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OXYGEN DELIVERY OF MEN AND WOMEN AT PEAK WINGATE TEST

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Abstract

SAGIV, MORAN; AMIR, OFFER; BEN-SIRA, DAVID; & AMIR, RUTHIE. Oxygen delivery of men and women at peak wingate test. Brazilian Journal of Biomotricity. v. 1, n. 3, p. 65-75, 2007. The present study was designed to investigate the left ventricular function and muscle oxygen delivery in young men and women at peak Wingate anaerobic test. Young healthy men and women underwent the Wingate anaerobic test. Two-dimensional direct M-mode echocardiography studies were performed with the subject seated on a bicycle ergometer. Arterial O₂ was defined from echocardiograph and venous oxygen content. At rest, left ventricular mass index, end diastolic dimension, maximal oxygen uptake, stroke volume and cardiac output were all significantly (p < 0.05) higher in men than in women. At peak Wingate anaerobic test, men compared to women had significantly (p < 0.05) higher values of cardiac output
(14.4±0.6 and 12±0.3 l•min⁻¹, respectively) and stroke volume (78.0±5.0 and 69.0±6.1 ml, respectively), while \((a-v)\text{O}_2\) (118.5±2.9 and 98.1±3.1 mlO₂, respectively), oxygen uptake (26.3±1.4 and 22.7±1.1 ml•kg⁻¹•min⁻¹, respectively) and %\text{VO}_2 out of total energy utilized (10.0 and 11.8 %, respectively) were significantly \((p < 0.05)\) lower. This study indicates gender-related differences in left ventricular response and muscle oxygen delivery of young men and women at peak all-out strenuous exercise. Data suggest that healthy women respond to the Wingate anaerobic test by increasing their muscle oxygen extraction in the face of lower oxygen delivery.

**Key words:** Strenuous exercise, echocardiograph, cardiac output, Fick equation, oxygen extraction.

**Introduction**

During heavy exercise that engenders significant lactic acidosis, oxygen uptake does not achieve steady state but continues to rise until exercise is terminated or exhaustion ensues (BARSTOW et al., 1991; ROSTON et al., 1987). Metabolic and left ventricular responses during incremental exercise differ between men and women of a similar fitness level (BEN-SIRA and SAGIV, 1977; KANG et al., 2006). Previous studies in healthy subjects have demonstrated that during aerobic exercise, oxygen uptake of men exceeds that of women due to gender-related variance in heart size (BEN-SIRA and SAGIV, 1977; SAGIV et al., 1991). It has been also suggested that the gender difference may bring about a relative decline in the performance of the female's heart, such as reduced stroke volume under elevated pressure loads (BEN-SIRA and SAGIV, 1977; SAGIV et al., 1999).

The Wingate anaerobic test is widely accepted and used in the evaluation of anaerobic performance capacity among adolescents and adults. Since this kind of effort is characterized by exposing subjects to a very high degree of sudden strenuous all-out exercise, it alters left ventricular contractility and function in young healthy adults (BEN-SIRA and SAGIV, 1977; FOSTER et al., 1981; SAGIV et al., 2000). Thus, oxygen delivery to the working muscles may be reduced.

Although there are studies on left ventricular function during maximal anaerobic dynamic exercise testing (HILL and SMITH, 1993; HILL et al., 1994; SMITH and HILL, 1991), the physiological variables that maintain muscle oxygen delivery and uptake at peak anaerobic effort are poorly understood. Accordingly, the present study was designed to investigate the cardiorespiratory responses to performing the 30-s all-out Wingate anaerobic test in young healthy men and women.

**Methods**

- **Subjects**

Thirty aerobically well-trained young healthy subjects; 15 men 21.2±1 and 15
women 20.8±1 years, volunteered to participate in this study. None of the female subjects was using birth control pills or receiving hormone replacement therapy. Clinical history revealed that all subjects were judged free of any cardiac problems, had no major medical risk factors and manifested normal responses during graded exercise stress tests up to their maximal oxygen uptake. Written informed consent approved by the Clinical Science Center Committee on Human Subjects was obtained from each subject after being fully informed of the details and possible discomforts associated with the experimental protocol.

