Autonomic Responses of Women With Parental Hypertension
Effects of Physical Activity and Fitness

Janet Buckworth, Rod K. Dishman, Kirk J. Cureton

Abstract We studied the moderating effects of cardiorespiratory fitness and physical activity on heart rate and blood pressure responses to psychophysiological stressors and the carotid-cardiac baroreflex in young normotensive women with a parental history of hypertension (n=31). Testing occurred during the follicular menstrual phase. Subjects were divided into high versus moderate (46.6±6.5 versus 35.9±1.9 mL·kg⁻¹·min⁻¹ V̇O₂peak and high versus moderate (1217.7±98.4 versus 1015.5±49.4 J·kg⁻¹·wk⁻¹) physical activity groups. The groups did not differ in heart rate or blood pressure responses to mental arithmetic or the cold-face test. However, the highly fit women had longer maximal R–R intervals compared with the moderately fit women when the carotid-cardiac baroreflex was stimulated by negative pressures applied to the neck during resting conditions (P<.01). The carotid-cardiac baroreflex was attenuated during mental arithmetic compared with rest in both the moderately fit and moderately active women but not in the highly fit and highly active groups. We find no evidence that aerobic fitness reduces sympathetic responses to laboratory stressors in young women with parental hypertension. Our findings are consistent with greater parasympathetic tone during sympathetic challenge for the highly fit and highly active subjects. Clarification of autonomic balance during carotid baroreflex stimulation at rest and during sympathetic challenge after exercise training would provide important information regarding mechanisms that regulate cardiovascular responses to autonomic challenge in women at risk for hypertension. (Hypertension. 1994;24:576-584.)

Key Words • physical fitness • exercise • blood pressure • autonomic nervous system • hypertension, genetic

Physical inactivity is an independent risk factor for coronary heart disease, and regular physical activity has an accepted role in primary and secondary prevention of cardiovascular diseases, including mild hypertension. 1-3 However, mechanisms underlying the salutary effect of exercise on cardiovascular health are not fully known and have not received much study in women. 4-5

Hyperresponsiveness of the sympathetic nervous system to psychophysiological stressors is an established model for studying the etiology of coronary heart disease, atherosclerosis, and primary hypertension. 6-13 Some investigators 14-16 have reported that cardiorespiratory fitness is associated with lower sympathetic responsiveness to various stressors (see Crews and Landers 17 for a review), while others 18-23 have found no effect (see Peronnet and Szabo 24 for a review). The controversy in this area can be explained partly by a lack of standardization in the measurement of fitness, physical activity, sympathetic activity, and stressor tasks. Few controlled training studies have been reported. Most studies using cross-sectional designs have relied on indirect estimates of fitness or unvalidated self-reports of physical activity. Effects of fitness and physical activity have not been compared directly. Plasma catecholamine levels have been used to estimate sympathetic activity in about a dozen published reports, 22-24 but most studies in this area have measured heart rate and blood pressure responses 17 without considering parasympathetic influences on these variables during autonomic challenge. Subjects typically have been normotensive or had an unknown risk for developing hypertension or cardiovascular diseases.

Also, despite gender differences in autonomic responses to stressors, 11-13 it is not clear from the current literature that physical activity and fitness modify this responsiveness in women. 25 Only 5 of the 50 or so published exercise studies of autonomic responsiveness that we are aware of have reported catecholamine levels or heart rate and blood pressure in women, with inconsistent results (eg, see Crews and Landers 17 and Peronnet and Szabo 24). Resting blood pressure in normotensive and hypertensive women has been lowered following regular exercise of moderate intensity. 2-3 Thus, it is of clinical interest to determine whether physical activity and fitness moderate blood pressure and heart rate responses to autonomic challenge among normotensive women who are at risk for developing hypertension.

The purpose of this study was to examine differences in autonomic responses to psychophysiological stressors in women with a parental history of hypertension who differed in cardiorespiratory fitness and physical activity levels. Women who have one or both biological parents diagnosed with hypertension have an increased risk for developing primary hypertension 25 and increased heart rate and blood pressure responses to various stressors. 9,26 We hypothesized that high compared with moderate levels of V̇O₂peak and physical activity would be associated with attenuated sympathetic responses to laboratory stressors and an augmented carotid-cardiac baroreflex indicative of increased parasympathetic activity. Sympathetic responsiveness was assessed by measur-
ing heart rate and blood pressure during standardized active (mental arithmetic) and passive (cold-face test) tasks known to elicit sympathetic activity and during recovery from these tasks. The rapid heart rate response (first 5 seconds) during application of graded negative pressure to the neck was used to estimate the carotid-cardiac baroreflex and parasympathetic tone at rest and during the sympathetic challenge of mental arithmetic. All women were examined during the follicular phase to control for variations in neuroendocrine levels and cardiovascular responsiveness that occur across the menstrual cycle.8,11,13,27

