Eur J Appl Physiol (1984) 52: 446–450

European Journal of
Applied
Physiology
and Occupational Physiology

Sex differences in endurance capacity and metabolic response to prolonged, heavy exercise

K. Froberg and P. K. Pedersen

Institute of Physical Education, Odense University, Campusvej 55, DK-5230 Odense M, Denmark

Summary. In order to test for possible sex differences in endurance capacity, groups of young, physically active women ($n = 6$) and men ($n = 7$) performed bicycle ergometer exercise at 80% and 90% of their maximal oxygen uptakes ($\dot{V}_{O_2\,max}$). The groups were matched for age and physical activity habits. At 80% $\dot{V}_{O_2\,max}$ the women performed significantly longer ($P < 0.05$), 53.8 ± 12.7 min vs 36.8 ± 12.2 min, respectively (means ± SD). Mid-exercise and terminal respiratory exchange ratio (R) values were significantly lower in women, suggesting a later occurrence of muscle glycogen depletion as a factor in their enhanced endurance. At 90% $\dot{V}_{O_2\,max}$ the endurance times were similar for men and women, 21.2 ± 10.3 min and 22.0 ± 5.0 min, respectively. The blood lactate levels reached in these experiments were only marginally lower (mean differences 1.5 to 2 mmol · l^{-1}) than those obtained at $\dot{V}_{O_2\,max}$, suggesting high lactate levels as a factor in exhaustion. The changes in body weight during the 80% experiments and the degree of hemoconcentration were not significantly different between men and women.

Key words: Men and women – Endurance capacity – Respiratory exchange ratio – Blood lactate – Weight loss – Hemoconcentration

Introduction

The increased participation of both men and women in endurance-type physical activities has brought about renewed interest in possible sex differences in performance capacity. Whereas most of the discussion relates to whether women possess the physical prerequisites to participate safely in such activities (Am Coll Sports Med 1979), the suggestion has been made that women are in fact better suited than men for prolonged, heavy exercise. The basis for this latter suggestion, however, seems scant, most of the evidence presented being indirect. Fox et al. 1969 found that women exposed to heat stress had lower evaporative heat loss and higher sweat onset threshold than men. This has been interpreted by some as evidence for a more effective, i.e., water conserving, thermoregulatory system. Another proposed mechanism is that of an increased fat utilization in women. This might be an advantage in that depletion of glycogen stores could be delayed. Lower respiratory exchange ratio (R) values for women during heavy exercise were presented by Nygaard 1981, reporting unpublished data by Runeson. No support for this contention, however, was found by Costill et al. 1979 or Powers et al. 1980 comparing men and women treadmill running at a bout 70% of maximal oxygen uptake ($\dot{V}_{O_2\,max}$).

Since no direct comparisons of endurance capacity in men and women have been performed, and since there are conflicting results on possible sex differences in metabolic response to heavy exercise we felt it of interest to perform experiments in which comparable groups of men and women performed heavy leg exercise until exhaustion.

Offprint requests to: P. K. Pedersen at the above address

Methods and procedures

Subjects

Six physically active young women and seven men volunteered for the study. Mean values ± SD for age, height, and weight were 26 ± 1 years, 169 ± 5 cm and 61 ± 5 kg for women, and 29 ± 3 years, 179 ± 5 cm and 72 ± 11 kg for men. The subjects were informed about possible risks or inconveniences, and of their right at any time to leave the study. The males and females were similar with respect to physical activity patterns because they were all physical education students who had been co-educated in activity

programs for about 15 h · week^{-1}, for almost a year. Furthermore, interviews regarding the amount and intensity of leisure time physical activity revealed no systematic between-group differences, although quite large intra-group variations.