- Procedures

Each subject reported to the laboratory three times. Sessions were spaced at least 48 hrs apart and on average at intervals of no more than 1 week. The first session was devoted to accustoming the subjects to the study procedures and general scope of the study. During the second session subjects underwent a graded maximal bicycle exercise test on a mechanical weight-adjusted Monark cycle-ergometer (Model 818). End point for the maximal aerobic exercise test was determined when a further increment in the work-load did not increase oxygen consumption or when the subject could not keep up with the rate of work according to the guidelines of the American College of Sports Medicine (ACSM, 2000). Oxygen uptake was determined 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 during recovery. Five-second recordings were obtained at rest and at peak exercise. Following warm-up, subjects cranked against an initial work rate of 100 watts, which was increased by 25 watts every minute until the subject could no longer continue at the predetermined pace. Blood pressure was taken using a standard sphygmomanometer cuff and mercury manometer mounted at eye level, with the subject in a sitting position, at rest and at peak exercise. During the third session, following warm-up, subjects were asked to perform the 30s all-out Wingate anaerobic test (BAR-OR et al., 1980), utilizing a weight-adjusted Monark cycle-ergometer (Model 864). Subjects were seated on the ergometer with their feet fastened to the pedals by means of racing-type toe-clips, and the seat height was adjusted. In addition, the subjects’ backs were strapped to the wall in order to minimize upper body movement, as well as to facilitate auscultation of blood pressure and echocardiographic measurements at peak exercise. The anaerobic test consisted of 30 seconds of supramaximal pedaling against a resistance determined relative to the subject’s body mass at 80 gr.*kg⁻¹ body weight (HILL and SMITH, 1993). At the command “start”, the subjects commenced cranking the pedals as fast as they could against the ergometer’s inertial resistance. The full, predetermined resistance load was applied within 3-4 seconds after the inertial resistance had been overcome. Pedal revolution count started at that moment by means of an electro-mechanical counter, and subjects maintained an all-out effort throughout the test. Strong verbal encouragement was given to ensure maximal effort. Time of day for testing was kept consistent for all subjects during the second and third testing sessions, to avoid problems
associated with diurnal variations.

- Lactate measurements

A 25 µl fingertip blood sample was taken at rest and at end exercise for determination of lactic acid concentration. 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 one 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

2-D, echocardiographic and M-mode images were performed at rest and at peak Wingate anaerobic test, utilizing a Vingmed 725 Sonotron and Sony recorder equipped with 2 and 3 MHz transducers. The diameters of the aorta were determined by 2-D directed M-mode. The left atrium was measured from the parasternal long-axis view. At rest, left ventricular end-diastolic and end-systolic diameters, inter-ventricular septum and left ventricular posterior wall thicknesses were measured from the parasternal long- and short-axis views as well as from 4 and 5 chamber views, just below the mitral valve level, according to the recommendations of the American Society of Echocardiography (SHAW et al., 1978). At peak Wingate anaerobic test, due to the short time available for measurements, left ventricular volumes and ejection fraction were determined using Simpson’s rule from apical 4 chamber view. All echocardiographic studies were performed with the subjects in the sitting position. The probe was hand-held and directed to a marked point from which the resting data were obtained. The beam was directed to the aortic valve outflow tract in the 5-chamber view, or from the suprasternal approach for those subjects in whom adequate imaging of 5-chamber or parasternal long axis views could not be obtained. To assess the objectivity of the echocardiographic readings, all recordings were evaluated by two independent experts. A high correlation (r = 0.91) was found for inter-observer reliability.

- Calculations

At rest and during exercise variables were computed as follows:

Stroke volume=the subtraction of end systolic volume from end diastolic volume.

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

Venous oxygen content (mLO₂•dl⁻¹) was calculated from the measured O₂ saturation and Hb concentration multiplied by 1.34 mLO₂.

Oxygen saturation and Hb concentration were measured independently in each blood sample (IOSM3 hemoximeter, Radiometer).

Arterial O₂ content was calculated utilizing the Fick equation, in which: \(VO₂ = HR \times SV (a-v) O₂\).

The arteriovenous \(O₂\) difference \((a-v) O₂\) was calculated by subtracting venous
O₂ content from the calculated arterial O₂ content, using VO₂, cardiac output and venous O₂ content measured.

Left ventricular mass index was calculated according to Devereux and Reichek (DEVEREUX and REICHEK, 1977).

% VO₂ out of energy utilized was calculated by dividing watts achieved at peak exercise (converted to VO₂ l·min⁻¹) by directly measured VO₂ (l·min⁻¹).

- Statistical methods

Data are reported as mean ± SD values. Two-way ANOVA with repeated measures was performed for multiple comparisons; post hoc analysis was performed by using the Tukey 2 multiple comparison test. The level of significance was set at alpha p<0.05.

