

Gender difference in anaerobic capacity: role of aerobic contribution

David W. Hill PhD and Jimmy C. Smith PhD

Department of Kinesiology, University of North Texas, Denton, Texas, USA

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 ($211 \pm 5 \text{ J kg}^{-1}$ versus $299 \pm 14 \text{ J kg}^{-1}$). Aerobic contribution was only 7% lower ($P = 0.12$) in women than men ($53 \pm 1 \text{ J kg}^{-1}$ versus $57 \pm 2 \text{ J kg}^{-1}$). 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 ($158 \pm 5 \text{ J kg}^{-1}$ versus $242 \pm 15 \text{ J kg}^{-1}$). 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 capacity³⁻⁶.

It is clear that even during short-term high-intensity exercise, some adenosine 5'-triphosphate (ATP) regeneration occurs via oxidative phosphorylation^{1,7-12}. The magnitude of aerobic contribution to all-out efforts of about 30-s duration has recently been estimated to be 9 to 19%⁸, 28%¹⁰, or as high as 40%¹¹.

There are differences between men and women in absolute and mass-corrected estimates of maximal aerobic power¹³ as well as in anaerobic power and capacity³⁻⁶. 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 subjects⁸⁻¹¹.

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 men¹.

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 mass¹ elicit higher values for work output or mean power output in 30-s tests^{2,5,14-16}, and the resistances selected for this study have been suggested as optimal settings for men and women, respectively¹².

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: 10 s before the start of the

Address for correspondence: David W. Hill PhD, Department of Kinesiology, PO Box 13857, University of North Texas, Denton, Texas 76203-3857, USA

© 1993 Butterworth-Heinemann Ltd
0306-3674/93/010045-04

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 kJ and in $J kg^{-1}$.

Determination 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 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 $20.92 kJ l O_2^{-1}$. 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 mouth¹⁷, 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 mass¹⁹ were used at the onset of exercise.

Stainsby *et al.*²⁰ and Cavanagh and Kram²¹ 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 calculations²². This has been suggested as appropriate for both aerobic and anaerobic exercise²². 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 $\dot{V}O_{2max}$ 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 mouth¹⁷ and the initial increase in $\dot{V}O_2$ at the mouth reflects a 'cardiodynamic effect'¹⁸. Therefore, aerobic contribution for the 0- to 10-s time period was calculated by back-extrapolation from the $\dot{V}O_2$ measured during the 10- to 15-s period in the test¹⁰. Aerobic contribution for the 10- to 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 Tabata⁹ used a value of $5.6 ml kg^{-1}$ body mass in one study and Medbø *et al.*²³ used $6.0 ml kg^{-1}$ body mass in another; DiPrampo *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, $J kg^{-1}$) for men and women

	Total work	Anaerobic work	Aerobic work
Men	25.0(2.3) kJ	20.3(2.1) kJ	4.6(0.2) kJ
Women	12.3(0.3) kJ	9.2(0.4) kJ	3.1(0.1) kJ
Difference	51%, $P < 0.01$	55%, $P < 0.01$	34%, $P < 0.01$
Men	299(14) $J kg^{-1}$	242(15) $J kg^{-1}$	57(2) $J kg^{-1}$
Women	211(5) $J kg^{-1}$	158(5) $J kg^{-1}$	53(1) $J kg^{-1}$
Difference	30%, $P < 0.01$	35%, $P < 0.01$	7%, $P = 0.12$

Difference scores are calculated as (men – women)/men $\times 100$

proportion ($P < 0.01$) of the total work aerobically than did men (25(1)% versus 20(1)%) ($P < 0.01$).

Aerobic metabolism gradually increased throughout 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.*⁶, 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.*⁶, 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 (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 Houston⁴ used the method of Evans and Quinney³ 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 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.*⁶; 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 population¹³. 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 anaerobically, 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 possibility 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 men³¹.

The gender differences in aerobic/anaerobic contribution 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 anaerobic contributions to short-term exercise by men and

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 30s was 30% lower in women than in men, when results were reported on a per-kilogramme basis. Anaerobic work over the 30s was 35% lower in women than in men. Therefore, we conclude that use of total work in 30s 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 30s against the resistances provided in this study.

