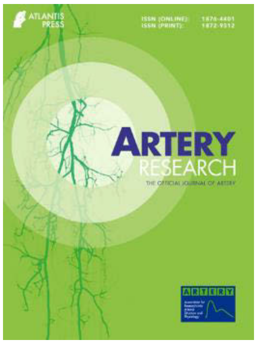

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Short communication

The acute effect of maximal aerobic and isometric exercise on arterial stiffness parameters in boys and men

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KEYWORDS
Arterial stiffness;
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Aerobic;
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Abstract *Purpose:* To evaluate whether the acute effects of aerobic or isometric exercise on arterial stiffness parameters differ between boys and men.
Methods: Fourteen boys (10 ± 2 years, BMI 17.8 ± 1.9 kg/m^2) and nine men (26 ± 3 years, BMI 24.4 ± 3.3 kg/m^2) completed maximal aerobic and isometric exercise testing. Blood pressure and arterial stiffness parameters [β-stiffness index, central pulse wave velocity (PWV)] were measured at rest, 5- and 20-min post-exercise.
Results: Systolic blood pressure (SBP) increased at 5 min and returned to resting values at 20 min in both groups for aerobic exercise (time $p < 0.01$). Men had a greater increase in SBP at 5 min post-isometric exercise than boys (interaction $p < 0.01$). Diastolic blood pressure was not different between groups for either exercise mode. At 5 min, aerobic exercise induced increases in β-stiffness index with greater increases seen in men (interaction $p < 0.01$). Isometric exercise resulted in opposite β-stiffness index responses; men increased whereas boys decreased (interaction $p < 0.05$). Boys had lower baseline PWV than men at all time points ($p < 0.01$) and PWV significantly increased in men at 5 min post-aerobic exercise ($p = 0.01$); this interaction approached significance ($p = 0.051$).

Abbreviations: BMI, body mass index; MVC, maximal voluntary contraction; PWV, pulse wave velocity; AC, arterial compliance; EP, elastic modulus; SBP, systolic blood pressure.

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Conclusion: Boys show a differential arterial stiffness response following both aerobic and isometric exercise in comparison to men, which may be attributable to the seemingly quicker SBP recovery seen in boys.

Background

Large artery distensibility decreases with age leading to an increase in arterial stiffness, which is an independent predictor of future cardiovascular events and mortality.[1] Arterial stiffness increases throughout childhood[2] but can be modulated by lifestyle factors as stiffness increases with obesity and hypertension and decreases with greater amounts of physical activity in children.[3] Additionally, fitness is associated with arterial stiffness in children[4] and adults with metabolic syndrome.[5] These factors lead one to believe that arterial health can by affected in childhood and potentially mitigated by exercise. Additionally, with age, maturation of the autonomic nervous system produces increases in sympathetic nervous system activity and reductions in parasympathetic nervous system input, which may also contribute to arterial stiffness.[6]

In adults, an acute bout of aerobic exercise has been shown to reduce arterial stiffness, whereas resistance exercise increases arterial stiffness.[7] Exercise may also provide a stimulus to unmask potential differences between populations that do not exist at rest.[8] While children have lower blood pressure responses to both aerobic[9] and isometric exercise,[10] which would likely influence changes in arterial stiffness following both exercise modes, little information is available. Thus, understanding the vascular responses to acute exercise can provide important information about vascular differences between healthy age groups. We hypothesize that boys will have a smaller reduction in arterial stiffness post-aerobic exercise and smaller increase in arterial stiffness post-resistance exercise compared to men, and that the boys would show a quicker recovery to baseline values post-exercise.

Aim

The aim of this study was to evaluate whether the acute effects of maximal aerobic or isometric exercise on arterial stiffness parameters differ between boys and men.

Methods

Twenty-three healthy and recreationally active males, fourteen boys (10 ± 2 years) and nine men (26 ± 3 years), were recruited for voluntary participation. The level of sexual maturation was not determined for the boys, but, no significant pubertal influences were expected based on their age. Written informed consent was obtained from all children's parents and all adult participants. This study was approved by the institutional review board at the University of Illinois at Urbana–Champaign.

On experimental days, participants reported to the lab having refrained from caffeine and a minimum 3-h fast. Body mass (kg) and height (cm) were measured and used to calculate body mass index (BMI) (kg/m^2).

The two visits were randomized but occurred at the same time of day. During visit one, participants performed a graded exercise test on a stationary cycle ergometer (Lode Excalibur Sport, Lode, Netherlands) to voluntary exhaustion to assess maximal aerobic capacity. Cycling began at 25 W and increased 25 W every 3 min until exhaustion. Heart rate was determined electronically by an ECG monitor. Maximal work rate attained was used as a measure of aerobic capacity.