Results

All subjects completed the 30-s study without any difficulties or clinical discomfort. Descriptive data of subjects' physical characteristics are given in Table 1. They reveal that values of weight, height, body surface area, left ventricular mass index, end diastolic dimension, maximal oxygen uptake and maximal cardiac output were all significantly (p < 0.05) higher for the men than for the women.

Table 1 - Subjects' physical characteristics (mean±SD).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Men</th>
<th>Women</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (kg)</td>
<td>62.2±6.7</td>
<td>55.4±7.1</td>
<td>p &lt; 0.02</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>178.9±6.3</td>
<td>170.2±5.0</td>
<td>p &lt; 0.05</td>
</tr>
<tr>
<td>Age (Years)</td>
<td>21.2±1.0</td>
<td>20.8±1.0</td>
<td></td>
</tr>
<tr>
<td>Body surface area (m²)</td>
<td>1.8±0.1</td>
<td>1.6±0.1</td>
<td>p &lt; 0.04</td>
</tr>
<tr>
<td>Left ventricular mass index (g · m²)</td>
<td>96.3±6.9</td>
<td>84.8±5.2</td>
<td>p &lt; 0.01</td>
</tr>
<tr>
<td>Lean body mass (kg)</td>
<td>55.5±6.0</td>
<td>48.9±4.9</td>
<td>p &lt; 0.01</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>10.8±2.5</td>
<td>11.7±3.0</td>
<td></td>
</tr>
<tr>
<td>End diastolic dimension (cm)</td>
<td>4.9±0.3</td>
<td>4.6±0.3</td>
<td>p &lt; 0.05</td>
</tr>
<tr>
<td>End systolic dimension (cm)</td>
<td>3.3±0.2</td>
<td>3.1±0.3</td>
<td></td>
</tr>
<tr>
<td>Ejection fraction</td>
<td>62.0±5.0</td>
<td>58±6.1</td>
<td></td>
</tr>
<tr>
<td>Maximal oxygen uptake (ml·kg⁻¹·min⁻¹)</td>
<td>60.1±6.3</td>
<td>53.4±5.1</td>
<td>p &lt; 0.04</td>
</tr>
<tr>
<td>Maximal cardiac output (l·min⁻¹)</td>
<td>24.6±1.2</td>
<td>21.9±1.3</td>
<td>p &lt; 0.05</td>
</tr>
<tr>
<td>Maximal heart rate (beats·min⁻¹)</td>
<td>213±6.6</td>
<td>215±7.3</td>
<td></td>
</tr>
<tr>
<td>Duration of maximal exercise (min)</td>
<td>6.5±0.4</td>
<td>6.3±0.6</td>
<td></td>
</tr>
</tbody>
</table>

*=Values obtained at maximal aerobic exercise

Descriptive statistics of hemodynamic variables at rest and left ventricular responses at peak Wingate anaerobic test are shown in Table 2. At rest, men compared to women manifested a significantly (p < 0.05) lower heart rate and higher values of cardiac output and (a-v)O₂ (see Figure 1). No differences
between groups were noted with regard to stroke volume (see Figure 2) or oxygen uptake (see Figure 3). At peak Wingate test, values for men for stroke volume (see Figure 3), cardiac output, lactate, diastolic blood pressure and total work load were all significantly ($p < 0.05$) higher, while (a-v) O$_2$ (see Figure 1), maximal oxygen uptake (see Figure 3) and %VO$_2$ out of total energy utilized were significantly ($p < 0.05$) lower than corresponding values for women.

**Table 2** - Hemodynamic responses and left ventricular function at rest and at peak Wingate anaerobic test in male and female subjects (mean±SD).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Rest</th>
<th>Exercise</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Men</strong></td>
<td><strong>Women</strong></td>
<td><strong>Men</strong></td>
<td><strong>Women</strong></td>
</tr>
<tr>
<td>Heart rate (beats•min$^{-1}$)</td>
<td>69.0±7.0</td>
<td>76.0±8.0</td>
<td>185.0±7.7</td>
</tr>
<tr>
<td>Cardiac output (l•min$^{-1}$)</td>
<td>5.6±0.3</td>
<td>5.0±0.5</td>
<td>14.4±0.6</td>
</tr>
<tr>
<td>Systolic BP (mm Hg)</td>
<td>106.0±8.8</td>
<td>103.0±6.4</td>
<td>191.1±10.0</td>
</tr>
<tr>
<td>Diastolic BP (mm Hg)</td>
<td>69.0±6.3</td>
<td>64.0±5.6</td>
<td>99.7±5.9</td>
</tr>
<tr>
<td>%VO$_2$ out of total energy utilized</td>
<td>10.0±0.4</td>
<td></td>
<td>11.8±0.4</td>
</tr>
<tr>
<td>Load (Watts)</td>
<td>492.2±24.1</td>
<td>419.5±14.6</td>
<td>a</td>
</tr>
<tr>
<td>Blood lactate (mmol•l$^{-1}$)</td>
<td>1.4±0.2</td>
<td>1.7±0.4</td>
<td>12.6±0.7</td>
</tr>
</tbody>
</table>