Methods

Subjects

Sixty-seven healthy adult females were recruited from a university student population and signed a written informed consent approved by the Institutional Review Board that outlined potential risks and benefits. Criteria for participation included age (18 to 30 years), sex (female), race (white), no current oral contraceptive use, general good health, eumenorrheic (ie, 24- to 30-day cycle duration and 11 to 12 cycles over the last 12 months), and normotensive systolic blood pressure (SBP) higher than 140 mm Hg and diastolic blood pressure (DBP) higher than 90 mm Hg, with at least one biological parent diagnosed by a physician as having essential hypertension. Exclusion criteria included menstrual disorders, depression, anxiety disorders, diabetes, pregnancy, cardiovascular disease, autonomic disorders, contraindications to vigorous exercise, and use of cardiovascular drugs.

Fifty-seven volunteers reported for a screening session. A medical history questionnaire about personal and family health was completed, and the 7-day recall interview28 was administered to determine physical activity level (in joules per kilogram per week). Blood pressure was verified by the mean of three seated resting blood pressure measurements. No volunteers had orthostatic hypotension. Twenty-six women were excluded or dropped out after the screening session. Sample means (±SD) for trait anxiety (36.8±8.8) and trait anger (19.5±4.7), which affect autonomic responses, for the remaining 31 women were similar to norms for college women (38.25±9.14 and 20.35±5.27, respectively).30,31

VO_{2peak} estimated from a graded maximal treadmill test and the 7-day recall interview, were used as grouping variables to analyze autonomic responsiveness. With the use of a median split, subjects were divided into two groups defined as highly fit (VO_{2peak}=46.62±6.5 mL·kg~{-1}·min~{-1}; range, 39.1 to 60.9 mL·kg~{-1}·min~{-1}; n=15) and moderately fit (VO_{2peak}=35.89±2.19 mL·kg~{-1}·min~{-1}; range, 33.3 to 38.9 mL·kg~{-1}·min~{-1}; n=16) according to population-based fitness classifications for women 20 to 29 years of age.32 The sample was also divided into highly active (1217.7±98.4 J·kg~{-1}·h~{-1}·wk~{-1}; range, 1105 to 1450 J·kg~{-1}·h~{-1}·wk~{-1}; n=16) and moderately active (1015.5±49.4 J·kg~{-1}·h~{-1}·wk~{-1}; range, 911 to 1083 J·kg~{-1}·h~{-1}·wk~{-1}; n=15) groups according to norms for women 20 to 29 years of age using the 7-day recall interview.28 Only 9 of the 31 subjects were in the same classification group for VO_{2peak} and physical activity. The correlation between hours per week spent in vigorous (≥419.1 J·kg~{-1}·h~{-1}) activity and total weekly expenditure was 0.80 (P<0.001). Results from a median split based on vigorous activity did not differ from those based on total expenditure.

Experimental Procedures

Measurement of Psychological Variables

To account for the potential influence of anxiety and anger on autonomic responsiveness, we administered the State-Trait Anxiety Inventory Form Y (STAI-Y)30 and the Trait version of Spielberger's State-Trait Anger Expression (STAXI) Scale31 during the screening session. Before administration of each stressor, state anxiety was measured by using the 10-item version of the State-Trait Anxiety Inventory form Y-130; state anger was measured with Spielberger's STAXI S-Anger scale.31

Perceived difficulty and effort were assessed after mental arithmetic to account for the influence of task difficulty and subject engagement on cardiovascular responses.10 Subjects were asked to respond to “How difficult did you perceive this task to be?” and “How much effort did you put into this task?” on separate five-point Likert scales. An aversion scale of 1 to 10026 and a four-item comfort scale32 were administered after the cold-face test and the baroreflex procedures to assess subject ratings of discomfort that could confound heart rate and blood pressure responses.

