published guidelines [35] regarding cuff length and width, placement of the cuff around the arm 2.5 cm above the antecubital space, and seating of the cuff of the arm by inflating and deflating the cuff before taking any measurements.

2.3.4. Measurement of metabolic demand

Adolescents were fitted with an appropriate sized face mask attached to a metabolic cart (Vmax Encore Metabolic Cart, Sensormedics) via a mass flow sensor and sampling line. Metabolic demand, indexed by O2 consumption [36], was measured on a breath-by-
breath basis using indirect calorimetry. The metabolic cart was calibrated according to manufacturer instructions prior to each subject appointment.

2.3.5. Exercise protocol
Adolescents rested quietly for a 10 minute baseline period and then completed five, 4-minute stages of increasing intensity on a treadmill. The exercise protocol was used to determine the relationship between O2 consumption and cardiovascular variables during exercise. This test also served as a measure of aerobic fitness, similar to the physical working capacity 170 test (PWCT170). The dependent measure in the PWCT170 is the O2 consumption attained at a HR of 170 beats per minute (bpm). The velocity and % grade was progressively increased until a HR of 170 bpm was attained. The workloads were designed to attain at least two and usually three HRs between 110 bpm and 170 + bpm for use in the regressions. Four minute stages were used to ensure that the subject reached a steady state of O2 consumption. Before beginning the protocol subjects were given time to learn to walk comfortably on the treadmill. HR and O2 consumption were measured continuously during baseline and exercise. SBP was measured twice during the last 2 min of baseline and twice during the last 2 min of each exercise stage. The average O2 consumption, HR, and SBP during the last 2 min of baseline and the last 2 min of each of the exercise stages were used as data.

2.3.6. Stress reactivity tasks
Adolescents completed a mirror star tracing task and an interpersonal speech task designed to increase cardiovascular reactivity. These moderately stressful tasks were chosen based on their ability to activate specific components of the sympathetic nervous system and their similarities to stressors that adolescents encounter during a typical school day. Also, they are common stressors that have been used in previous research in this age group [6,8]. The order of the stress tasks was counterbalanced across subjects. Subjects were given a five minute rest between tasks.

2.3.6.1. Mirror star tracing task. The mirror star tracing task requires vigilance and attention and produces alpha-adrenergic activation resulting in vasoconstriction and increased BP with smaller increase in HR [37]. For this task adolescents sat at a table with a computer monitor in front of them. Adolescents were instructed to slide a computer mouse to control a cursor to trace a five-sided star. To produce a mirror-tracing effect, both horizontal and vertical movements of the cursor were programmed to be reversed relative to movement of the mirror. Adolescents were instructed to trace the star as quickly as possible without allowing the cursor to stray out-of-bounds in either the center or the area surrounding the external border of the star. Out-of-bounds errors were noted with a large red X that quickly flashed on the screen and a beeping sound. Adolescents were instructed to complete as many stars as possible with as few errors as possible in 4 min. HR and O2 consumption were measured continuously during the task. SBP was measured twice during the last 2 min of the task.

2.3.6.2. Speech task. Speech tasks produce a predominately beta-adrenergic-induced pressor response during preparation of the speech, while actually giving the speech promotes a mix of alpha and beta adrenergic activation [38]. Adolescents were given 4 min to prepare and 3 min to deliver a speech about why they believed they were a good friend. Adolescents were informed that their speeches would be recorded and judged for honesty, believability, and confidence. After adolescents stopped speaking, an additional ad lib period was provided in which adolescents were encouraged to continue talking by adding any additional information that others should know about them, or restating or summarizing their main qualities that make them a good friend. HR and O2 consumption were measured continuously while preparing and delivering the speech. SBP was measured twice during the last .2 min of the speech preparation period and the actual speech.