Maximal working capacity

After two or more habituation experiments each individual performed two maximal tests on cycle ergometer (Monark-Cardionics) on separate days. The first was a progressive exercise test; the subjects performed two 4 min moderate exercise loads (60 and 120 W for women, 120 and 180 W for men) following which the work rate was increased by 30 W at 2 min intervals until exhaustion. Pedal rate was 60 min^{-1}. Oxygen uptake ($\dot{V}_{O_2}$), CO_2 output ($\dot{V}_{CO_2}$), minute ventilation ($\dot{V}_E$), heart rate (HR), and blood lactate concentration (HLa) were measured during the last minute of each work rate. HLa was also measured 1 and 3 min after completion of the test in order to obtain peak values (HLa max). Based on the information from this test a second test was performed in which 10 min warm-up was followed by work at supramaximal intensity until exhaustion. The highest values of $\dot{V}_{O_2}$ obtained in these tests were used as $\dot{V}_{O_2\,max}$; in no case was the difference between the two values larger than 9%. Criteria for maximal effort during the tests were the attainment of the following test values: HR > 175 bt · min^{-1}, HLa > 8 mmol · l^{-1}, R > 1.05 and ventilatory coefficient for O_2 ($\dot{V}_E$ BTPS · $\dot{V}_{O_2}$ STPD^{-1}) > 30 l · l^{-1}.

Endurance experiments

The work loads in the endurance experiments were assigned to elicit oxygen uptake levels of 80% and 90% of $\dot{V}_{O_2\,max}$ (80% exp and 90% exp) with a precision of between 0.05–0.10 l · min^{-1}.

The subjects reported to the laboratory in the morning about 1 h after a light breakfast. Records were provided by the subjects of the preceding 3 days food intake to serve as a simple check of normal glycogen stores. No coffee, tea, or heavy physical activity was allowed on the morning of the experiment. After 15 min sitting rest, during which period resting values of selected variables were obtained, endurance exercise was initiated at the designated intensity. $\dot{V}_{O_2}$, $\dot{V}_{CO_2}$, HR, and $\dot{V}_E$ were measured each min for the first 6 min of exercise and every other min from min 6–12. Depending on the subject's endurance capacity measurements were continued at min 20, 40, 60, and so on until exhaustion. Blood samples for lactate determination were drawn every other min during the first 12 min of exercise and simultaneously with the respiratory measurements during the remaining period. Exhaustion was defined as the time when the subject was no longer able to maintain the desired pedal rate of 60 min^{-1}. Men and women were instructed at a joint session of the importance of continuing exercise until complete exhaustion. No verbal or other encouragement was used during the experiment. When approaching exhaustion the subjects reported to the investigators who would resume measurements irrespective of the above time table. The two endurance tests were separated by at least 1 week. The 90% exp was always performed first.

Body weight (scale accurate to 0.05 kg), and hemoglobin concentration [Hb] and hematocrit % (Hct) in venous blood were measured before and immediately after the 80% exp. Water intake was also recorded in the 80% exp; water was allowed ad lib in all experiments. Room temperatures ranged from 21–25° C, and relative humidity from 55–68%. A fan was directed towards the subjects.

Techniques

Oxygen uptake and related variables were measured with conventional Douglas bag technique. O_2 and CO_2 contents were analysed with Servomex OA 184 and Beckman LB2 analysers. The analysers were checked daily by comparisons with results obtained with the Scholander method. The subjects breathed through a low-resistance Otis-McKerrow valve. Expired gas volume was measured with a 130 l Tissot spirometer. HR was obtained from the ECG. Lactate concentration was measured in "arterialized" blood (Forster et al. 1972) from prewarmed finger tips and analysed by an enzymatic method (Hohorst 1970). Pedal rate was monitored via a microswitch connected to the 3-channel Brush recorder. Skinfold measurements (Ponderal caliber) were performed according to the method of Durnin and Womersley 1974 in order to provide an estimate of fat free body weight.

Statistics

Mean values and standard deviation were calculated with conventional procedures. Between-group differences were analysed for by means of a two-tailed Student's *t*-test, after first testing for homogeneity of variance (*F*-test). $P < 0.05$ were taken to indicate statistical significance.

