MAXIMAL CARDIORESPIRATORY RESPONSES OF MALES AND FEMALES TO BICYCLE AND TREADMILL ERGOMETRY

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Introduction

The emergence of females in all realms of activity has prompted more investigation of their functional capabilities. At present there is a dearth of comparative information in the physiological realm which has led to diverse conjecture regarding the ability of females to compete with and against males. Generally, females do not respond differently than males to submaximal work (14, 18). At maximum performance levels, however, males are significantly superior when parameters are considered in absolute terms (10, 13, 15, 18). When parameters are considered relative to body size, as, per kilogram body weight (BW) or lean body mass (LBM), the differences are reduced but not totally removed (10, 13).

The purpose of this study was to compare the physiological response of comparable groups of males and females to maximal exercise stress. More specifically, this research evaluated and compared (1) the cardiorespiratory response of each sex relative to body composition on a bicycle ergometer and motor-driven treadmill, and (2) the difference in the reaction of both sexes to the two forms of ergometry.

Methodology

Subjects. The subjects were 13 male and 11 female volunteers whose activity levels ranged from sedentary to trained in both sexes. There was approximately the same proportion of trained individuals in each group as determined by subject questioning prior to experimentation. Testing order for administration of the two forms of ergometry was determined randomly. Group physical characteristics are shown in Table I.

Bicycle ergometer test. Each subject reported to the laboratory at least 2 hours postabsorptive and without strenuous exercise for 12 hours preceding the test. A 5-minute warmup, 720 kpm/min for males and 360 kpm/min for females, was given. Following a 5-minute rest each subject began pedalling at a load which would exhaust the individual in 5-10 minutes (based on subjective estimates of their physical condition). Subjects ceased exercising by voluntary termination or when the pedalling rate fell below 50 rpm.

One-minute aliquots of expired gas were collected

throughout the test on the apparatus previously described (17). Gas samples were analyzed using electronic analyzers (Beckman E-2 oxygen and MSA Lira 300 Carbon dioxide analyzers) routinely calibrated with standard reference gases previously analyzed on a Lloyd-Haldane chemical apparatus. Heart rate was recorded during the last 15 seconds of every minute of exercise by telemetered electrocardiography (Narco Bio-System).

TABLE I

Group Physical Characteristics

Variable	Males (n = 13)		Females (n = 11)		% Diff. $\frac{M - F}{M} \times 100$
	Mean	SD	Mean	SD	
Age (yrs)	26.37	4.97	23.98	3.95	9.1
Height (cm)	179.1	7.3	163.0	5.1	9.0
Weight (kg)	77.64	18.10	57.18	7.38	26.4
BSA (m ²)	1.90	0.23	1.59	0.11	16.3
LBM* (kg)	67.91	14.26	44.69	4.51	34.2
BCM* (kg)	38.52	8.09	23.88	2.31	38.0
%Fat*	13.3	5.5	21.8	9.9	63.9

*Calculated from total body potassium.

Treadmill test. Each subject reported to the laboratory in a rested postabsorptive state as in the bicycle ergometer test. Males warmed up with a 5-minute run at 11.3 km/hr (0% grade), while females used a 5-minute walk at 5.6 km/hr (0% grade), each followed by a 5-minute rest. The maximal stress test for males followed the protocol of Costill and Fox (4): 4 minutes at 0% grade followed by an initial increment to 4% elevation, with 2% increments every 2 minutes thereafter until voluntary termination. Female subjects followed the protocol of Costill and others (5): 2 minutes at 0% grade followed by 2.5% grade increments every 2 minutes until exhaustion. In both cases the speed of the treadmill for each subject was subjectively chosen on the basis of physical condition to reach termination in 5-10 minutes. Speeds ranged from 12.9 to 17.7 km/hr for males and 8.0 to 11.3 km/hr for females. One-minute heart rates were taken and gas aliquots collected and analyzed as described previously.