2.3.7. Carotid artery intima-media thickness
Ultrasound measures were performed with the Biosound Esaote (MyLab 25 Gold) ultrasound imaging machine (Biosound Esaote, Inc., Indianapolis, Indiana) and with a 7.5 MHz transducer. The images were recorded on videotape using a super VHS recorder and analyzed offline. Adolescents rested quietly in a supine position with the head resting on a pillow. Three electrocardiogram leads were placed on the participant. A plastic arc with angles printed on it was placed around the participant’s neck to determine angles at which the sonographer scanned. The near and far wall of the right and left common carotid arteries, bifurcation, and internal carotid arteries was scanned by trained and research certified ultrasound technicians. A hypoallergenic ultrasound gel was applied to the area to be scanned. A preliminary exploratory transverse scan was performed to assess the adolescent’s anatomy and determine the optimum angle for the scan. Once the angle was determined, an exploratory longitudinal scan was performed of the common carotid, the bulb, and the internal carotid. To clearly distinguish the internal from external carotid arteries based on differences in the flow velocity profiles in the two vessels, a brief doppler scan was performed. Beginning at the determined optimal angle, standardized longitudinal images were acquired of the near and far walls of the distal 1.0 cm portion of the common carotid, the carotid bifurcation, and the proximal 1.0 cm of the internal carotid arteries. The maximum IMT was measured in the common carotid artery, bulb, and internal carotid artery from three interrogation angles on the right and left side. After selection of the single maximum IMT from the three angles of the near and far wall in each anatomical segment (1×2×3=6 on the right and the left), the mean values of these 12 single maximum IMT values were computed as the mean maximum CIMT. Note: mean maximum CIMT is the outcome variable used in the ACAPS [39] and PREVENT [40] clinical trials.

2.3.8. Analytic plan
Separate one-way ANOVA was used to test differences between boys and girls for participant characteristics. Two-way ANOVA, with gender as a between factor and day (exercise, stress) as a within factor, was used to compare baseline cardiovascular measures on the exercise and stress days between the boys and the girls. Traditional cardiovascular reactivity scores were computed by creating change scores for each of the stress tasks (star tracing, speech preparation, speech). Because the order of the stress tasks was counterbalanced across subjects, the rest period that immediately preceded the stress task was used in computing the change scores. Separate change scores were calculated for HR and SBP by subtracting the average rest value before the task from the average value obtained during the last 2 min of each task. Excess HR and SBP, based on metabolic demand, were determined by calculating individualized linear regression coefficients, using a fixed intercept, of O2 consumption on HR and SBP during the exercise test for each subject. The average O2 consumption collected during each stress task (star tracing, speech preparation, speech) was used to predict each subject’s HR and SBP based on the individual regression equations calculated during the exercise test. Excess HR and SBP for each stress task were calculated as the difference between the actual and the predicted HR or SBP for each task. Two-way repeated measures ANOVA (gender, task) was used to determine gender differences in traditionally measured cardiovascular reactivity and the excess cardiovascular response for each psychological stress task.

Univariate correlations were used to determine if traditionally measured cardiovascular reactivity was correlated with the excess HR and SBP for each stress task. Hierarchical regression models were used to determine if traditional cardiovascular reactivity during
each psychological stress task significantly added to the prediction of CIMT when controlling for gender, BMI percentile, SES, fitness, and baseline cardiovascular values. Gender, BMI, and SES were added together as the first block and then fitness, baseline cardiovascular measures, and cardiovascular reactivity measures were added independently as separate steps in the model. Similar hierarchical regression models were used to determine if excess HR or SBP during each psychological stress task predicted CIMT while controlling for SES, BMI percentile, fitness, and the predicted cardiovascular value. A gender by reactivity term was added in a final block to each regression model to determine if cardiovascular responses to psychological stress are moderated by gender. An alpha level of 0.05 for was used for all analyses.

3. Results

3.1. Participant characteristics

Participant characteristics of the boys and girls are shown in Table 1. Boys had greater fitness (F(1,52) = 20.11, p < 0.001, \( \beta = 0.28 \)) and CIMT (F(1,52) = 8.81, p = 0.005, \( \beta = 0.15 \)) than the girls. There were no other differences between the boys and girls for any of the physical or demographic characteristics. There were no differences in baseline cardiovascular measures between the boys and girls on the exercise and stress days.