Results

The average $\dot{V}_{O_2\,max}$ in l · min^{-1} was 30% lower in the women than in the men (Table 1); relative to body weight the difference was 17%, and relative to lean body mass 6%, the latter of which was not statistically significant. The values obtained in men and women during the maximal exercise tests for HR, HLa, R, and $\dot{V}_E \cdot \dot{V}_{O_2}{}^{-1}$ support the impression that both groups made maximal effort. There were no statistically significant differences.

The women performed significantly longer than the men in the 80% exp (Fig. 1). The mean difference was 17 min, or close to 50% ($P < 0.05$). In the 90% exp the performance times of men and women were not significantly different.

In the endurance experiments the fast rise in $\dot{V}_{O_2}$ during the first 5 min was followed by a slow upward "drift" over the rest of the exercise period (Table 2). The $\dot{V}_{O_2}$ values from 6 min until exhaustion averaged 79% of the $\dot{V}_{O_2\,max}$ for women and 80% for men in the 80% exp; the corresponding values in the 90% exp were 88% and 86%. There were no significant differences between the groups.

The values of R decreased gradually with working time as a result of a slower rise in $\dot{V}_{CO_2}$ than in $\dot{V}_{O_2}$ (Table 2). R was significantly lower in the women during the latter part of the 80% exp ($P < 0.01$). During the first part of the 80% exp, as well as during the 90%, the differences did not achieve statistical significance.

Table 1. Maximal values (mean ± 1 SD) for oxygen uptake and other cardiorespiratory functions in young, physically active women ($n = 6$) and men ($n = 7$)

	Women (W)	Men (M)	W in % of M	Sign
$\dot{V}_{O_2\,max}$				
$l \cdot min^{-1}$	3.04 ± 0.38	4.36 ± 0.74	70	**
$ml \cdot min^{-1} \cdot kg^{-1}$	50 ± 4	60 ± 4	83	**
$ml \cdot min^{-1} \cdot kg^{-1}$ lean	65 ± 4	69 ± 4	94	NS
$\dot{V}_{E\,max}$ $l \cdot min^{-1}$ BTPS	121.5 ± 14.3	165.1 ± 37.5	74	*
HR max $bt \cdot min^{-1}$	190 ± 6	185 ± 4	103	NS
HLa max $mmol \cdot l^{-1}$	10.3 ± 1.7	12.3 ± 1.9	84	NS
R	1.13 ± 0.05	1.18 ± 0.05	96	NS
$\dot{V}_E \cdot \dot{V}_{O_2}{}^{-1}\,l \cdot l^{-1}$	40.3 ± 3.5	38.1 ± 4.4	106	NS

* $P < 0.05$; ** $P < 0.01$; NS = non significant

Table 2. Metabolic and cardiorespiratory responses of women ($n = 6$) and men ($n = 7$) to exhaustive cycle ergometer exercise at 80% and 90% of $\dot{V}_{O_2\,max}$

		80% experiment				90% experiment		
		min 5–6	min 11–12	min 19–20	Exhaustion	min 5–6	min 11–12	Exhaustion
$\%\dot{V}_{O_2\,max}$	Women	76 ± 1	78 ± 2	81 ± 1	84 ± 2	84 ± 1	88 ± 1	90 ± 1
	Men	75 ± 1	79 ± 1	81 ± 1	84 ± 1	82 ± 1	86 ± 1	88 ± 1
	Sign	NS	NS	NS	NS	NS	NS	NS
R	Women	0.94 ± 0.02	0.94 ± 0.02	0.92 ± 0.01	0.90 ± 0.01	0.97 ± 0.02	0.97 ± 0.02	0.95 ± 0.02
	Men	0.99 ± 0.01	0.96 ± 0.01	0.97 ± 0.01	0.96 ± 0.01	1.02 ± 0.02	0.99 ± 0.01	1.00 ± 0.02
	Sign	NS	NS	**	**	NS	NS	NS
HLa	Women	3.93 ± 0.60	4.12 ± 0.82	4.45 ± 0.89	5.35 ± 0.86	5.46 ± 0.61	6.94 ± 0.90	8.14 ± 0.67
$mmol \cdot l^{-1}$	Men	5.12 ± 0.33	6.04 ± 0.55	6.86 ± 0.73	8.09 ± 1.04	6.92 ± 0.62	8.71 ± 1.04	10.56 ± 1.02
	Sign	NS	NS	NS	NS	NS	NS	NS
HR	Women	160 ± 5	169 ± 6	173 ± 6	185 ± 6	171 ± 8	180 ± 9	185 ± 8
$bt \cdot min^{-1}$	Men	156 ± 3	164 ± 3	170 ± 3	179 ± 2	167 ± 7	175 ± 6	181 ± 6
	Sign	NS	NS	NS	NS	NS	NS	NS

