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Are there Differences between Adolescent Males and Females for Maintaining the Metabolic Cost at Maximal Oxygen Uptake?

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Abstract

Purpose: The present study looked at gender difference in oxygen delivery-extraction at maximal oxygen uptake in healthy adolescents.

Methods: 36 adolescent males (14.9 ± 1.1 years) and 33 adolescent females (15.0 ± 1.1 years) underwent a maximal oxygen uptake test and a two dimensional direct m-mode echocardiography performed on a bicycle ergometry. Arteriovenous oxygen difference was defined by utilizing the Fick equation.

Results: At rest, males compared to females had significantly ($p<0.05$) higher oxygen extraction (38.8 ± 1.4 and 31.8 ± 1.2 $mL.kg^{-1} min^{-1}$ respectively), systolic blood pressure, and mean arterial blood pressure. At peak exercise test, males compared to females demonstrated significant ($P<0.05$) higher values for cardiac output (16.6 ± 0.7 and 15.4 ± 0.6 $L{\cdot}min^{-1}$ respectively), stroke volume (83.9 ± 5.1 and 78.5 ± 4.6 mL respectively), oxygen uptake (47.3 ± 3.7 and 39.6 ± 1.1 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$, respectively), while oxygen extraction was significantly higher in females compared to males (123.6 ± 7.6 and 115.5 ± 5.4 $mL.L^{-1}$ respectively).

Conclusions: This study suggests that normal adolescents; male and females respond to the maximal oxygen uptake test by increased their left ventricular systolic function, however, it was less augmented in the females due to gender and energy metabolism differences. Consequently, females increased their oxygen extraction more than the males as a compensation for the lower cardiac output and hence, lower oxygen delivery.

Keywords: Oxygen extraction; Oxygen delivery; Echocardiograph; Cardiac output; Fick equation

Introduction

Maximal oxygen uptake (VO_{2max}) can be limited by oxygen delivery, arterial oxygen content and oxygen extraction [1]. Mean values for VO_{2max} in children, adolescents and adults are consistently greater in males than females, whether VO_{2max} is expressed in absolute terms or relative to lean body mass [2]. Factors linked mainly to oxygen-carrying capacity and cardiac size have been shown to contribute significantly to this gender-related difference [3]. The difference between females and males that facilitates oxygen extraction is the differences in muscle fiber recruitment patterns [3].

During the period of adolescence, many structural, hormonal, biochemical and physiological changes take place that interfere with the oxygen delivery and extraction relationship. As a consequence, maximal levels of the aerobic exercise test can create a response of significant lactic acidosis [4], left ventricular contractility and function in healthy adolescent subjects may be altered. Namely, exercise may induce a myocardial phenotype that reduces Ca^{+2} responsiveness during acidosis [5].

Although much data is available on left ventricular function and VO_{2max} in adolescents, little data is available on gender differences at this age in relation to the balance between oxygen delivery and oxygen extraction at VO_{2max}. Therefore, the purpose of the present study was to look at gender differences in oxygen delivery and utilization at VO_{2max} in adolescents males and females.

Methods

Subjects

69 adolescents which covered a range of fitness levels, volunteered to take part in this study. They were 36 males (15.1 ± 1.1 yrs.) and 33 females (14 ± 1.3 yrs.). Subjects were recruited from nearby schools and subjects were cleared to participate *via* a coronary artery screening process and medical history. A written informed consent was obtained from each subject's parents, which was approved by the Clinical Science Center Committee on Human Subjects and by the Institution Review Board.

Procedure and measurements

Each subject reported to the laboratory two times. The first session was devoted to accustom the subjects to the study procedures and to the general scope of the study. During the second session, subjects underwent a maximal graded exercise test on a mechanical weight-adjusted Monark cycle-ergometer (Model 818). Maximal tests were terminated by the following criteria: a) leveling off or no further increase in VO_2 with increasing work rate, b) respiratory exchange ratio >1.1, or c) when the subject could not keep up with the load, according to the guidelines of the American College of Sports Medicine [6].

Subjects were tied by torso-straps to the wall while cycling to

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minimize movement of the upper body and to facilitate auscultation of blood pressure and echocardiographic measurements at peak exercise. Time of day for testing was kept consistent among subjects to control for problems associated with diurnal variations.