3.2. Gender differences in cardiovascular responses to stress tasks

Fig. 1 shows traditional HR reactivity and excess HR for each of the stress tasks for the boys and girls. For traditional HR reactivity, there was a significant main effect for gender (F(1,52) = 13.89, p < 0.001, \( \beta = 0.21 \)) but the gender by task interaction was not significant (p = 0.39). The significance did not change when covarying for SES, BMI percentile, and fitness. For excess HR, the gender effect was F(1,52) = 3.05, p = 0.09, \( \beta = 0.06 \). Fig. 2 shows traditional SBP reactivity and excess SBP for each of the stress tasks for the boys and girls. There were no gender differences in traditional SBP reactivity (p = 0.87) or excess SBP (p = 0.55).

3.3. Correlations between cardiovascular reactivity and excess HR and BP

Fig. 3 shows the relationships between traditional cardiovascular reactivity and excess HR and SBP during the speech task. Traditional cardiovascular reactivity was correlated with excess HR (r = 0.58, p < 0.001) and excess SBP (r = 0.75, p < 0.001) during the speech. Traditional HR (r = 0.43, p < 0.001) and SBP (r = 0.53, p < 0.001) reactivity were also significantly correlated with excess HR and SBP during speech preparation and star tracing (data not shown).

3.4. Cardiovascular reactivity and excess HR and SBP to predict CIMT

Neither traditional HR reactivity (p ≥ 0.19), nor excess HR (p ≥ 0.51), during any of the stress tasks was significantly associated with CIMT (data not shown). The gender by HR reactivity interaction was not significant for any of the stress tasks (p ≥ 0.58).

The hierarchical regression models to predict CIMT from traditional SBP reactivity during the star tracing, speech preparation, and speech stressors are shown in Table 2. Traditional SBP reactivity during speech preparation significantly improved the prediction of CIMT (β = 0.30, p = 0.02, R² increase = 0.09) when controlling for gender, BMI, SES, fitness, and baseline SBP. Similarly, excess SBP (β = 0.30, p = 0.02, R² increase = 0.08) during speech preparation was also significantly associated with CIMT (Table 3). Excess SBP during star tracing (p = 0.44) and speech (p = 0.06) did not significantly add to the prediction of CIMT (data not shown). The gender by SBP reactivity interaction was not significant for any of the stress tasks (p ≥ 0.18).

4. Discussion

The results of this study confirm previous work in our laboratory that traditionally measured SBP reactivity to acute psychological stress independently predicts CIMT in youth. It has been hypothesized that the increases in HR and SBP during acute psychological stress are in excess of what is needed for the metabolic demand and that this excess response contributes to the pathogenesis of CVD [4,26,27]. This study was the first to determine whether excess HR and SBP based on the metabolic demand were associated with...
CIMT. Excess SBP during acute psychological stress was significantly associated with CIMT, similar to traditionally measured SBP reactivity.

Ultrasound measurement of CIMT allows for the non-invasive study of the initial steps of the atherogenic process by providing information regarding the structural properties of the arterial system [17,21–23]. The use of this imaging technique has materially advanced the understanding of the causes, development, and pathophysiological mechanisms of the atherosclerotic process and CVD risk and has provided valuable insight into future risk for CVD as early as childhood [17,21,24,41]. We have previously shown that traditionally measured SBP reactivity to speech predicts CIMT in children independent of age, percent body fat, race, SES, and baseline SBP [11]. We have also shown that traditionally measured SBP reactivity to preparing and delivering a speech, along with an aggregate SBP reactivity measure across multiple stressors predicts CIMT in adolescents, while controlling for age, BMI percentile, gender, and baseline SBP [6]. We have also shown that traditionally measured SBP reactivity to preparing and delivering a speech, along with an aggregate SBP reactivity measure across multiple stressors predicts CIMT in adolescents, while controlling for age, BMI percentile, gender, and baseline SBP.

Examining the differences between exercise and psychological stress may provide insight into the pathophysiological mechanisms whereby cardiovascular reactivity during psychological stress is associated with CIMT and an increased risk for CVD [4,26]. Increases in cardiovascular responses to exercise are thought to be appropriate given the corresponding increase in metabolic demand [4,26,27]. Conversely, it has been postulated that cardiovascular responses to acute psychological stress are in excess of what would be expected based on the lower metabolic demand and it is hypothesized that this excess cardiovascular response contributes to CVD pathogenesis [4,26,27]. However, previous studies did not include measures of

![Fig. 2](image1.png)

**Fig. 2.** Traditional SBP reactivity (top) and excess SBP (bottom) during star tracing, speech, preparation, and speech of the boys and girls. There were no differences between the boys and girls.