Body composition assessment. Body composition was evaluated by whole-body potassium counting using a 4π

liquid scintillation counter (23). Each subject was counted for 2 consecutive 4-minute periods with 4-minute background counts taken before and after the subject count. Efficiency of the counter was determined at each test session by counting a phantom of known ^{40}K activity. Subjects were counted on 2 separate occasions within a time period of 5 to 9 days. Total body potassium (TBK), lean body mass (LBM), fat weight (FW), and percent fat (%fat) were calculated at each occasion (3) with the mean representing the subject. The potassium constant used for males was 2.66 g K/kg LBM (8) and for females was 2.50 g K/kg LBM (9). Body cell mass (BCM) was calculated according to Moore and others (20).

Subcutaneous skinfolds were taken on each subject using Harpenden callipers at the following sites: triceps, subscapular, suprailiac, anterior thigh, and posterior calf.

Site locations and measurement methods were those of Wilmore and Behnke (25, 26).

Leg volume was measured by water displacement. Each measure was accomplished by submerging the right leg to the gluteal furrow.

Results

Maximal cardiorespiratory parameters are shown in Table II. In the case of both bicycle and treadmill, neither maximal heart rates nor breathing rates were significantly different between the sexes while maximal oxygen intake (VO_2max), pulmonary ventilation (V_E), and O_2 pulse were significantly different ($p < .001$). When VO_2max was assessed in terms of body composition, only the treadmill value expressed in terms of BCM was not significantly different (Table II).

TABLE II

Maximal Cardiorespiratory Parameters for Males (n = 13) and Females (n = 11)

Variable	Males Mean	SD	Females Mean	SD	Diff. (M - F)	% Diff. $\frac{M - F}{M} \times 100$	t ratio
<i>Bicycle Ergometer</i>							
VO_2max (l/min)	4.09	0.53	2.18	0.43	1.91	46.7	9.57*
VO_2max (ml/kg BW/min)	54.1	8.8	38.8	10.2	15.3	39.4	3.95*
VO_2max (ml/kg LBM/min)	61.5	8.4	49.2	10.5	12.3	25.0	3.19*
VO_2max (ml/kg BCM/min)	108.4	14.8	92.0	19.7	16.4	17.8	2.33*
V_E (l/min BTPS)	156.8	32.6	89.3	11.1	67.5	43.0	6.53*
Breathing rate (breaths/min)	55.2	9.0	52.9	7.5	2.3	4.2	0.67
Maximal Heart Rate (bpm)	178.2	12.2	184.9	10.4	-6.7	-3.8	-1.43
O_2 Pulse (ml/beat)	23.1	3.9	11.8	2.0	11.3	48.9	8.69*
<i>Treadmill</i>							
VO_2max (l/min)	4.46	0.51	2.46	0.38	2.00	44.8	10.73*
VO_2max (ml/kg BW/min)	59.1	11.3	43.5	8.1	15.6	35.9	4.55*
VO_2max (ml/kg LBM/min)	67.4	11.0	55.4	8.9	12.0	21.7	4.85*
VO_2max (ml/kg BCM/min)	118.9	19.3	103.7	16.6	15.2	14.7	2.05
V_E (l/min BTPS)	154.1	29.3	89.9	8.2	64.2	41.7	4.56*
Breathing rate (breaths/min)	54.5	9.0	53.9	9.1	0.6	1.1	0.30
Maximal Heart Rate (bpm)	186.5	11.8	189.7	9.8	-3.2	-1.7	0.38
O_2 Pulse (ml/beat)	23.8	2.8	13.0	1.9	10.8	45.4	10.85*