Oxygen uptake was determined *via* breath by breath utilizing the Medical Graphics (St. Paul, MN) metabolic cart. The metabolic cart was calibrated before each test with known primary standard quality gases. A 12-lead electrocardiogram and heart rate were continuously monitored at rest, during exercise and recovery. Five-second recordings were obtained at rest and at VO_{2max}. Following warm-up, the adolescents pedaled against an initial work rate of 50 watts which was increased by 25 watts every minute until the subject could no longer continue at the predetermined pace of 80 rpm. Cardiac output was measured at peak exercise by means of echocardiography. Blood pressure was taken using a standard sphygmomanometer cuff and mercury manometer mounted at eye level, in the sitting position at rest and at peak exercise.

A 25 µ fingertip blood sample was taken at rest and during the 2nd minute of recovery after completion of the exercise test to determine the lactic acid concentration at peak aerobic effort. The sample was immediately transferred to a micro-tube containing 100 µ of 7% perchloric acid. The tubes were centrifuged after standing for at least 1 hour. Twenty microliter aliquots of the supernatant were subsequently used for lactic acid analysis on the Analox LM3 analyzer (Analox Instruments, England; Reagent Kit No. GMRD-071).

Echocardiographic data processing

All echocardiographic studies were performed with the subjects in the sitting position at rest, and at peak aerobic effort, according to the recommendations of the American Society of Echocardiography.

Adipose fat assessment included measurement of total body weight (± 0.05 kg) and skin folds thicknesses at 8 sites (± 1 mm) using the Lange Caliper (chest, acilla, triceps, subscapula, abdomen, suprailium, quadriceps and circumferences at the shoulder). Antropometric procedures followed the recommendations of Behnke and Wilmore.

Calculations

At rest and during exercise variables were computed as follow:

Stroke volume is the difference between left ventricular end diastolic volume and end systolic volume.

Left ventricular mass index was calculated according to Devereux [7].

Left ventricular contractility is the result of systolic blood pressure over end systolic volume.

Cardiac output is the product of heart rate and stroke volume.

Total peripheral resistance is calculated as: (mean arterial blood pressure × 80)/cardiac output [8].

Arteriovenous oxygen difference [$(a\text{-}v)O_2$] was calculated from cardiac output (Q) and oxygen uptake (VO_2) using the Fick Principle.

$$Q = VO_2/(a\text{-}v)O_2$$

Therefore,

$$(a\text{-}v)O_2 = VO_2/Q.$$

Statistical methods

Two-way ANOVA with repeated measures on the rest exercise dimension was employed for each of the variables measured in order to detect variations in the experimental parameters. In addition, Turkey HSD procedure was used for specific Post-Hoc comparisons.

Results

All subjects completed the test without any difficulties or clinical abnormalities. Descriptive data of the subjects‘ physical characteristics are given in Table 1. It can be seen that hemoglobin level did not differ between groups. Weight, lean body mass, height and left ventricular mass index were significantly ($p<0.05$) higher for males. Descriptive statistics for the hemodynamic and left ventricular responses are given in Table 2. At rest, males had significantly higher values compared to females in ($p<0.05$) $(a\text{-}v)O_2$, end diastolic dimension, systolic blood pressure and mean arterial blood pressure. At peak exercise test, males had significantly higher values compared to females in ($P<0.05$) cardiac output, stroke volume (Figure 1), VO_{2max} (Figure 2), VO_2m_{2max} corrected for lean body mass, end diastolic and systolic volumes, systolic blood pressure, $(a\text{-}v)O_2$ and workload, while females achieved a significant ($P<0.05$) higher values for $(a\text{-}v)O_2$ (Figure 3).