Values are means ± SE; * $P < 0.05$; ** $P < 0.01$; NS = non significant

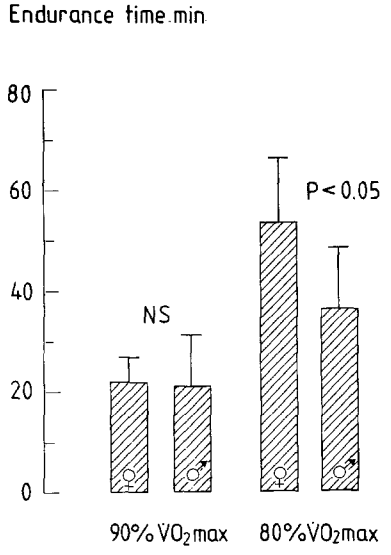

Fig. 1. Endurance time of young women ($n = 6$) and men ($n = 7$) during two heavy bicycle ergometer tasks performed until exhaustion. Values are means and 1 SD

The lactate concentrations increased continually during the 90% exp reaching 8.1 $mmol \cdot l^{-1}$ for women and 10.6 $mmol \cdot l^{-1}$ for men at exhaustion (Table 2). The rate of change in the 80% exp was lower and values at exhaustion were 5.4 $mmol \cdot l^{-1}$ for women and 8.1 $mmol \cdot l^{-1}$ for men. The differences between men and women were not statistically significant ($0.05 < P < 0.1$). The HR response to prolonged exercise was not different for men and women, in both groups it rose gradually over the working period and ended at levels slightly below HR max.

The body weight decreased significantly during the 80% experiment by an average of 0.77 kg for women and 0.84 kg for men representing 1.24 and 1.15% of body weight. Since on average the women performed longer than the men there was a tendency towards lower weight loss in women for a given performance time but the difference was not statistically significant. [Hb] and Hct at rest were signif-

icantly lower in women by about 10%. These differences were maintained during the exhaustive exercise in which [Hb] and Hct increased by approximately 5% for both men and women.

Discussion

The main finding of the study was the observation of longer times to exhaustion for women at 80% $\dot{V}_{O_2\,max}$ with no significant difference between men and women at 90% $\dot{V}_{O_2\,max}$. There is limited information available on the relationship between time to exhaustion and relative or absolute work load. The performance times observed in the present study are not appreciably different from those reported for the few comparable studies (Adams and Welch 1980; Saltin and Rowell 1980). The minor differences can be attributed to variations in experimental protocols such as use of incentives, pauses, warm-ups etc. The magnitude of the HR and HLa values at exhaustion support the impression of well motivated effort during the endurance tests in the present study.

Depletion of muscle glycogen stores has been proposed as a cause for fatigue during prolonged exercise (Bergström et al. 1967). The depletion needs not include the muscle as a whole but could be restricted to specific groups of muscle fibres (Saltin 1975). The significantly lower R values observed in the 80% exp may be indicative of an increased fat metabolism in women. This raises the possibility that the longer performance rides were obtained because more work could be performed before critically low muscle glycogen levels were reached. The interpretation of R values as indicators for substrate utilization in heavy exercise, however, is not without problems. Accumulation of lactic acid may give rise to CO_2 washout from endogenous stores, artificially increasing R above actual metabolic conditions. The rate of change in lactate values during the latter part of the 80% exp, however, was low, less than 0.1 $mmol \cdot l^{-1} \cdot min^{-1}$. We therefore conclude that the observed differences in R and in endurance time are best explained as a result of differences in substrate utilization. Supportive evidence for less glycogen utilization in women was provided by Nygaard et al. 1978. After a day of recreational skiing the glycogen content of the thigh muscle in women was reduced only half as much as in men. The investigated groups were comparable with respect to amount of skiing, skill level, food intake etc.