*t = 2.07 significant at .05 level

The difference between bicycle and treadmill $\dot{V}O_2$ max (l/min) for females was comparable to that of males (males = $8.3 \pm 7.1\%$; females = $12.8 \pm 10.1\%$) as shown in Figure 1. In both cases the difference between bicycle and treadmill $\dot{V}O_2$ max were significant ($p < .05$) whether expressed in l/min or in terms of body composition (ml/kg BW/min, ml/kg LBM/min and ml/kg BCM/min). Both males and females exhibited a significantly higher maximal heart rate on the treadmill than on the bicycle. The higher $\dot{V}O_2$ max and the slightly higher HR of the females combined to yield a significantly higher O_2 pulse during treadmill exercise. In males the smaller increase in $\dot{V}O_2$ max and the greater increase in HR produced an insignificantly higher O_2 pulse during treadmill stress. Neither maximum breathing rate nor $\dot{V}E$ were significantly different between ergometers for both sexes.

Figure 1. Comparison of $\dot{V}O_2$ max (l/min) on bicycle and treadmill for males ($n = 13$, $\circ$) and females ($n = 11$, $\bullet$).

TABLE 1
Relationships of Anthropometric and Maximal Oxygen Intake Measures

Variable	Males														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Age (yrs)															
2. Ht (cm)			.83	.78	.86			.86	.80						
3. Wt (kg)				.98	.95			.95	.99						
4. BSA (m^2)		.82	.97		.94	.70		.94	.98						
5. LBM (kg)								1.00	.95						
6. Fat Wt (kg)			.86	.74			.89		.72	.66	.79				
7. %Fat			.74			.98				.73	.75				
8. BCM (kg)					1.00				.95						
9. LV (l)	.75														
10. Thigh SKF (mm)											.73				
11. Calf SKF (mm)			.76												
12. Abdominal SKF (mm)															
13. Subscapular SKF (mm)													.79		
14. Triceps SKF (mm)										.77	.88				
15. $\dot{V}O_2$ max* (l/min)										.74					
16. $\dot{V}O_2$ max* (ml/kg/min)										.85					
17. HRmax* (bpm)															
18. O_2 Pulse* (ml/beat)															
19. $\dot{V}E$ * (l/min BTPS)															
20. Breathing Rate (breaths/min)															
21. $\dot{V}O_2$ max** (l/min)															
22. $\dot{V}O_2$ max** (ml/kg/min)															
23. HRmax** (bpm)															
24. O_2 Pulse** (ml/beat)															
25. $\dot{V}E$ ** (l/min BTPS)															
26. Breathing Rate (breaths/min)															

*Measured on the bicycle ergometer

Females

Females

Males

$$\text{VO}_2 \text{ max (1/min)} = 2.947 + 0.149 \text{ LV (1)} - 0.0322 \text{ thigh SKF (mm)} - 0.0011 \text{ calf SKF (mm)}$$
$$R = .75 \text{ SEE} = 0.400 \text{ 1/min}$$

Females

$$\text{VO}_2 \text{ max (1/min)} = 3.062 + 0.0249 \text{ LV (1)} - 0.0585 \text{ thigh SKF (mm)} - 0.0099 \text{ calf SKF (mm)}$$
$$R = .75 \text{ SEE} = 0.345 \text{ 1/min}$$

Discussion

The difference in $\text{VO}_2 \text{ max}$ (ml/kg/min) between the sexes found in this study was slightly greater than previous investigations (Table IV). The difference may have been spuriously affected by the relatively small number of subjects studied and their diverse fitness levels. When $\text{VO}_2 \text{ max}$ was considered relative to BCM, the difference between the sexes was reduced to a value comparable to that found by MacNab and others (13) who considered $\text{VO}_2 \text{ max}$ in terms of LBM determined densitometrically. Those authors explained the difference between the sexes ($\sim 14\%$) as being due to differences in haemoglobin content, although they did not actually measure that parameter. While it seems inviting to say that the remaining difference in $\text{VO}_2 \text{ max}$ between the sexes, when LBM is accounted for, is due to the lower haemoglobin content of the females' blood, (16, 24), this may be an oversimplification. Nagle (21) stated that the difference between the sexes was due largely to the smaller organs (lungs, heart, and skeletal muscles) of the female. It may be the interaction of several physiological parameters that results in a lower $\text{VO}_2 \text{ max/kg}$ ratio in females. Further research is necessary before definitive statements can be made.