Testing Protocol

Two stressor sessions were conducted at the same time of day during separate days of the subjects' follicular phase (defined as days 5 through 13 based on self-report). In our laboratory and elsewhere, self-reported menses corresponds closely with estimates based on basal body temperature charts. Testing was scheduled after the next cycle for subjects who were unsure of specific dates. Sessions and tasks within each session were counterbalanced. Body composition and fitness testing were conducted at a third meeting (see below). Subjects were asked to refrain from food, caffeine, and alcohol for 3 to 4 hours before all testing sessions.

Psychophysiological testing. Mental arithmetic and cold-face testing were conducted in one session while the subject was seated inside a sound-attenuated ([60 dB(A)] below ambient) isolation chamber under thermoneutral conditions (22±1°C). Blood pressure and heart rate responses were recorded with a 2300 Finapres blood pressure monitor (Ohmeda Monitoring Systems) with the pressure cuff placed on the middle finger of the subject's non-dominant hand maintained at heart level. Heart rate and blood pressure measures from the Finapres recorder have been validated against simultaneous intra-arterial monitoring.24 After 10 minutes of accommodation to the equipment, initial baseline records of heart rate, SBP, DBP, and mean arterial pressure (MAP) were measured on-line and averaged over a 5-minute baseline by using Data Acquisition System’s DATAO version 3.50 (TJS Software) on an IBM 286 microcomputer. Baseline readings were recorded by having subjects perform mental arithmetic or the cold-face test. For the mental arithmetic test, the subject was instructed to subtract serially by seven aloud as quickly and accurately as possible, without the aid of calculator or paper and pencil.6 A new four-digit number was announced at the beginning of each 1-minute interval of the 5-minute task. Task instructions and new numbers were presented on audiotape, and responses were tape-recorded for scoring. Blood pressure and heart rate were measured during minutes 2 to 3 and 4 to 5 of the task and during minutes 2 to 3 and 5 to 6 of stressor recovery.

The second task was administered after 10 minutes of rest and 5 minutes of baseline recording. For the cold-face test, instructions were announced over an intercom for the subject to secure headgear constructed of elastic, Velcro, and a rectangular ice bag filled with crushed ice and water (3°C to 4°C) on her forehead and to close her eyes. Heart rate, SBP, DBP, and MAP were recorded during the first and second minutes of the cold-face test. After 2 minutes, the subject was told to remove the headgear and open her eyes. Blood pressure and heart rate during minutes 2 to 3 and 5 to 6 of cold-face test recovery were recorded.

Baroreflex testing was conducted at a separate session in the isolation chamber. Three Ag-AgCl electrodes were placed in a modified V5 configuration, and the Finapres blood pressure cuff was attached. A model 2000-01 silicone elastomer neck chamber (Engineering Development Laboratory, Inc) was secured around the subject's neck. After the subject rested quietly in a supine position for 10 minutes, baseline heart rate and blood pressure readings were gathered for 5 minutes.
TABLE 1. Characteristics of Highly Fit Versus Moderately Fit Subjects

<table>
<thead>
<tr>
<th>Variable</th>
<th>Highly Fit (n=15)</th>
<th>Moderately Fit (n=16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>20.1±1.8</td>
<td>21.5±2.1</td>
</tr>
<tr>
<td>Height, cm</td>
<td>164.9±7.4</td>
<td>163.9±4.7</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>57.8±8.8</td>
<td>65.2±9.9*</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>20.9±2.3</td>
<td>24.2±3.5*</td>
</tr>
<tr>
<td>Body fat, %</td>
<td>21.7±5.1</td>
<td>30.4±7.4*</td>
</tr>
<tr>
<td>Resting heart rate, bpm</td>
<td>76.8±1.4</td>
<td>74.8±8.4</td>
</tr>
<tr>
<td>SBP, mm Hg</td>
<td>118.2±10.2</td>
<td>118.6±6.3</td>
</tr>
<tr>
<td>DBP, mm Hg</td>
<td>68.3±4.4</td>
<td>70.8±4.4</td>
</tr>
<tr>
<td>MAP, mm Hg</td>
<td>84.9±5.8</td>
<td>85.8±4.1</td>
</tr>
<tr>
<td>VO₂peak, (mL·kg⁻¹·min⁻¹)</td>
<td>46.6±6.5</td>
<td>35.9±1.9*</td>
</tr>
<tr>
<td>VO₂peak, L·min⁻¹</td>
<td>2.64±0.49</td>
<td>2.32±0.33*</td>
</tr>
<tr>
<td>Total 7-day recall, J·kg⁻¹·wk⁻¹</td>
<td>1159.1±125.9</td>
<td>1082.9±123.7</td>
</tr>
<tr>
<td>Heart 7-day recall, J·kg⁻¹·wk⁻¹ (≥41.9 J·kg⁻¹·h⁻¹)</td>
<td>125.2±107.2</td>
<td>59.0±108.8</td>
</tr>
<tr>
<td>Trait anxiety</td>
<td>39.3±9.2</td>
<td>34.5±8.1</td>
</tr>
<tr>
<td>Trait anger</td>
<td>19.9±5.6</td>
<td>18.9±3.1</td>
</tr>
</tbody>
</table>

BMI indicates body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; and MAP, mean arterial pressure. Values are mean±SD.