The present observation of lower R values in women during prolonged exercise is in conflict with studies by Costill et al. 1979 and Powers et al. 1980 who reported no significant difference. The discrepancy could be the result of differences in the work loads employed. Both Costill et al. 1979 and Powers et al. 1980 used lower relative work loads. The significance of carbohydrate as an energy source during exercise is reduced at lower work loads.

The discrepancy may, however, also reflect another relationship. Both above studies aimed specifically at comparing men and women with similar $\dot{V}_{O_2\,max} \cdot kg^{-1}$. In the present study the focus was on selection of men and women who had similar physical activity patterns, and as it turned out the $\dot{V}_{O_2\,max} \cdot kg^{-1}$ was 15–20% lower in women than in men. This, incidentally, is presumably typical of sex differences in general. The fact that we came to a different conclusion regarding sex differences in metabolic response to exercise, compared with studies in which different procedures were employed in the selection of participants, emphasizes the importance of specifying the background of the subjects in any study of sex differences. The employment of different activities for the endurance tests in the studies may possibly affect the R values obtained, and perhaps also the performance times, but we have found no evidence that it should give rise to systematic differences between sexes.

The present study offers no direct explanation for the observed differences in substrate utilization between men and women. Bass et al. 1975 and Komi and Karlsson 1978 have reported lower glycolytic enzyme activity levels in women, while at the same time the differences in the oxidative enzyme activities were non significant. This relative "imbalance" between glycolytic and oxidative enzymes in women compared with men could be involved in the women's relative preference of fat as an energy source in heavy exercise. However, the possibility that the different R-values were caused by differences in the mobilization of free fatty acids cannot be excluded.

Since a sex difference was found for endurance time in the 80% exp but not in the 90% exp, exhaustion may be related to different mechanisms in the two situations. The attainment of high muscle lactate levels has been proposed as a cause for fatigue in intense exercise. A decline in peak tension development with increased muscle lactate level was reported by Fitts and Holloszy 1977 for isolated frog muscle and by Tesch et al. 1978 for humans. The effects were ascribed to increases in acidity affecting contraction-coupling mechanisms (Fucs et al. 1970; Nakamura and Schwartz 1972) and/or regulatory enzymes in the glycolytic pathway (Trivedi and Danforth 1966). In the 90% exp in the present study very high blood lactate levels were observed at exhaustion. Both women and men attained values that were only 1.5–2 $mmol \cdot l^{-1}$ below the values obtained in the maximal tests (Table 2). With an

average performance time of about 22 min the muscle lactate values were supposedly also very high. Although the evidence is indirect the observation of near-maximal HLa levels at exhaustion may justify considering lactate a factor in the development of fatigue in the 90% exp.

The present study found little support for a lower evaporative heat loss in women than in men. The weight losses were quite similar both in absolute (about 0.8 kg) and in relative terms (about 1.2% body weight). After correcting for observed differences in endurance time in the 80% exp the differences were still non significant. The increases in [Hb] and Hct during the 80% exp were also similar in men and women, about 5%.

In conclusion, we interprete the observed superior endurance capacity for women in bicycle ergometer exercise at 80% $\dot{V}_{O_2\,max}$ as being most likely caused by a later occurrence of glycogen depletion in the exercising muscles. In exercise at 90% $\dot{V}_{O_2\,max}$ – for which no sex difference in endurance time was found – the accumulation of lactic acid may be a factor in the termination of exercise.

Acknowledgements. The skillfull technical assistance of Benthe Jørgensen, Nada Larsen and Brit Thobo-Carlsen is greatly appreciated. We especially thank our subjects for their cooperation during the tests. The authors are grateful to Drs. H. G. Welch, L. Garby, O. Lammert, and E. T. Howley for constructive suggestions in the preparation of the manuscript.

