Gender difference in anaerobic capacity: role of aerobic contribution

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The purpose of this study was to evaluate effects of gender on anaerobic and aerobic contributions to high-intensity exercise. A group of 38 subjects (22 women, 16 men) performed modified Wingate tests against resistances of 0.086 kg kg\(^{-1}\) body mass (0.844 N kg\(^{-1}\)) for women and 0.095 kg kg\(^{-1}\) body mass (0.932 N kg\(^{-1}\)) for men. The aerobic contribution to total work performed was determined from breath-by-breath analyses of expired gases during each test. Total work in 30 s was 30% lower (Student's t test; \(P < 0.01\)) in women than men (211 ± 5 J kg\(^{-1}\) versus 299 ± 14 J kg\(^{-1}\)). Aerobic contribution was only 7% lower (\(P = 0.12\)) in women than men (53 ± 1 J kg\(^{-1}\) versus 57 ± 2 J kg\(^{-1}\)). The anaerobic component of the work performed, determined by subtraction of the aerobic component from total work in 30 s, was 35% lower (\(P < 0.01\)) in women than men (158 ± 5 J kg\(^{-1}\) versus 242 ± 15 J kg\(^{-1}\)). It is concluded that, because women provide a relatively higher (\(P < 0.01\)) portion of the energy for a 30-s test aerobically than men (25% versus 20%), total work during a Wingate test actually underestimates the gender difference in anaerobic capacity between women and men.

Keywords: Anaerobic power, anaerobic capacity, aerobic metabolism, men, women, gender differences, sex differences

The Wingate power test\(^1\)\(^2\) is one example of a test that has been designed to estimate anaerobic power and capacity during cycling exercise. Men and women show consistent differences in absolute and mass-corrected estimates of anaerobic power and capacity\(^3\)\(^-\)\(^6\).

It is clear that even during short-term high-intensity exercise, some adenosine 5'-triphosphatase (ATP) regeneration occurs via oxidative phosphorylation\(^1\)\(^-\)\(^4\)\(^-\)\(^12\). The magnitude of aerobic contribution to all-out efforts of about 30-s duration has recently been estimated to be 9 to 13%\(^7\)\(^-\)\(^12\), and as high as 40%\(^11\).

There are differences between men and women in absolute and mass-corrected estimates of maximal aerobic power\(^13\) as well as in anaerobic power and capacity\(^3\)\(^-\)\(^6\). All recent studies of the interplay between aerobic and anaerobic energy sources during Wingate tests, or other tests involving short-term high power outputs, have used male subjects\(^8\)\(^-\)\(^11\).

The purpose of this study was to evaluate effects of gender on the aerobic and anaerobic contributions to performance during a modified Wingate power test. These comparisons will provide insight into some factors related to the gender difference in measures of anaerobic capacity.

Subjects and methods

A total of 92 modified Wingate power tests was performed by 38 healthy college students. Subjects performed up to five tests, each on a different day. Data from some tests were lost because of technical problems; complete results were available from between two and five tests per person. Each individual’s results were averaged in order that each subject contributed only one data point to the statistical analyses. The 22 women had a mean(s.d.) age of 22(4) years, height 168(7) cm, and mass 58.2(7.7) kg; the 16 men had a mean age of 23(2) years, height 180(9) cm, and mass 82.1(16.1) kg. The subjects were physical education majors who ranged in fitness level. There were several men and women who were quite sedentary and also several men and women who were apparently fit. None of the subjects was in training for a competitive sport at the time of the study.

Modified Wingate tests – selection of resistance

Tests were performed on a basket-loaded Monark 864 ergometer, with a resistance of 0.086 kg kg\(^{-1}\) body mass (0.844 N kg\(^{-1}\)) for women and 0.095 kg kg\(^{-1}\) body mass (0.932 N kg\(^{-1}\)) for men\(^1\).

Fair comparison of men’s and women’s performances requires optimal resistance settings for each gender. Resistances that are well above the original 0.075 kg kg\(^{-1}\) body mass\(^1\) elicit higher values for work output or mean power output in 30-s tests\(^5\)\(^-\)\(^8\)\(^-\)\(^10\), and the resistances selected for this study have been suggested as optimal settings for men and women, respectively\(^12\).

Modified Wingate tests – test administration

Subjects performed a 6-min warm-up on the cycle ergometer, at a work rate of about 90 W for men or 60 W for women, and then rested, seated, on the ergometer for 5 min. They were then directed by standardized instructions: 10s before the start of the
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test, they began unloaded pedalling; 4 s before the start of the test, they accelerated maximally; at '0's', the resistance was applied, and the test began.

During the 30-s test, pedal revolutions were mechanically determined using a read switch and magnet attached to the pedal crank. Revolutions were recorded for each 5-s period during the test.