Variable	Males	Females
N of subjects	36	33
Age (years)	14.9 ± 1.1	15.0 ± 1.1
Weight (kg)	44 .3 ± 3.9	49.3 ± 3.9‡
Height (cm)	167.7 ± 3.1	155.6 ± 5.4‡
Fat (%)	15.5 ± 0.4	20.2 ± 0.3‡
Lean body mass (kg)	44.9 ± 2.2	42.2 ± 2.9‡
Venous hemoglobin ($g{\cdot}dl^{-1}$)	13.9 ± 0.9	13.5 ± 0.8
Left ventricular posterior wall (mm)	10.0 ± 1.0	10.0 ± 1.0
Intraventricular septum thickness (mm)	10.0 ± 1.0	10.0 ± 1.0
Left ventricular mass index ($g{\cdot}m^{-2}$)	71.9 ± 4.2	67.0 ± 3.5‡
Aortic valve diameter (cm)	1.7 ± 0.2	1.7 ± 0.2
‡ = significant differences between groups		

Table 1: Subjects' physical characteristics at rest (mean ± S.D.).

Variable	Males		Females	
	REST	AEROBIC	REST	AEROBIC
HR ($beats{\cdot}min^{-1}$)	73.7 ± 4.7	198.1 ± 9.7	78.1 ± 3.7	196.1 ± 8.7
Q ($L{\cdot}min^{-1}$)	4.7 ± 0.3	16.6 ± 0.7	4.8 ± 0.2	15.4 ± 0.6†
EDV (mL)	98.4 ± 4.6	121.8 ± 7.2	95.6 ± 4.6	111.8 ± 6.9†
ESV (mL)	34.2 ± 2.1	37.7 ± 2.8	34.2 ± 2.9	33.3 ± 1.8†
SBP (mmHg)	115.4 ± 6.2‡	183.7 ± 6.4	107.8 ± 6.2	172.9 ± 5.3†
DBP (mmHg)	65.6 ± 6.6	62.2 ± 5.3	61.7 ± 5.6	60.2 ± 5.3
MABP (mmHg)	82.2 ± 4.9‡	102.7 ± 8.4	77.1 ± 4.7	97.8 ± 7.9
P/V (ratio)	3.4 ± 0.5	4.9 ± 1.1	3.2 ± 0.4	5.2 ± 1.2
TPR ($dynes{\cdot}s^{-1}{\cdot}cm^{-}$)/10	137.0 ± 14.0	49.5 ± 6.9	140.0 ± 9.4	50.8 ± 6.9
LBM VO_2($mL{\cdot}kg^{-1}{\cdot}min^{-1}$	4.0 ± 0.3	51.2 ± 2.7	3.5 ± 0.3	48.4 ± 2.8†
LA ($mM{\cdot}l^{-1}$)	1.4 ± 0.3	12.3 ± 1.7	1.4 ± 0.3	10.9 ± 1.9
ML (watts)	-------	188.0 ± 8.9	-------	165.0 ± 9.4†

‡: significant differences between groups at rest; †: significant differences between groups at peak aerobic exercise; HR: Heart Rate; SV: Stroke Volume; Q: Cardiac output; EDV: End Diastolic Volume; ESV: End Systolic Volume; SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure; MABP: Mean Arterial Blood Pressure; P/V: SBP/ESV; TPR: Total Peripheral Resistance; VO_2: Oxygen uptake; LBM: Lean Body Mass; $(a\text{-}v)O_2$: Oxygen extraction; LA: Lactic Acid; ML: Maximal Load

Table 2: Hemodynamic responses and echocardiographic measurements at rest and at peak aerobic exercise (mean ± SD).

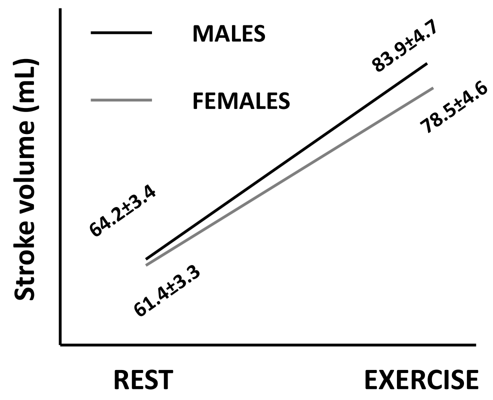

Figure 1: Stroke volume responses for adolescent males and adolescent females at rest and at maximal aerobic exercise.

Figure 2: Oxygen uptake responses for adolescent males and adolescent females at rest and at maximal aerobic exercise.