*Significant difference between groups, P<.05.

TABLE 2. Characteristics of Highly Active Versus Moderately Active Subjects

<table>
<thead>
<tr>
<th>Variable</th>
<th>Highly Active (n=16)</th>
<th>Moderately Active (n=15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>20.1±1.7</td>
<td>21.5±2.3</td>
</tr>
<tr>
<td>Height, cm</td>
<td>162.9±5.5</td>
<td>166.0±6.4</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>57.7±5.9</td>
<td>65.3±11.6*</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>21.9±2.9</td>
<td>23.6±3.9</td>
</tr>
<tr>
<td>Body fat, %</td>
<td>23.9±8.9</td>
<td>29.5±6.2*</td>
</tr>
<tr>
<td>Resting heart rate, bpm</td>
<td>76.5±9.9</td>
<td>75.3±7.4</td>
</tr>
<tr>
<td>SBP, mm Hg</td>
<td>119.4±7.1</td>
<td>118.2±7.5</td>
</tr>
<tr>
<td>DBP, mm Hg</td>
<td>69.1±4.5</td>
<td>70.2±5.1</td>
</tr>
<tr>
<td>MAP, mm Hg</td>
<td>85.1±4.2</td>
<td>85.6±5.8</td>
</tr>
<tr>
<td>VO₂peak, (mL·kg⁻¹·min⁻¹)</td>
<td>42.9±8.2</td>
<td>39.2±5.5</td>
</tr>
<tr>
<td>VO₂peak, L·min⁻¹</td>
<td>2.47±0.47</td>
<td>2.48±0.41</td>
</tr>
<tr>
<td>Total 7-day recall, J·kg⁻¹·wk⁻¹</td>
<td>1217.7±98.4</td>
<td>1015.5±49.4*</td>
</tr>
<tr>
<td>Heart 7-day recall, J·kg⁻¹·wk⁻¹ (≥41.9 J·kg⁻¹·h⁻¹)</td>
<td>146.5±127.3</td>
<td>29.3±39.3*</td>
</tr>
<tr>
<td>Trait anxiety</td>
<td>37.3±10.0</td>
<td>36.3±7.7</td>
</tr>
<tr>
<td>Trait anger</td>
<td>20.1±5.8</td>
<td>18.9±3.1</td>
</tr>
</tbody>
</table>

Definitions are as in Table 1. Values are mean±SD. *Significant difference between groups, P<.05.

Heart rate responses to baroreflex stimulation were measured during three trials of five graded increments of negative pressure (−10, −20, −30, −40, and −50 mm Hg) delivered bilaterally to the neck chamber by a vacuum pump and sustained for 10 seconds each. Pressure was confirmed by movement in a mercury manometer and simultaneous transduction of pressure by a PT5 Volumetric Pressure Transducer input to a model 7P122 amplifier and 78D recorder (Grass Instrument Co). To control for the effects of breathing on heart rate variability, each subject was instructed to hold her breath in the middle of an exhalation 5 seconds before application of negative pressure.23 Blood pressure was recorded during the 15-second breath-hold by not engaging the automatic calibration function of the Finapres. MAP recorded 2 seconds before application of negative pressure was used to compute the pre-stimulus estimated carotid sinus pressure (ECSP) (MAP−applied negative pressure). Signals were input to a Grass model 7P511 amplifier and 78D recorder to record maximal R-R intervals during the first 5 seconds of the stimulus for analysis of baroreflex response.23 A record of the R-R interval was triggered by input of pressure change detected by the PT5 transducer with the 7P122 amplifier to an ANL-300 dual-threshold comparator (MED Associates, Inc). R-R signals were sent to a DIG-150 one shot (MED Associates) and held for 40 milliseconds for sampling by a model ANL 947 12-bit analog-to-digital convertor (MED Associates) at a sampling rate of 1000s. A data acquisition program (DAS SYSTEM version 1.8, MED Associates) and an IBM 386 microcomputer were used to convert the digital signals to an R-R interval duration for each cardiac cycle. Audiotaped instructions were used to synchronize the breath-holds with blood pressure recording, pressure application, and the R-R recording. Thirty-five seconds elapsed between each of the five pressure applications, and 2 minutes of rest preceded each trial.