Peak power, or anaerobic power, was the highest power produced in a 5-s segment of the test, and was expressed in W and in W kg\(^{-1}\). The traditional measure of anaerobic capacity, the total external work performed in the 30-s test, was expressed in J and in J kg\(^{-1}\).

Determinant of aerobic versus anaerobic contribution

\(\dot{V}O_2\) during the tests was determined on a breath-by-breath basis using a SensorMedics 4400tc metabolic cart (SensorMedics, Anaheim, California, USA). The SensorMedics system incorporates fast-responding gas analysers, a turbine flowmeter, and a computer correction to account for the time difference in responses of the flowmeter and the gas analysers.

Aerobic contribution was calculated based on the \(\dot{V}O_2\) that was measured during the test, and then converted to work units with a factor of 20.92 kJ 1 L\(^{-1}\). The following assumptions were made:

1. Muscular (gross) efficiency was 22%.
2. There was a time delay of approximately 10–15 s between increased \(\dot{V}O_2\) at the muscle and increased \(\dot{V}O_2\) at the mouth\(^{17}\), and the initial increase in \(\dot{V}O_2\) at the mouth reflected a 'cardiodynamic effect'\(^{18}\).
3. \(O_2\) stores of about 2.3 ml kg\(^{-1}\) body mass\(^{19}\) were used at the onset of exercise.

Stainsby et al.\(^{20}\) and Cavanagh and Kram\(^{21}\) have argued in favour of the use of muscular rather than net efficiency measures. In the present study, a 22% muscular efficiency was used in calculations\(^{22}\). This has been suggested as appropriate for both aerobic and anaerobic exercise\(^{22}\). We are not aware of any reports of gender differences in efficiency. We have compared efficiency of men and women performing cycling exercise at between 55% and 65% of \(\dot{V}O_2\)\(_{max}\) and found no difference (\(t_{12} = 0.37, P = 0.72\)) in efficiency (unpublished).

The time delay of ≈10–15 s between increased \(\dot{V}O_2\) at the muscle and increased \(\dot{V}O_2\) at the mouth\(^{17}\) and the initial increase in \(\dot{V}O_2\) at the mouth reflects a 'cardiodynamic effect'\(^{18}\). Therefore, aerobic contribution for the 0–10 s time period was calculated by back-extrapolation from the \(\dot{V}O_2\) measured during the 10–15 s period in the test\(^{10}\). Aerobic contribution for the 10–30 s time period is based directly on \(\dot{V}O_2\) measured during that time.

Previous estimates of the magnitude of the \(O_2\) stores have varied. Barstow et al.\(^{19}\) have reported values equivalent to 2.3 ml kg\(^{-1}\) body mass; Medbø and Tabata\(^{20}\) used a value of 5.6 ml kg\(^{-1}\) body mass in one study and Medbø et al.\(^{22}\) used 6.0 ml kg\(^{-1}\) body mass in another; DiPrampero et al.\(^{24}\) have estimated that the stores are as high as 6.4 ml kg\(^{-1}\) body mass.

Inman et al.\(^{25}\) reported depletion of 139 ml from \(O_2\) stores during the transition from rest to submaximal exercise (100 W) – this was equivalent to 2.1 ml kg\(^{-1}\) body mass. We have selected the theoretical value of 2.3 ml kg\(^{-1}\) body mass proposed by Barstow et al.\(^{19}\) as it most closely approximated the value actually measured by Inman et al.\(^{25}\) We are not aware of any reports of gender differences in the size of the \(O_2\) stores. The magnitude of the stores is estimated as a function of body mass, and this should account for the differences in body size between the sexes.

Data analyses

Aerobic contribution was expressed in terms of absolute power output (W), power output relative to body mass (W kg\(^{-1}\)), or aerobic work performed as a percentage of the total work performed. Anaerobic contribution was calculated based on differences between total measured power or work and the estimated aerobic contributions. Total work in 30 s has traditionally been termed the anaerobic capacity. In this paper, total work is separated into its aerobic and anaerobic components.

Gender differences were evaluated statistically using \(t\) tests for independent means. Values are expressed as means(s.e.).

Results

Peak power, which always occurred during the first 5-s segment of the exercise test, was 595(18) W (10.2(0.2) W kg\(^{-1}\)) for the women and 1099(76) W (13.3(0.4) W kg\(^{-1}\)) for the men. Relative to body mass, the women's mean peak power was 77% of the men's (\(P < 0.01\)).

Over the course of the test, power output declined 50(1)% in the women and 45(3)% in the men. This power decline, or fatigue index, was the same (\(P = 0.10\)) in the women and men.