References

- 1 Bar-Or O. The Wingate anaerobic test: an update on methodology, reliability, and validity. *Sports Med* 1987; **4**: 381–94.
- 2 Bar-Or O, Dotan R, Inbar O. A 30 second all-out ergometric test – its reliability and validity for anaerobic capacity. *Isr J Med Sci* 1977; **13**: 126.
- 3 Evans JA, Quinney HA. Determination of resistance settings for anaerobic power testing. *Can J Appl Sport Sci* 1981; **6**: 53–6.
- 4 Froese EA, Houston ME. Performance during the Wingate anaerobic test and muscle morphology in males and females. *Int J Sports Med* 1987; **8**: 35–9.
- 5 Murphy MM, Patton JF, Frederick FA. Comparative anaerobic power of men and women. *Aviat Space Environ Med* 1986; **57**: 636–41.
- 6 Serresse O, Ama PFM, Simoneau J-A, Lortie G, Bouchard C, Boulay MR. Anaerobic performances of sedentary and trained subjects. *Can J Sport Sci* 1989; **14**: 46–52.
- 7 Hill DW, Smith JC. Contribution of energy systems during a Wingate power test. *Br J Sports Med* 1991; **25**: 196–9.
- 8 Kavanagh MF, Jacobs I. Breath-by-breath oxygen consumption during performance of the Wingate Test. *Can J Sport Sci* 1988; **13**: 91–3.
- 9 Medbø JI, Tabata I. Relative importance of aerobic and anaerobic energy release during short-lasting exhausting bicycle exercise. *J Appl Physiol* 1989; **67**: 1881–6.
- 10 Serresse O, Lortie G, Bouchard C, Boulay MR. Estimation of the contribution of the various energy systems during maximal work of short duration. *Int J Sports Med* 1988; **9**: 456–60.
- 11 Stevens GHJ, Wilson BW, Raven PB. Aerobic contribution to the Wingate test. *Med Sci Sports Exerc* 1986; **18**(Suppl): 2.
- 12 Vandewalle H, Kapitaniak B, Grün S, Raveneau S, Monod H. Comparison between a 30-s all-out test and a time-work test on a cycle ergometer. *Eur J Appl Physiol* 1989; **58**: 375–81.
- 13 McArdle WD, Katch FI, Katch VL. *Exercise Physiology: Energy, Nutrition, and Human Performance*, 3rd ed. Philadelphia, Pennsylvania, USA: Lea and Febiger, 1991; 205–18.
- 14 Lopato M, Montgomery D. The effect of body mass on power output in the Wingate test. *Can J Sport Sci* 1989; **14**: 123P.
- 15 Shaw K, Davy K, Coleman C, Kamimukai C. Optimal resistance loading of the Wingate power test in female softball players. *Med Sci Sports Exerc* 1988; **20**(Suppl): 18.
- 16 Sposa E, Perez HR, Wygand JW, Moruzzi R. Optimal resistance loading of Wingate power testing in soccer players. *Med Sci Sports Exerc* 1987; **19**(Suppl): 73.
- 17 Hughson RL, Sherrill DL, Swanson GD. Kinetics of $\dot{V}O_2$ with impulse and step exercise in humans. *J Appl Physiol* 1988; **64**: 451–9.
- 18 Whipp BJ, Ward SA, Lamarra N, Davis JA, Wasserman K. Parameters of ventilatory and gas exchange dynamics during exercise. *J Appl Physiol* 1982; **52**: 1506–13.
- 19 Barstow TJ, Lamarra N, Whipp BJ. Modulation of muscle and pulmonary O_2 uptakes by circulatory dynamics during exercise. *J Appl Physiol* 1990; **68**: 979–89.
- 20 Stainsby WN, Gladden LB, Barclay JK, Wilson BA. Exercise efficiency: validity of base-line subtractions. *J Appl Physiol: Respirat Environ Exerc Physiol* 1980; **48**: 518–22.
- 21 Cavanagh PR, Kram R. The efficiency of human movement – a statement of the problem. *Med Sci Sports Exerc* 1985; **17**: 304–8.
- 22 Davies CTM, Sandstrom ER. Maximal mechanical power output and capacity of cyclists and young adults. *Eur J Appl Physiol* 1989; **58**: 838–44.
- 23 Medbø JI, Mohn A-C, Tabata I, Bahr R, Vaage O, Sejersted OM. Anaerobic capacity determined by maximal accumulated O_2 deficit. *J Appl Physiol* 1988; **64**: 50–60.
- 24 diPrampo PE, Boutellier U, Pietsch P. Oxygen deficit and stores at onset of muscular exercise in humans. *J Appl Physiol: Respir Environ Exerc Physiol* 1983; **55**: 146–53.
- 25 Inman MD, Hughson RL, Weisiger KH, Swanson GD. Estimate of mean tissue O_2 consumption at onset of exercise in males. *J Appl Physiol* 1987; **63**: 1578–85.
- 26 Maud PJ, Shultz BB. Norms for the Wingate Anaerobic Test with comparison to another similar test. *Res Q Exerc Sport* 1989; **60**: 144–51.
- 27 Davy K, Pizza F, Guastella P, McGuire J, Wygand J. Optimal loading of Wingate power testing in conditioned athletes. *Med Sci Sports Exerc* 1989; **21**(Suppl): 27.
- 28 Beld K, Skinner JS, Vu Tran Z. Load optimization for peak and mean power output on the Wingate anaerobic test. *Med Sci Sports Exerc* 1989; **21**(Suppl): 26.
- 29 Nebelsick-Gullett LJ, Housh TJ, Johnson GO, Bauge SM. A comparison between methods of measuring anaerobic work capacity. *Ergonomics* 1988; **31**: 1413–19.
- 30 Vandewalle H, Pérès G, Monod H. Standard anaerobic exercise tests. *Sports Med* 1987; **4**: 268–89.
- 31 Fox EL, Bowers RW, Foss ML. *The Physiological Basis of Physical Education and Athletics*, 4th ed. Dubuque, Iowa, USA: Wm C Brown, 1988; 384.