This research was supported by a grant from The Research Council of The Danish Sports Federation.

Preliminary results from the study were presented at the Scandinavian Society for Physiology and Pharmacology meeting in Stockholm Nov 1983.

References

Adams RP, Welch HG (1980) Oxygen uptake, acid-base status, and performance with varied inspired oxygen fractions. J Appl Physiol Respir Environ Exercise Physiol 49: 863–868

American College of Sports Medicine (1979) Opinion statement on the participation of the female athlete in long-distance running. Med Sci Sports 11: ix-xi

Bass A, Vondra K, Rath R, Vitek V (1975) M. femoris of man, a muscle with an unusual enzyme activity pattern of energy supplying metabolism in mammals. Pflügers Arch 354: 249–255

Bergström J, Hermansen L, Hultman E, Saltin B (1967) Diet, muscle glycogen and physical performance. Acta Physiol Scand 71: 140–150

Costill D, Fink WJ, Getchell LH, Ivy JL, Witzmann FA (1979) Lipid metabolism in skeletal muscle of endurance-trained males and females. J Appl Physiol 47: 787–791

Durnin JVGA, Womersley J (1974) Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged from 16 to 72 years. Br J Nutr 32: 77–97

Fitts RH, Holloszy JO (1977) Lactate and contractile force in frog muscle during development of fatigue and recovery. Am J Physiol 231: 430–433

Forster HB, Dempsey JA, Thomson J, Vidruk E, DoPico GA (1972) Estimation of arterial PO_2, PCO_2, pH and lactate from arterialized venous blood. J Appl Physiol 32: 134–137

Fox RH, Löfstedt BE, Woodward PM, Eriksson E, Werkström B (1969) Comparison of thermoregulatory function in men and women. J Appl Physiol 26: 444–453

Fuchs F, Reddy V, Briggs FN (1970) The interaction of cations with the calcium-binding site of troponin. Biochim Biophys Acta 221: 407–409

Hohorst JJ (1970) L-(+)-Lactat. Bestimmung mit Lactathehydrogenase und NAD. In: Bergmeyer MU (ed) Methoden der enzymatischen Analyse. Verlag Chemie, Weinheim, 2. ed, pp 1425–1429

Komi P, Karlsson J (1978) Skeletal muscle fibre types, enzyme activities and physical performance in young males and females. Acta Physiol Scand 103: 210–218

Nakamura Y, Schwartz S (1972) The influence of hydrogen ion concentration on calcium binding and release by skeletal muscle sarcoplasmatic reticulum. J Gen Physiol 59: 22–32

Nygaard E (1981) Women and exercise – with special reference to muscle morphology and metabolism. In: Poortmans J, Niset G (eds) Biochem Exercise IV B. Univ Park Press Baltimore, pp 161–175

Nygaard E, Andersen P, Nilsson P, Eriksson E, Kjessel T, Saltin B (1978) Glycogen depletion pattern and lactate accumulation in leg muscles during recreational downhill skiing. Eur J Appl Physiol 38: 261–269

Powers SK, Riley W, Howley ET (1980) Comparison of fat metabolism between trained men and women during prolonged aerobic work. Res Quart 51: 427–431

Saltin B (1975) Adaptive changes in carbohydrate metabolism with exercise. In: Howald H, Poortmans J (eds) Metabolic adaptation to prolonged physical exercise. Birkhäuser Verlag, Basel, pp 94–100

Saltin B, Rowell LB (1980) Functional adaptations to physical activity and inactivity. Fed Proc 39: 1506–1513

Tesch P, Sjödin B, Thorstensson A, Karlsson J (1978) Muscle fatigue and its relation to lactate accumulation and LDH activity in man. Acta Physiol Scand 103: 413–420

Trivedi B, Danforth WH (1966) Effect of pH on the kinetics of frog muscle phosphofructokinase. J Biol Chem 241: 4110–4112

Accepted March 5, 1984