Mean values for total work in 30 s, and the aerobic and anaerobic portions of that work, are presented in Table 1. Women performed 49% as much work as men in the 30 s (\(P < 0.01\)), about 45% as much anaerobic work (\(P < 0.01\)), and about 67% as much aerobic work (\(P < 0.01\)). When measures were corrected for body mass, the gender differences were reduced: women performed 71% as much total work (\(P < 0.01\)), about 65% as much anaerobic work (\(P < 0.01\)), and about 93% as much aerobic work (\(P = 0.12\)). Over the 30-s test, women performed a greater

### Table 1. Mean(s.e.) absolute and mass-corrected total work, aerobic work, and anaerobic work (kJ, kg\(^{-1}\)) for men and women

<table>
<thead>
<tr>
<th></th>
<th>Total work</th>
<th>Anaerobic work</th>
<th>Aerobic work</th>
</tr>
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<tbody>
<tr>
<td><strong>Men</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25.0(2.3) kJ</td>
<td>20.3(2.1) kJ</td>
<td>4.60(2.0) kJ</td>
<td></td>
</tr>
<tr>
<td>12.3(0.3) kJ</td>
<td>9.20(0.4) kJ</td>
<td>3.10(0.1) kJ</td>
<td></td>
</tr>
<tr>
<td><strong>Difference</strong></td>
<td>51%, (P &lt; 0.01)</td>
<td>55%, (P &lt; 0.01)</td>
<td>34%, (P &lt; 0.01)</td>
</tr>
<tr>
<td><strong>Women</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>299(14) kg(^{-1})</td>
<td>242(15) kg(^{-1})</td>
<td>57(2) kg(^{-1})</td>
<td></td>
</tr>
<tr>
<td>211(5) kg(^{-1})</td>
<td>158(5) kg(^{-1})</td>
<td>53(1) kg(^{-1})</td>
<td></td>
</tr>
<tr>
<td><strong>Difference</strong></td>
<td>30%, (P &lt; 0.01)</td>
<td>35%, (P &lt; 0.01)</td>
<td>7%, (P = 0.12)</td>
</tr>
</tbody>
</table>

Difference scores are calculated as (men - women)/men × 100
proportion ($P < 0.01$) of the total work aerobically
than did men (25(1)% versus 20(1)% ($P < 0.01$).
Aerobic metabolism gradually increased through-
out the test. The aerobic power output peaked at 137(5) W
(2.4(0.1) W kg$^{-1}$) for women and 199(8) W
(2.5(0.1) W kg$^{-1}$) for men. During the last 5 s of
the test, aerobic mechanisms were responsible for 47(1)%
of the power output for the women and 36(3)% of the
power output for men.

Discussion
Peak power and anaerobic capacity
Peak power values in this study are similar to values
that have been reported elsewhere.$^{4,6,26}$ Our
women’s and men’s peak powers were 10.2 and
13.3 W kg$^{-1}$. Our women’s means were 17% higher
than the 8.7 W kg$^{-1}$ reported for the female physical
education students of Serresse et al.$^{9}$, but within the
range of 9.1 to 11.1 W kg$^{-1}$ reported by Shaw et al.$^{15}$
for women softball players. Our men’s means were
11% higher than the 12.0 W kg$^{-1}$ reported for the
male physical education students of Serresse et al.$^{9}$,
but within the range of 13.2 to 14.7 W kg$^{-1}$ reported
by Davy et al.$^{27}$ for 12 ‘conditioned athletes’, and
similar to the 12.7 W kg$^{-1}$ of the untrained men of
Beld et al.$^{28}$
The mean amount of work performed by the
women in the 30-s test (211(5) J kg$^{-1}$) was similar to
the mean of 217 (no s.e. provided) from 25 women
that was reported by Nebelsick-Gullett et al.$^{29}$; and
the men’s mean of 299(14) J kg$^{-1}$ is similar to the value
of 294(8) J kg$^{-1}$ reported by Vandewalle et al.$^{30}$
By the very nature of this paper, it is acknowledged
that the terms peak anaerobic power and anaerobic
capacity are misnomers, and that reported values
quantify power output or work performed that is not
all derived from anaerobic sources. Thus, we have
chosen to refer to the total work performed in 30 s as
such, and not as anaerobic capacity. Moreover, it is
acknowledged that a 30-s test is not long enough to
exhaust the glycolytic system.