During visit two, isometric testing of maximal muscular strength of the quadriceps was performed using a leg dynamometer (Biodex, Shirley, NY) to determine maximal voluntary contraction (MVC).[11] Following a 5-min rest, a 3-min isometric contraction at 30% MVC was performed. These two modes of exercise were chosen because they produce opposite responses in arterial stiffness in adults.[7]

Heart rate was measured via a three lead electrocardiogram. Brachial blood pressure was measured by standard auscultatory methods on the left arm. All physiologic variables and carotid measurements were determined in the supine position at rest, 5-, and 20-min post-exercise. Immediate post-exercise measurements were not obtained as 5-min was required to position each participant, whereas previous research suggests at 20-min after acute exercise, significant alterations occur in the vascular wall properties, hence our reasoning for including this time point.[12] Central pulse wave velocity (PWV) was assessed by sequentially recording pressure waveforms from the carotid and femoral arteries (SphygmoCor SCOR, PWV Medical, Sydney, Australia) using standard methods.[13] Carotid artery diameters were obtained via ultrasonography using a high frequency (5–13 MHz) linear array probe (Aloka Ultrasound 5500 System, Japan) and β-stiffness index was calculated.[14]

Findings are expressed as mean ± SD. Two-way repeated measures ANOVA (time * group) was used to compare boys and men. When the ANOVA yielded a significant result ($p < 0.05$), post-hoc comparisons were made using the Bonferroni correction for multiple comparisons. Data analysis was performed with SPSS software, version 22.0 (Chicago, IL).

Results

Mean height, body mass, and BMI values for boys were 143 ± 9 cm, 36.9 ± 7.4 kg, and 17.8 ± 1.9 kg/m^2, respectively, and 175 ± 6 cm, 74.8 ± 11.0 kg, and 24.4 ± 3.3 kg/m^2 for men. The boys achieved significantly lower maximal work rate of 102 ± 12 W on the maximal exercise test and significantly lower maximal isometric torque of 93 ± 23 ft lbs, compared to the men (206.25 ± 34.7 W and 226.6 ± 76 ft lbs). Boys also attained significantly higher maximal heart rates compared to men (196 ± 12 vs 186 ± 8 bpm). Table 1 outlines hemodynamic variables at rest, 5-, and 20-min post-exercise.

Boys had lower resting systolic blood pressure (SBP) than men ($p < 0.05$). SBP during aerobic exercise increased at 5-min post and returned to resting values at 20-min in both groups (p for time <0.01), whereas men had a much greater increase in SBP 5-min post-isometric exercise than boys (p for interaction<0.01). Diastolic blood pressure was not different between groups for either mode of exercise ($p > 0.05$) and isometric exercise elicited a change over time ($p < 0.01$).

Boys had lower PWV than men at all time points ($p < 0.01$) and PWV significantly increased in men at 5 min post-aerobic exercise ($p = 0.01$); this interaction approached significance ($p = 0.051$) (Fig. 1). Group-by-time interaction effects were found in both aerobic ($p = 0.04$) and isometric ($p = 0.04$) exercise for β-stiffness. Aerobic exercise caused a smaller increase in stiffness 5-min post-exercise for boys and boys produced opposite (reduced stiffness) changes compared to men after isometric exercise.

Table 1 Hemodynamic variables at baseline, 5 min, and 20 min post aerobic and isometric exercise.

	Rest	5 min post	20 min post
Heart rate (bpm)			
Aerobic[c]			
Boys	78 ± 12	102 ± 13[e]	90 ± 14[e,f]
Men	56 ± 8[d]	99 ± 13[e]	92 ± 15[e,f]
Isometric[c]			
Boys	77 ± 9	72 ± 10[e]	72 ± 9[e]
Men	57 ± 8[d]	66 ± 13[e]	62 ± 10[d]
Systolic blood pressure (mmHg)			
Aerobic[a,b]			
Boys	111 ± 12	130 ± 16[e]	111 ± 11[f]
Men	117 ± 16	146 ± 26[e]	125 ± 14[d,f]
Isometric[c]			
Boys	105 ± 12	107 ± 12	102 ± 11[f]
Men	118 ± 12[d]	144 ± 22[d,e]	122 ± 16[d,f]
Diastolic blood pressure (mmHg)			
Aerobic			
Boys	67 ± 8	66 ± 12	72 ± 8
Men	63 ± 8	63 ± 10	65 ± 8
Isometric[b]			
Boys	66 ± 6	73 ± 8[e]	71 ± 6[e]
Men	65 ± 6	71 ± 5	65 ± 6

Values are mean ± SD. $N = 14$ for boys aerobic; $N = 13$ for boys isometric; $N = 9$ for men.
[a] Main group effect.
[b] Main time effect.
[c] Group * time interaction effect.
[d] Different from boys at time point.
[e] Different from baseline value.
[f] Different from 5-min post; $p < 0.05$ for all.