*a* = Significant difference between groups during exercise ($p < 0.05$); *b* = Significant difference from rest to exercise.

**Figure 1** - Oxygen extraction (a-v)O$_2$ responses for men and women at rest and peak anaerobic exercise.
Figure 2 - Stroke volume responses for men and women at rest and peak anaerobic exercise.

Figure 3 - Oxygen uptake for men and women at rest and peak anaerobic exercise.
Discussion

The current study suggests a gender-related differential response of men and women to all-out Wingate anaerobic exercise. We found that women were significantly different from men in both left ventricular function and muscle oxygen delivery. Moreover, the higher absolute values of muscle oxygen uptake attained by women at peak Wingate anaerobic test accounted for 11.8% of total energy expenditure compared to 10% out of total energy utilized by men, despite the significant gender-associated differences in peak power output, total body mass and lean body mass. Given that exercise oxygen consumption is maintained due to the balance between oxygen delivery and extraction, our data suggest that a significant increase in oxygen extraction compensated for the lower cardiac output of the women.

The higher oxygen uptake in the peak Wingate anaerobic test among women may have been the result of different muscle fiber recruitment patterns or different energy efficiencies of the fibers recruited during exercise. Previous findings (TOFT et al., 2003) indicated that in a normal population, men have larger muscle fibers than women but similar fiber composition. However, gender-related differences exist in the size of individual skeletal fibers, and this may influence metabolism and the adaptive response to exercise (FOX et al., 2003). Moreover, the nature of the contractile and metabolic properties of skeletal muscle suggests that the speed of shortening influences energy turnover during contractions. In vitro studies using isolated muscles and single muscle fibers have demonstrated that energy varies with shortening velocity (HE et al., 2000; KANG et al. 2006) and that the efficiency of different fiber types is closely related to their velocity of contraction (DI PRAMPERO et al., 1988; HE et al., 2000; REGGEIANI et al., 1977). As shown in the women in our study, the efficiency of slow twitch fibers at low contraction velocities is higher than for fast twitch fibers and vice versa at high speeds (HE et al., 2000). Thus, it seems that the lower velocity of contraction in women compared to men enabled the women to utilize additional slower twitch fibers relative to men, and hence to increase their ability to extract oxygen.

Values of cardiac output at peak Wingate anaerobic test were low in both men and women (14.4 l·min\(^{-1}\) and 12.3 l·min\(^{-1}\), respectively) compared to what one would expect during maximal dynamic exercise. The explanation for the lower cardiac output at peak Wingate anaerobic test might be related to the short duration of the test, which in turn did not allow for an appropriate adjustment of circulation, resulting in a relatively high total peripheral resistance that was not as low as that manifested during aerobic exercise.

Echocardiographic indices and blood pressure response in the present study were similar to those seen during isometric exercise, indicating that the auto-regulation mechanism is not involved when sudden strenuous exercise is performed. Moreover, this response is in agreement with previous reports which suggested that during strenuous exercise well-trained healthy young adult subjects did not increase stroke volume, and that sometimes stroke volume was reduced (BEN-SIRA and SAGIV, 1977; SAGIV et al., 2000). The assumed lack of auto-regulation may indicate that the reduced stroke volume observed in men...
at peak Wingate anaerobic test was due to a relatively high pressure opposing left ventricular ejection. It seems that at peak exercise our women were able to maintain similar values of stroke volume than those at rest, due to a lesser increase in mean arterial blood pressure and due to increased ventricular contractility.

Conclusions
The present study indicates gender-related differences in left ventricular response and muscle oxygen delivery of young men and women at peak all-out strenuous exercise. Data suggest that healthy women response to the Wingate anaerobic test by increasing their muscle oxygen extraction in the face of lower oxygen delivery.

References