Gender differences in total work performed in 30 s
The 30-s work output of men and women has been
compared in two recent studies.$^{4,5}$ Murphy et al.$^{5}$
used 0.075 kg kg$^{-1}$ body mass (0.736 N kg$^{-1}$) for
both the men and women; they reported women’s 30-s
work capacity relative to body mass to be 78% that of
men. Froese and Houston$^{4}$ used the method of Evans
and Quinnine$^{8}$ to determine resistance settings based
on mass and thigh volume; these were 0.100 kg kg$^{-1}$
body mass (0.981 N kg$^{-1}$) for the men and
0.098 kg kg$^{-1}$ body mass (0.961 N kg$^{-1}$) for the
women. They reported that women had relative 30-s
work capacities of about 85% those of men, but
commented that the load of 0.098 kg kg$^{-1}$
(0.961 N kg$^{-1}$) was too high for the women in their
study. Serresse et al.$^{6}$ reported that women’s 10-s
work capacity was about 72% of men’s, and 90-s capacity
was about 77% of men’s – a resistance of 0.09 kg kg$^{-1}$
body mass (0.883 N kg$^{-1}$) was used for both women
and men in the 10-s test, and a resistance of
0.05 kg kg$^{-1}$ (0.491 N kg$^{-1}$) was used for both men
and women in the 90-s test.
We report a gender difference in 30-s work
capacities similar to that of Serresse et al.$^{5}$; compared
with the men, on a per-kilogramme basis, women
performed only 71% as much total work.

Gender differences in aerobic and anaerobic
contributions
In this study, women performed 30% less work in
30 s than did the men – 211(5) J kg$^{-1}$ compared with
299(14) J kg$^{-1}$. Comparison with the results of
Murphy et al.$^{5}$ suggests that further correction for
differences in body composition was not likely to
narrow this difference to even within 20%. This
suggests that, on a per-kilogramme basis, women
have an anaerobic capacity – specifically, that is a 30-s
work capacity – of about 71% that of men.
Despite the relatively large difference in total work
performed during the 30-s test, women and men had
similar aerobic contributions. Work attributable
to aerobic mechanisms was 53(1) J kg$^{-1}$ for the
women and 57(2) J kg$^{-1}$ for men. These values differed
by only 7% ($P = 0.12$). This is not surprising,
considering that the gender difference in $\dot{V}O_2_{max}$
would be expected to be less than 20% in this population.$^{13}$
The difference between actual anaerobic contribution
during a 30-s bout of exercise (i.e. total work minus
aerobic work) was larger than the 30% difference
between the total work performed by men and women.
The traditional measure of ‘anaerobic capacity’,
using total work in 30 s, may actually underestimate
the real gender difference in anaerobic capacity. In
fact, the gender difference was 35%, not 30% –
women were able to produce 158(5) J kg$^{-1}$ anaero-
biically, which is only 65%, not 71%, of the
242(15) J kg$^{-1}$ produced by the men.
Indeed, the actual gender difference in anaerobic
capacity may be even greater than this 35% value.
Anaerobic capacity is not exhausted in $30 s^{1,10,21,23}$.
In the final 5 s of the test, men’s anaerobic energy
production was almost twice that of the women’s (4.8
versus 2.7 W kg$^{-1}$) suggesting that the men had a
larger anaerobic reserve still untapped. This possi-
bility is supported by the fact that there was a greater
($P = 0.02$) decline in power output, that is, a larger
fatigue index, in the women (50(1)%)) than in the men
(44(2)%). Thus, while we report a difference of 35%
in anaerobic work capacity in 30 s, we suggest that
over a longer test (i.e. to exhaustion of the glycolytic
mechanisms) the difference might be even greater. A
larger difference would be compatible with the
finding that maximal blood lactate levels in women
are only slightly more than half those of men.$^{31}$
The gender differences in aerobic/anaerobic con-
tribution may in part reflect a training effect or cultural
bias. However, there was a wide range of fitness
levels, as evidenced by achieved $\dot{V}O_2$ during the tests,
and there was no evidence of a trend for either the
men or women to be relatively more fit or trained.
Further studies comparing the aerobic and anaero-
bic contributions to short-term exercise by men and
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women against a variety of relative resistances may explain the relationships between resistance and 30-s work capacity, aerobic contribution, and anaerobic contribution more fully – and the role of gender in modifying these relationships.

Summary of findings

We have compared the work capacity of men and women using a modified Wingate power test with resistances determined based on gender and mass. Our results suggest that during the 30-s test, a significant portion of the total ATP regeneration is via aerobic mechanisms; this aerobic contribution is greater in women than in men when expressed as a percentage of total work accomplished, but is quite similar in women and men when expressed relative to body mass.

Total work performed in 30 s was 30% lower in women than in men, when results were reported on a per-kilogramme basis. Anaerobic work over the 30 s was 35% lower in women than in men. Therefore, we conclude that use of total work in 30 s as a measure of anaerobic capacity of men and women may actually underestimate the gender difference in the anaerobic capacity, because women make a relatively larger aerobic contribution during short-term exercise than do men, at least when exercising maximally for 30 s against the resistances provided in this study.

References