Discussion

Following maximal exercise, boys revealed an altered arterial stiffness response in comparison to men. In boys, acute aerobic exercise elicited a smaller increase in stiffness whereas isometric exercise resulted in a decrease in stiffness, which was opposite men. Interestingly, boys increased stiffness in response to aerobic exercise which has also been shown in adults 0–15 min after exercise.[15] The decrease in stiffness in response to isometric exercise in boys however, is a unique finding not previously reported. This suggests differential regulation of arterial function in boys versus men, which may be related to differences in sympathetic output or transduction.[16,17]

The blood pressure response may indicate why we saw differential stiffness responses. Albeit boys having an initial lower SBP than men, they may recover more quickly following exercise, evidenced by smaller differences in SBP from rest to 5 min in both aerobic and isometric exercise. This recovery of SBP may partially explain why we see a stiffness decrease in boys and increase in men post-isometric exercise and a similar stiffness response following aerobic exercise but of different magnitude. A previous study has shown increased cardiac parasympathetic nervous activity and greater central cholinergic modulation of heart rate in children compared to young adults leading to a quicker heart rate recovery post-acute exercise, which may be applicable to blood pressure as well.[18] However, Heffernan et al. showed opposite arterial stiffness responses following aerobic (decreased stiffness) and resistance exercise (increased stiffness) in men, while there was no difference in sympathetic modulation between the exercise modes.[7] Future studies with data during exercise could further clarify if changes in stiffness are attributable to a higher rise in stiffness during exercise or a quicker blood pressure recovery in children.

These differential stiffness responses may be attributable to arterial composition, such that children have a higher elastin to collagen ratio whereas adults have increased collagen in central arteries.[19,20] Greater elastin allows for tensile support but also the ability to distribute stress uniformly throughout the arterial wall in order to dissipate pressure as blood flows through the arterial tree, increasing compliance and decreasing stiffness. This increased arterial compliance observed in children is beneficial to reduce the workload on the heart, as well as decrease risk of end organ damage.

There are several limitations to our study. Our sample size is small and only boys and men were included. Thus generalizing our findings should be done with caution due to our sample. Brachial blood pressure was used for calculation of carotid beta stiffness instead of central blood pressure. This could have a high impact on the outcomes due to the known differences in pulse pressure amplification between individuals even with similar brachial pressures, and that amplification is higher in younger individuals.[21] Additionally, there are expected differences

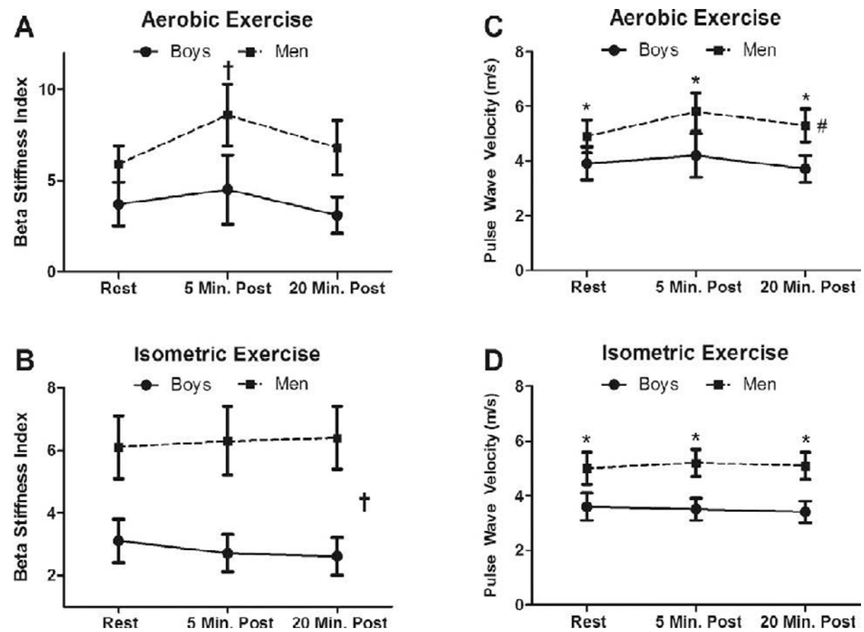

Figure 1 Beta stiffness index (A, B) and pulse wave velocity (C, D) response to aerobic and isometric exercise in boys and men. Values are means ± SD. *: Groups significantly different at time point ($p < 0.05$); #: Significant time effect ($p < 0.05$); †: Significant group * time interaction effects ($p < 0.05$). Interaction effect for beta stiffness index (Panels A and B) following aerobic exercise with a greater magnitude of increase in men at 5-min post; and following isometric exercise with the response in opposite directions (increase in men, decrease in boys over time) ($p < 0.05$). PWV was significantly lower in boys than in men at all time points for both aerobic (panel C) and isometric (panel D) exercise. Following aerobic exercise, PWV increased in men but not in boys at 5-min post and the interaction effect approached significance ($p = 0.51$).

in outcome measures at baseline between boys and men that should be considered when interpreting the data. Furthermore, the difference between boys and men in the time of exercise during the maximal aerobic exercise may have influenced our results.

Overall, boys and men have a differential arterial stiffness response following maximal aerobic and isometric exercise, which may be attributable to the differences in blood pressure recovery.

Conflict of interest statement

The authors have no conflicts of interest or financial disclosures to report.

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Subject characteristics of the child group and exercise protocols have been previously published (Eur J Appl Phys and MSSE), but none of the current data other than subject characteristics of the boys appear in those publications.

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