Mental arithmetic during baroreflex testing involved serial subtraction by six from a four-digit number announced at the 2-minute period preceding pressure trials. Subjects were instructed to report answers aloud while keeping their chins stable with respect to the neck chamber. After each breath-hold, subjects resumed subtraction and continued until the next breath-hold cue.

The means of three trials at rest and during mental arithmetic were used in the analyses. The reliability of the three trials determined by the Cronbach coefficient was .97 and .95 for maximal R-R interval and MAP, respectively, at rest and .96 and .94 for maximal R-R interval and MAP, respectively, during mental arithmetic.

**Physiological testing.** VO₂peak was determined by open-circuit spirometry using a modified incline-graded treadmill test.36 Subjects walked/run continuously during a series of 3-minute bouts starting at 0% grade at 1.7 mph, followed by grade increments of 2% every 3 minutes with speeds increasing across the grade increments to 2.5, 3.4, 4.2, and 5.1 mph until voluntary exhaustion.

Oxygen consumption was measured each minute by a computerized open-circuit gas analysis system. Minute ventilation was measured with a Rayfield dry gas meter. Expired oxygen and carbon dioxide concentrations were measured by Ametek S-3A/L and CD-3A gas analyzers calibrated by standard gases using the micro-Scholander technique. VO₂peak was defined as a lack of increase in oxygen consumption with increasing work rate or heart rate within 10 beats per minute (bpm) of age-predicted maximal heart rate and a respiratory exchange ratio of 1.1 or greater. Heart rate was measured with minute-to-minute recordings obtained with the Linq Heart Watch monitor (model 8799, Computer Instruments Corp). In our laboratory and elsewhere,37 correlations between the heart watch and cardiocotachometer recording have approximated .98 (SEE, 0.5 bpm).

Percentage of body fat was assessed by hydrostatic weighing. Dry weight was measured with a Homs platform scale. Underwater weight with residual lung volume determination was...
assessed by using a Chatillon autopsy scale and closed-circuit oxygen rebreathing technique. Three independent measures of underwater weight and residual lung volume were obtained. Mean body density from the three trials was used to estimate percentage body fat using the Siri equation [percentage body fat = (495/body density) - 450].

Statistical Analysis

Mixed-model ANOVAs with two levels of the between-subject factor (highly fit versus moderately fit, highly active versus moderately active) and five levels of the within-subject factor (time) were used to test hypotheses pertaining to heart rate, SBP, DBP, and MAP during the mental arithmetic and cold-face procedures. The analysis was decomposed by contrasts for significant interaction effects. When the sphericity assumption was violated for the repeated measures, df was corrected using the Greenhouse-Geisser ε. Slopes and intercepts from the linear regression of ECSP on maximal R-R interval at rest and during mental arithmetic were compared between fitness and activity groups.

Fig 1. Line graphs show mean (±SEM) heart rate in highly fit (n=15) and moderately fit (n=16) and highly active (n=16) and moderately active (n=15) groups during mental arithmetic (A and C) and cold-face test (B and D). Sequence of mental arithmetic included resting baseline measured for 5 minutes followed by 5 minutes of mental arithmetic with responses recorded at minutes 2 to 3 and 4 to 5 (stressor) and 6 minutes of recovery with measures at minutes 2 to 3 and 5 to 6. Sequence of cold-face test included resting baseline measured for 5 minutes followed by 2 minutes of cold-face application with responses recorded at minutes 1 and 2 (stressor), and 6 minutes of recovery with measures at minutes 2 to 3 and 5 to 6.

Missing baroreflex data were evenly distributed between the dichotomous fitness and physical activity groups.

Results

No significant differences in heart rate and blood pressure responses to mental arithmetic or the cold-face test were found between groups representing different levels of VO2peak and physical activity. In contrast, the highly fit women had longer R-R intervals compared with the moderately fit women during stimulation of the carotid-cardiac baroreflex at rest. The carotid-cardiac baroreflex was attenuated during mental arithmetic compared with rest in both the moderately active and moderately fit women but not in the highly fit and highly active groups.