TABLE IV

Difference in $\text{VO}_2 \text{ max}$ (ml/kg/min) for Males and Females with Bicycle and Treadmill Ergometry

Study	Bicycle $\dot{\text{V}}\text{O}_2 \text{ max.}$			Treadmill $\dot{\text{V}}\text{O}_2 \text{ max.}$		
	Male	Female	%Diff.	Male	Female	%Diff.
Metheny & others (18)				51.3	40.9	25.4
Hermanson A & Anderson S (10)	71	55	29.1			
	44	38	15.8			
MacNab & others (13)	46.5	35.7	30.2	51.7	39.1	32.2
Present Study	54.1	38.8	39.4	59.1	43.5	35.9

A = Athletes
S = Students

The difference in $\text{VO}_2 \text{ max}$ (1/min) for males between bicycle and treadmill exercise (8.3%) was similar to the mean value of 13 studies reported in the literature (mean = $9.2 \pm 4.4\%$). The only two studies reporting differences between $\text{VO}_2 \text{ max}$ on bicycle and treadmill for females showed 4.5% (1) and 9.4% (13) greater aerobic capacities during maximal treadmill stress. The difference found in this study (12.8%) was only slightly greater. The hypothesis that uphill treadmill running involves a greater muscle mass and therefore elicits a greater $\text{VO}_2 \text{ max}$ than bicycling (19) appears to have been substantiated by Secher and others (22), who reported a 6% higher $\text{VO}_2 \text{ max}$ during arm + leg work than during leg work alone. Furthermore, arm + leg work did not result in a higher $\text{VO}_2 \text{ max}$ than uphill treadmill running.

The greater maximal heart rate shown in treadmill exercise probably resulted in a greater cardiac output which coincided with earlier observations (11, 19). If the assumption is made that O_2 pulse is a relative measure of stroke volume (2), the significantly higher O_2 pulse for females during treadmill exercise might indicate an increase in stroke volume. An increased cardiac output in females, therefore, would have been produced by increases in both heart rate and stroke volume. However, since O_2 pulse was not significantly increased in males exercising on the treadmill, the increase in cardiac output would have resulted principally from an increase in heart rate. Because O_2 pulse must also involve, to some degree, the arteriovenous oxygen difference, and since the reaction of the a-v O_2 difference during bicycle and treadmill exercise remains controversial (7, 19), further definitive research needs to be undertaken in this area.

The low correlation between leg volume and $\text{VO}_2 \text{ max}$ (1/min) in females appeared to be due to the influence of adipose deposits in the lower limbs. When leg volume was "corrected" to lean leg volume by accounting for thigh and calf skinfold thicknesses, the leg volume/ $\text{VO}_2 \text{ max}$ relationship was significant ($p < .01$) in both sexes. The argument (6) that the major factors determining $\text{VO}_2 \text{ max}$ during bicycle ergometry were the size and composition of the lower limbs has been challenged (12). When body weight was partialled out of the leg volume/ $\text{VO}_2 \text{ max}$ relationship, the association was drastically reduced as shown elsewhere (12), and leg dimensions offered no greater advantage than body weight as a general reference standard for $\text{VO}_2 \text{ max}$. However, the higher correlation and lower standard error of estimate for the regression of $\text{VO}_2 \text{ max}$ on leg volume, especially when the latter is corrected for adipose tissue, offers great promise for the prediction of $\text{VO}_2 \text{ max}$ from anthropometric measurements.

In conclusion, even with the limited sample observed here, males appear to differ in aerobic capacity from

females no matter what the frame of reference. While the difference may be small when assessed in terms of LBM, both sexes must carry the entire body weight

when participating in physical activity. To this end the greater relative fat content of females is certainly a hinderance.

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