![Fig. 3](image2.png)

**Fig. 3.** Univariate correlation of traditional HR (top) and SBP (bottom) reactivity with excess HR and SBP during the speech. Traditional cardiovascular reactivity was calculated as the actual task value minus the resting value before the task. Excess was calculated as the actual task value minus the predicted value based on the metabolic demand during the task.

<table>
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<th>Table 2</th>
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<tr>
<td>Hierarchal regression to predict CIMT from SBP reactivity during acute psychological stress.</td>
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<td></td>
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<tr>
<td>Step 1</td>
</tr>
<tr>
<td>Gender</td>
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<tr>
<td>BMI</td>
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<tr>
<td>SES</td>
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<tr>
<td>Step 2</td>
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<tr>
<td>Fitness</td>
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<td>Step 3</td>
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<td>Baseline SBP</td>
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<tr>
<td>Step 4: Individually tested SBP reactivity predictors*</td>
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<tr>
<td>Star</td>
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<td>Speech preparation</td>
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<td>Speech</td>
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* p < 0.05.  
** p < 0.01.  
* The incremental increase in R² was tested independently for SBP reactivity during the star, speech preparation, and speech stressors.
the CVD pathogenesis so this association could not be tested. In the present study, excess SBP during speech preparation was significantly associated with CIMT similar to traditionally measured SBP reactivity during speech preparation. The current study, then, extends previous research by providing initial support that cardiovascular responses in excess of what would be expected based on the metabolic demand are associated with CVD pathogenesis. Neither traditional HR reactivity, nor excess HR, was associated with CIMT for any of the stress tasks. These results are consistent with previous research in adolescents [6].

Different laboratory stress tasks produce unique physiologic responses and; therefore, all tasks are not similarly associated with CVD risk. In the present study, reactivity during the star tracing was not associated with measures of CIMT, which is similar to previous work in adolescents [6]. Star tracing results in more alpha-adrenergic activation [37] compared to the greater beta-adrenergic activation of the speech task [38]. Repeated increases in beta-adrenergic tone increase the risk for arterial remodeling and CVD [42,43]. Furthermore, interpersonal stress tasks, such as the speech task, impose greater social threat and are more representative of daily life stressors than the mirror star tracing task [44,45]. Thus, it is not surprising that reactivity during speech preparation, but not during mirror star tracing, was associated with CIMT. Contrary to previous findings, SBP reactivity during the speech was not associated with CIMT. One notable difference in the present study is the counter-balancing of the stress tasks. In our previous studies, we either used only one stress task [11] or did not counterbalance the speech task with the star tracing task [6]. Additionally, we measured O₂ consumption during the speech, which required the adolescents to wear a mask that covered their mouth and nose. Speaking with a mask on may have influenced the experience or perception of the task.

Men and women have different CVD risk [46]. Therefore, determining whether differences in cardiovascular reactivity between genders affect cardiovascular health at a young age is important to identify potential mechanisms which may account for gender differences in adult CVD. In the present study, girls had greater traditional HR reactivity for all psychological stress tasks. There were no other gender differences in reactivity measures observed in this study.

<table>
<thead>
<tr>
<th>Step</th>
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<th>SEB</th>
<th>B</th>
<th>R²</th>
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<tr>
<td>1</td>
<td>Gender</td>
<td>-0.04</td>
<td>0.01</td>
<td>-0.49**</td>
<td>0.18**</td>
</tr>
<tr>
<td></td>
<td>BMI</td>
<td>0.000</td>
<td>0.000</td>
<td>0.12</td>
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<tr>
<td></td>
<td>SES</td>
<td>0.000</td>
<td>0.001</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fitness</td>
<td>-0.001</td>
<td>0.001</td>
<td>-0.11</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Predicted SBP</td>
<td>0.001</td>
<td>0.001</td>
<td>0.25</td>
<td>0.15**</td>
</tr>
<tr>
<td>3</td>
<td>Excess SBP</td>
<td>0.001</td>
<td>0.000</td>
<td>0.300</td>
<td>0.23**</td>
</tr>
</tbody>
</table>

*p < 0.05.