Moderating Variables

Table 1 summarizes characteristics of the highly fit and moderately fit groups. Highly fit subjects had significantly higher VO2peak (in milliliters per kilogram per minute [mL·kg⁻¹·min⁻¹]) [F(1,29)=39.83, P<.0001] and VO2peak (in liters per minute [L·min⁻¹]) [F(1,29)=4.65, P<.05]. There were no significant differences in age, height, resting cardiovascular variables, 7-day recall for total joules per kilogram per week (J·kg⁻¹·wk⁻¹) and heavy (>294 J·kg⁻¹·h⁻¹) physical activity, trait anger, or trait anxiety. Thus, the fitness groups were equated on physical activity level and several variables that influence heart rate and blood pressure responses to
stressors. Consistent with the fitness dichotomy, moderately fit subjects were heavier than highly fit subjects [F(1,29)=4.81, P<.05] and had a higher percentage of body fat [F(1,29)=14.45, P<.001] and body mass index [F(1,29)=9.40, P<.01]. The higher percentage of body fat in the moderately fit group could confound group comparisons of blood pressure responses.25 Therefore, the difference between groups in aerobic capacity expressed as milliliters per kilogram fat-free weight per minute (mL·kg FFW⁻¹·min⁻¹) was calculated. Groups defined as highly fit and moderately fit based on Vo₂peak (mL·kg⁻¹·min⁻¹) were also significantly different in Vo₂peak (mL·kg FFW⁻¹·min⁻¹) [F(1,29)=7.44, P=.05]. Vo₂peak was highly correlated (r=.75, P<.0001), and group assignment was not different from that based on Vc^peak (mL·kg FFW⁻¹·min⁻¹) scores.

Table 2 summarizes characteristics of the highly active and moderately active groups. Highly active subjects had significantly higher 7-day total activity (J·kg⁻¹·wk⁻¹) [F(1,29)=51.13, P<.0001] and heavy activity (≥294 J·kg⁻¹·h⁻¹) [F(1,29)=11.66, P<.01] compared with moderately active subjects. The groups were equated on Vo₂peak in mL·kg⁻¹·min⁻¹, Vo₂peak in mL·kg FFW⁻¹·min⁻¹, and Vo₂peak in L·min⁻¹, and there were no group differences in age, height, resting cardiovascular variables, trait anger, or trait anxiety. Moderately active subjects were heavier than highly active subjects [F(1,29)=5.52, P<.05] and had a higher percentage of body fat [F(1,29)=4.23, P<.05].

Measures of effect and task perceptions did not differ between fitness and activity groups with the following exceptions. The resting baroreflex session was rated more aversive by the moderately fit group (68.46±23.6) than by the highly fit group (41.84±29.9) [F(1,24)=6.35, P<.05]. The percentage of correct responses for the mental arithmetic task was higher for the highly active group (84.4±8.9%) than for the moderately active group (73.9±12.3%) [F(1,29)=7.33, P<.05]. Because aversion to resting baroreflex testing and the percentage of correct responses for mental arithmetic were not significantly correlated with the dependent variables in the fitness and activity groups, respectively, they were not considered as covariates in the statistical analyses.

Mental Arithmetic

We expected that heart rate and SBP would increase less during mental arithmetic and recover more quickly in the highly fit and highly active groups compared with the moderately fit and moderately active groups, respectively. There were no significant group-by-time interactions or group main effects for heart rate, SBP, DBP, or MAP responses for the fitness and activity group ANOVAs (Figs 1 and 2). Heart rate before, during, and after mental arithmetic was lower by about one-third SD (d=0.30 to 0.33) in the highly fit group compared with
the moderately fit group (Fig 1A). Heart rate in the highly active group was also lower (d=0.30) during mental arithmetic and recovery compared with the moderately active group (Fig 1C).

**Cold-Face Test**

Heart rate responses to the cold-face test were expected to be lower in the highly fit and highly active groups compared with the moderately fit and moderately active groups. No significant group-by-time interactions or group main effects were found for heart rate, SBP, DBP, or MAP responses in the ANOVAs comparing groups on fitness or physical activity (Figs 1 and 2). Effect sizes (d) for the lower heart rates in the highly fit compared with the moderately fit subjects at the second minute of the cold-face test and the two recovery measurements were 0.45, 0.43, and 0.44, respectively (Fig 1B). Heart rate was lower for the highly active group compared with the moderately active group during the last minute of recovery (d~0.48) (Fig 1D).