Figure 3: Oxygen extraction [$(a-v)O_2$], responses for adolescent males and adolescent females at rest and at maximal aerobic exercise.

Discussion

The present study did not show a significant difference between males and females in lactic acid at peak exercise, gender differences in absolute oxygen uptake and extraction values were revealed. In adults, gender differences in VO_{2max} have been attributed to daily level of physical activity, body composition, blood hemoglobin concentration, cardiac size and function.

One factor that can explain the differences in VO_{2max} is the habitual physical activity level in adolescent males compared to adolescent females. Habitual physical activity level typically is greater in adolescent males; however it is unlikely that habitual physical activity level plays an important role in defining differences in physical fitness. That reason helped determine how adolescent males and adolescent females were definitive the physical education teachers report in similar levels of habitual activity. In addition, subjects were selected for their non-athleticism. The daily level of physical activity in adolescents typically lacks the physiological trigger to sufficiently improve $\dot{V}O_{2max}$, thus, additional factors must contribute to gender differences in achieving VO_{2max} in adolescents besides habitual physical activity level factors such as body composition, cardiac output and oxygen extraction.

Other factors explaining the significantly higher values of absolute oxygen uptake in the male adolescents is the differences between the groups in fat percentage. Expressing VO_{2max} relative to fat-free mass or lean body mass did not eliminate these differences although they were reduced slightly. Differences in body composition were one factor for this gender difference. In the present study, the average percent of body fat was 15.5% for the male adolescents and 20.2% for the adolescent females and when VO_{2max} was expressed relative to lean body mass the gender gap was narrowed to 5.8 from an earlier gap of 12.8%. The influence of body fat on gender differences in VO_{2max} per kilogram correlates with data reported previously for boys and girls [2]. The mean body fat content of the young adult woman is approximately 1.7 times greater than her male peers, an inert exercise load that contributes to the „per kilogram" denominator in expressions of maximal aerobic power [9]. When VO_{2max} comparisons are made between men and women relative to lean body mass instead of total body mass, the gender difference is reduced by approximately one half [7]. Mean values for VO_{2max} are consistently greater in boys than in girls throughout the course of childhood, adolescence, and adulthood [2]. This gender-related difference in aerobic fitness is evident whether VO_{2max} is expressed in absolute terms or relative to lean body mass. Thus, according to the Fick equation, gender differences in VO_{2max} that remain after body composition correction must be explained by oxygen delivery and oxygen extraction.

Oxygen delivery is composed of hemoglobin concentration, the ability to carry oxygen, and cardiac function. The present study's hemoglobin concentrations were measured virtually identical in the adolescent males and adolescent females. Thus, it did not play an important role in observed gender differences in aerobic fitness. The hemoglobin values reported in the present study are in concur with previously reported values for male and female adolescents [10], however, they differ from those reported for adults. The erythrogenic stimulation of testosterone at adolescence gives adult men a 2 $g\,dL^{-1}$ greater hemoglobin level than women and correspondingly higher arterial blood oxygen content. Since venous oxygen content at maximal exercise is independent of gender, the maximal $(a-v)O_2$ difference is typically about 20% greater in adult men [11]. In addition, adult women have a smaller heart size, a diminished rise in exercise ejection fraction, and a lower maximal cardiac output than men, even when body size and composition are taken into account [12]. This indicates adolescence has no influence in hemoglobin concentration on gender differences at VO_{2max}, and suggests the present study's exercise oxygen uptake values were maintained by the interplay between the oxygen transport system and oxygen extraction. We assume the subjects were healthy differences in oxygen uptake and were not abnormal due to hemoglobin levels and hemoglobin saturation differences.

Thus, cardiac output and oxygen extraction are two major factors that can limit oxygen uptake at maximal exertion. In young healthy subjects, VO_{2max} attained at maximal effort is determined by a combination of oxygen delivery and oxygen extraction. If there is no pulmonary limitation (e.g., arterial desaturation), arterial oxygen content stays relatively constant up to maximal exertion, and venous oxygen content is reduced to the point that the local oxygen pressure in the capillaries becomes insufficient to drive oxygen diffusion into the tissues. At maximal exertion, oxygen extraction can reach values of 140-180 $mLO_{2.}L^{-1}$ blood [13].