**p < 0.01.

What is interesting in this study is not just the association of SBP reactivity during speech preparation with CIMT or gender differences in reactivity; which have been previously reported, but the similar associations of traditional reactivity and excess cardiovascular responses with CIMT. Traditionally measured HR and SBP reactivity and excess HR and SBP responses had similar associations with CIMT across all stress tasks and similar interactions with gender. Although this was not surprising given the high correlations between traditional and excess measures of reactivity, it does raise questions about what additional information measuring metabolic demand during psychological stress provides above that of traditional measures of cardiovascular reactivity. Measuring metabolic demand imposes additional subject burden and may change the characteristics of psychological stress tasks, which may be unnecessary if traditionally measured cardiovascular reactivity provides the same information.

This study is not without limitations. The wearing of the mask to measure O₂ consumption may have been uncomfortable and mildly stressful for the adolescents. This could have affected both baseline and task measures. We included only healthy, normal weight adolescents in this study. The results may have differed if we included youth with known diseases or overweight youth. We used CIMT as our only measure of CVD risk. Greater CIMT in adults increases the risk for stroke, myocardial infarction, and cardiovascular mortality [52,53]. However, the relationship between CIMT in youth and CVD in adulthood is not well understood. Additionally, autopsy findings show that the earliest structural changes in arterial vasculature appear in the abdominal aorta [54]. Thus, IMT measurements of the abdominal aorta may provide a better indicator of subclinical atherosclerosis in younger populations [55]. Nonetheless, IMT assessment of the carotid artery is used widely in research as an index of systemic arterial wall thickness and increased risk for CVD in adolescents [24]. The cross sectional design limits our ability to determine a causal role for stress-induced cardiovascular reactivity in the progression of CIMT. Most hypothesize that increased cardiovascular responses in excess of what is needed for the metabolic demand during psychological stress contribute to the development of thicker CIMT and an increased risk for CVD. However, it is also possible that adolescents with thicker CIMT exhibit greater SBP responses to psychological stress. Furthermore, other variables that were not measured (i.e. lipids, genetic factors, coping strategies) could account for the association of cardiovascular reactivity and CIMT. Future research should continue to explore stress reactivity in larger sample sizes and with longitudinal designs to better understand how acute psychological stress or differences in reactivity contribute to CVD risk in youth.

The idea of the metabolic appropriateness of cardiovascular responses during psychological stress is an important area of research given the different CVD risk associated with similar responses during exercise and psychological stress. It will be important for future research to determine whether the magnitude of excess cardiovascular response relative to the metabolic demand differs for various age, SES, and race groups, since these variables are known to influence CVD. We examined only HR and SBP which are overt cardiovascular parameters and which increase during both exercise and psychological stress. Diastolic blood pressure (DBP) stays the same or decreases during submaximal aerobic exercise in healthy adolescents and does not correlate as closely with O₂ consumption as HR or SBP during increasing exercise intensity. However, examining the metabolic appropriateness of DBP responses during psychological stress is important because DBP reactivity is correlated with CVD risk in both adults [56] and youth [57]. Additionally, it will be important to determine how measures of metabolic demand during psychological stress
testing improve our knowledge of the relationship between acute psychological stress and CVD risk.

5. Conclusions

In conclusion, the present study adds to the growing body of literature showing a link between increased SBP reactivity to acute psychological stress and an increased risk for CVD in youth. The results further add to the literature by showing similar associations of traditional SBP reactivity and excess SBP with CIMT. Research in children and adolescents in relation to CVD should be a priority, since the beginnings of CVD appear in youth. Studies that look at these responses at an early age, where the atherosclerotic build up and accumulation of other confounding risk factors is likely to be less than in adult populations, may give a clearer insight into the mechanisms whereby cardiovascular reactivity is associated with the pathogenesis of CVD.

Acknowledgments

We thank Vivian Boyd and Debbie Saltino for their technical assistance in completing the ultrasound measurements. We also thank Nick Chernega, Tom McCarthy, Leah Scarborough, Laura Iafrati, and Bill Salttery for their help with data collection and data entry. This work was funded by the Mark Diamond Research Fund (to Dr. Lambiase) and the University at Buffalo Income Fund Reimbursable account (Dr. Roemmich).

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