**Carotid-Cardiac Baroreflex at Rest and During Mental Arithmetic**

We expected baroreflex gain or sensitivity, indicated by the slope of the relation between ECSP and maximal R-R interval, to be greater at rest and during mental arithmetic for highly fit and highly active groups compared with moderately fit and moderately active groups, respectively. According to Rowell,$^4$ differences in heart rate before application of pressure can change the set point, decreasing baroreflex gain as the initial heart rate increases. Differences in baseline heart rate as a function of group and condition were not significant unless noted.

Slopes for maximal R-R interval did not differ between the highly fit and moderately fit groups at rest, but the intercept for the highly fit group was significantly greater (86.47±30.5) (milliseconds±SEE) [F(1,127)=8.06, P<.01] (Fig 3A), indicative of bradycardia across levels of neck suction in the highly fit group. Slopes and intercepts for maximal R-R interval at rest were not different as a function of physical activity level (Fig 3B).

Slopes and intercepts for maximal R-R intervals during mental arithmetic did not differ between the highly fit and moderately fit groups (Fig 3C). However, the slope for maximal R-R interval during mental arithmetic was significantly greater [F(1,106)=5.07, P<.05] for the moderately active compared with the highly active subjects (Fig 3D). Maximal R-R intervals were smaller at the lower applied pressures in the moderately active group but were comparable to those in the highly active group at the higher pressures.

Responses during rest and mental arithmetic were compared within each fitness and activity group, but no differences between testing conditions were found for the highly fit and highly active groups (Fig 4A and 4B), although baseline heart rate for the highly active group was significantly different between rest and mental arithmetic \(t(15)=2.4, P<.05\). Also, the slopes for the response during mental arithmetic were more curvilinear than slopes measured at rest. First- and second-order regression lines were fit to the baroreflex responses during mental arithmetic (Fig 4A and 4B), and a significant quadratic trend was found for the highly fit \[F(1,9)=174.24, P<.0001\] and the highly active \[F(1,10)=208.75, P<.0001\] group data.
FIG 4. Line graphs show carotid-cardiac baroreflex response depicted by maximal R-R interval response as a function of estimated carotid sinus pressure (ECSP) at rest and during mental arithmetic for the highly fit group (A), highly active group (B), moderately fit group (C), and moderately active group (D). First- and second-order regression lines are shown for the highly fit group data (A) and the highly active group (D) during mental arithmetic. Values are mean±SEM.

The slope for maximal R-R interval was significantly greater during mental arithmetic compared with rest in the moderately fit group \( F(1,116)=5.54, P<.05 \) and the moderately active group \( F(1,106)=15.75, P<.0001 \) (Fig 4C and 4D). Attenuation of the carotid-cardiac baroreflex occurred in each of these groups when low negative pressures were applied to the neck during mental arithmetic compared with rest.

Discussion

We have described a cross-sectional comparison of young white, normotensive women with a parental history of hypertension who were divided into two groups based on either aerobic fitness or physical activity levels. The moderating effects of \( \text{VO}_2\text{peak} \) and physical activity levels were examined separately for heart rate and blood pressure responses to mental arithmetic and the cold-face test and for the carotid-cardiac baroreflex at rest and during mental arithmetic. Subjects were tested during the follicular menstrual phase to control for variations in cardiovascular responsiveness across the menstrual cycle.

We did not find clear support for hypotheses that high fitness and high physical activity would be associated with lower resting heart rate or blood pressure responses to mental arithmetic or the cold-face test. However, the highly fit women had longer R-R intervals compared with the moderately fit women during stimulation of the carotid-cardiac baroreflex at rest. Also, the carotid-cardiac baroreflex was attenuated during mental arithmetic compared with rest in both the moderately active and moderately fit women but not in the highly fit and highly active groups. The baroreflex responses are consistent with greater parasympathetic tone during sympathetic challenge for the highly fit and highly active subjects.

The attenuated carotid-cardiac baroreflex observed during mental arithmetic in the present study is consistent with previous reports by other investigators. Anderson et al43 found increased muscle sympathetic nerve activity during mental arithmetic even with carotid baroreflex stimulation. Ditto and France44 observed a decreased carotid-cardiac reflex in women during mental arithmetic compared with resting conditions. Floras and colleagues45 reported that women with untreated primary hypertension who had an attenuated cardiac baroreflex to phenylephrine-induced increases in SBP also had higher MAP during mental arithmetic. Our findings suggest an enhanced parasympathetic influence at the lower pressures in the highly fit and highly active groups compared with the less fit and less active groups. Physical activity and aerobic fitness may modify the carotid-cardiac baroreflex during stress by improved parasympathetic tone.