The adolescent females increased their oxygen extraction from rest to maximal exercise significantly higher than males. Our data suggest that a significant increase in oxygen extraction compensated for the lower cardiac output in adolescent females, since, the adolescent males increased their cardiac output from rest by 353% and the adolescent females increased it by 321%. Males have larger muscle fibers than females, but similar fiber composition to females, influencing metabolism and the adaptive response to exercise [14]. The higher oxygen extraction during the maximal aerobic test among female adolescents may have been the result of different muscle fiber recruitment patterns or different energy efficiencies of the fibers recruited during exercise. Previous findings [14] indicated that in a normal population, men have larger muscle fibers than women but similar fiber composition. The mechanism that enables the females to increase their oxygen extraction during exercise is the lower velocity of contraction by skeletal muscles [11]. From *in vitro* studies, it has been observed that at low contraction velocities, the efficiency of slow twitch fibers is higher than of fast twitch fibers, and the reverse is observed at high speeds. The increased oxygen extraction by the adolescent females in the present study, do not agree with previously reported data [11]. Therefore, it seems there are no gender differences in energy metabolism that cause differences in VO_{2max} but rather, differences in oxygen delivery.

Cardiac output values for our adolescents at maximal aerobic test were low compared to young adults during maximal bicycle exercise [15]; 16.6 $L.min^{-1}$ in the adolescent males and 15.4 $L.min^{-1}$ for the adolescent females. The explanation for the lower cardiac output in both adolescent groups in the peak aerobic test compared to young adults might be related to: a) smaller ventricular cavities as reflected by the left ventricular mass index, b) the increased after-load, and c) an inappropriate adjustment of the circulation system.

In the present study, at peak aerobic exercise echocardiographic. Indices and blood pressure response in the adolescent males and adolescent females were similar to those seen during peak aerobic exercise in young adults, indicating that adolescents can increase their left ventricular contractility and function as do young adults [14]. Stroke volume was higher in the adolescent males than adolescent females which could be a reflection of the significant differences in left ventricular mass index. It seems adolescent females were not able to increase their stroke volume to higher values which could be attributed to the smaller left ventricular cavities [15]. A study suggested that at maximal exercise, only stroke volume differentiated in males versus females [2]. This gender difference was attributed by certain authors to a higher left ventricular mass in boys, whereas others [2] did not observe any difference in resting echocardiographic measures. To the best of our knowledge, only Rowland et al. [3] focused on children and the impact of cardiac function, size of left ventricular mass and body composition in the gender-related difference of VO_{2max}. These authors demonstrated that cardiac functional capacity (i.e., stroke volume) as well as body composition account for the differences in maximal oxygen uptake between prepubescent boys and girls. Thus, it is not clear how the gender differences in overall cardiac dimensions are related to the gender difference in VO_{2max}. It is also unknown whether heart size differences between adolescent females and adolescent males reflects in only general body size (in particular of lean body mass), or a more fundamental functional difference exist.

Clinical implications

Exercise responses during different modes have been attentive on male subjects. However, gender differences in work capacity, metabolism and cardiovascular responses were seen between males and females during exercise. Considerate gender differences as a tool for clinicians, physiologists and physicians to understand mechanisms responsible for any differences in health and disease. In addition, it is relevant to improve physical performance and training regimes for competitive athletes. Physiological losses in both sexes, of aerobic capacity occur as a natural consequence of disease and aging, but are clearly enhanced by an inactive lifestyle. From a clinical perspective for females and males, increased cardiovascular and metabolic abilities are associated with longevity and decreased risk of disease.

Conclusions

This study suggests that normal adolescents; male and females respond to the maximal oxygen uptake test by increased their left ventricular systolic function, however, it was less augmented in the females due to the gender and energy metabolism differences. Consequently, females increased their oxygen extraction more than the males as a compensation for the lower cardiac output and hence, lower oxygen delivery. This indicates energy metabolism at the working muscles is the same in males and females. Thus, gender differences in energy metabolism at the skeletal muscles do not account for the differences in VO_{2max}.

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