Our results do not support the hypothesis that carotid-cardiac baroreflex sensitivity at rest would be greater as a function of aerobic fitness or physical activity levels. However, the larger intercept for R-R interval in the highly fit and active groups compared with the moderately fit and active groups was consistent with the bradycardia demonstrated during other stressors. Although there was no difference in the sensitivity of the carotid-cardiac baroreflex between rest and mental arithmetic response in the highly fit and highly active
groups, both moderately fit and moderately active groups showed a difference in slopes between measures at rest and during mental arithmetic. The steeper slope observed during mental arithmetic was explained by smaller R-R intervals during application of lower pressures, with R-R intervals similar to those at rest during application of higher pressures. These observations are consistent with an attenuation of the cardiovagal response for the moderately fit and active groups through a stressor-induced increase in sympathetic activity. 26,43

The carotid-cardiac baroreflex responses in the highly fit and highly active groups during mental arithmetic were different from their responses at rest. The more curvilinear slope during mental arithmetic suggests a response saturation at higher levels of pressure not evident during pressure applications at rest 62 but no difference in parasympathetic tone between mental arithmetic and rest at lower applied pressures.

The use of more subjects with a larger separation in VO2peak or physical activity may detect lower heart rate and SBP during mental arithmetic and the cold-face test in similar studies of highly fit and active subjects. Our highly fit and highly active groups had heart rates that were about one-third SD lower than those of the moderately fit and moderately active subjects, indicating a bradycardia maintained during mental arithmetic. A similar bradycardia was observed for the highly fit group during the cold-face test. About 20 subjects in each group would have provided a power of 0.80 for detecting these smaller-than-expected effects in this experiment. A greater dichotomy of fitness or physical activity may yield larger group differences in heart rate and SBP during sympathetic challenge. 22 Our comparison of highly versus moderately fit and active subjects addresses the dose-gradient effects of fitness and physical activity on autonomic responsiveness. Comparisons with low fitness subjects also can address the effects of physical inactivity.

We hypothesized that heart rate and blood pressure would be significantly lower for highly fit and highly active groups during the cold-face test. The cold-face test was not successful in eliciting the vagal response of lowered heart rate described by other investigators. 10,26 Anderson et al 26 and Muranaka et al 9 reported increased SBP and DBP during administration of the cold-face test, but they reported larger increases in DBP presumably associated with α-adrenergic activation. Increases in SBP were larger than increases in DBP in the present study, regardless of fitness or activity levels. The SBP response observed in the present study leads us to question the generalizability of vagal and α-adrenergic activation during prolonged application of the cold-face test.

The roles of the parasympathetic and sympathetic nervous systems and the separate contributions of physical activity and aerobic fitness in stress responsiveness need further study. Increased parasympathetic tone 46,47 and possible decreases in peripheral sympathetic tone 47 associated with aerobic fitness could modify the heightened sympathetic activity reported for young adults with a parental history of hypertension. Few studies have been conducted in this area. Thus, little is known about psychophysiological mechanisms, particularly sympathetic and parasympathetic influences that regulate the stress response in women. 10 We are unaware of other studies comparing the carotid-cardiac baroreflex at rest and during sympathetic challenge in women with a parental history of hypertension while controlling for menstrual status. Thus, our study increases the understanding of how fitness and physical activity moderate autonomic responses that are relevant for health. Clarification of autonomic balance during carotid baroreflex stimulation at rest and during sympathetic challenge before and after exercise training would provide important information regarding mechanisms that regulate the responses of heart rate and blood pressure at rest and in response to autonomic challenge.

Understanding the effect of aerobic fitness and physical activity on autonomic responses during stress is an important area of research into the role of exercise in the primary and secondary prevention of mild hypertension. Past studies show that a regular program of moderately intense physical activity is accompanied by clinically important reductions in resting blood pressure. A clinical implication suggested by our findings is that physical activity and cardiorespiratory fitness may help regulate blood pressure during stress by enhancing parasympathetic tone. The efficacy of such effects for the prevention of primary hypertension in normotensive groups at risk for developing hypertension warrants investigation. We recommend that future studies in this area manipulate physical activity and aerobic fitness independently of each other and use measures of sympathetic and parasympathetic influence on autonomic responses, such as heart rate variability. 20,48

References


Autonomic responses of women with parental hypertension. Effects of physical activity and fitness.
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