Gender differences in the systolic blood pressure response to exercise

Previous work has shown a gender difference in the normal cardiac response to exercise. Men had significantly higher absolute systolic blood pressure responses at 50%, 75%, and 100% peak heart rate on all modalities ($p < 0.05$). This difference is absent when systolic blood pressure is adjusted for body surface area, is reduced when adjusted for body weights, and is reversed when systolic blood pressure is adjusted for lean body mass. The influence of gender on the systolic blood pressure response to dynamic exercise was independent of exercise modality. Men had a higher systolic blood pressure in spite of the fact that they had similar sympathetic nervous system response as indicated by urinary norepinephrine excretion. Gender differences in systolic blood pressure responses were altered when adjusted for body weight, body surface area, and lean body mass. (AM HEART J 1991;121:524.)

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Men and women have been shown to have a different cardiovascular response to exercise.[1-5] Higgenbotham et al.[2] noted that men and women maintain cardiac output with exercise in different ways. With the use of exercise radionucleotide angiography, men were shown to increase stroke volume by an increase in ejection fraction, whereas women were shown to increase stroke volume through an increase in end-diastolic volume. Gender differences have also been noted in stroke volume at the same percentage of maximal oxygen consumption (VO_2)[1, 4] and in maximal VO_2, although not when expressed in terms of lean body mass (LBM).[3, 4, 6]

Systolic blood pressure (SBP) normally increases during dynamic exercise, and Higgenbotham et al.[2] found men and women to have the same SBP at equal work loads during incremental exercise on the treadmill. Possible gender differences at similar relative intensities have not been evaluated. The present study was performed to assess gender differences in SBP on four different exercise modalities during maximal and submaximal aerobic exercise. In addition, the sympathoadrenal response to exercise was investigated through measurement of urinary catecholamine excretion.

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METHODS

The subjects were 10 men and 10 women with no signs, symptoms, or history of cardiovascular disease. There were no selection criteria relative to training status. The subjects gave informed consent, and the protocol was approved by the Human Investigations Committee at Lenox Hill Hospital.

All subjects exercised at random on four exercise modalities: (1) motorized treadmill, (2) Fitron bicycle ergometer (Cybex, Ronkonkoma, N.Y., (3) AMF Benchmark rowing ergometer (Membrex, Garfield, N.J.) and (4) arm ergometer (a Collins pedal ergometer [Warren E. Collins Inc., Braintree, Mass.] suspended at shoulder level). Each test was separated by at least 2 days, and the four tests were completed within a 2-week period. Subjects who were not familiar with a rowing ergometer were allowed to familiarize themselves with the apparatus on a separate day.

All exercise protocols were intermittent with 3 minutes of work followed by 30 seconds of rest to allow for blood pressure measurement by auscultation. All subjects exercised to volitional fatigue. Exercise on the bicycle, rowing, and arm ergometers was done at a constant cycle rate, and resistance was progressively increased. The starting work rate on the bicycle was 400 kpm/min, and was increased by 200 kpm/min for men and by 150 kpm/min for women with each stage. Exercise with the arm ergometer began with a work rate of 25 W and was increased by 20 W for men and 15 W for women. Exercise with the rowing ergometer began at a rate of 7 to 8 cal/min, and the rate was increased by 2 cal/min for men. Women began exercise with the rowing ergometer at a rate 6 cal/min, and the rate was increased by 1 to 2 cal at each stage. (The calories referred to here are the units of work indicated by the ergometer. According to oxygen consumption measures, it is an overestimation.) The treadmill protocol involved 3-minute stages, which began with a speed of 3.5 mph that was increased by a grade of 5% at each stage until a grade of 25% was reached. Thereafter, speed was increased by 1 mph each stage. To ensure accurate measurement, the appropriate size blood pressure cuffs were used and were inflated at the end of each stage while the subjects were exercising so that blood pressure could be obtained immediately as the subject rested for 30 seconds between stages. Heart rate and VO_2 were measured during the last minute of each stage of work.

Oxygen consumption was measured continuously by a Sensor Medics Metabolic Measurement Cart (Sensor Medics Corp., Anaheim, Calif.). Calibration with standard gases that spanned a range of 0% to 4% carbon dioxide and 0% to 16% oxygen was performed before each test. Heart rate was monitored continuously in leads II, aVF, and V_5.

Subjects were asked to give a urine specimen immediately before and after exercise for measurement of norepinephrine and epinephrine levels. The urine was acidified to a pH of 3, preserved with glutathione and ethylenediaminetetracetic acid, and stored at −70° F until analysis. Catecholamines were measured by high-pressure liquid chromatography (BAS, West Lafayette, Ind.) with electrochemical detection. All samples from each subject were run in the same assay. To correct for differences in urinary volume, all values are expressed in nonograms per milligram of creatinine excretion. Body composition was measured on a separate day with bioelectrical impedance[7,8] when the subjects were in a state of euhydration (RJL Systems, Detroit, Mich.).

To make comparisons of heart rate and SBP at 50% and 75% of peak, a linear regression of heart rate versus SBP was performed for each subject on each modality. In all cases, correlation coefficients were in excess of 0.9. Heart rates at 50% and 75% peak were substituted into each equation to arrive at the SBP value. This procedure was used to avoid subjective use of values close to 50% and 75% of peak heart rate and to eliminate any error term associated with percentage of peak heart rate. There were no systematic differences in correlation coefficients between men and women, and second order regressions did not improve the fit. The mean standard error of the individual regressions was 5 mm Hg, which is small enough to be near the range of measurement error by auscultation. Because of the gender differences in other measures of cardiovascular performance that appear to be associated with body mass, we also examined SBP after adjustment for total body weight (BW), body surface area (BSA), and LBM.

Statistics. Data were analyzed for gender differences with a two way analysis of variance in a repeat measures design and with un-paired t-tests. Pearson's product moment correlations were used to assess the relationships of LBM, BSA, and BW with blood pressure during exercise. All values are expressed as mean ± standard error. Significance was accepted for all analyses at the $p < 0.05$ level.

RESULTS

The group characteristics are shown in Table I. There were no significant differences in age or resting SBP between men and women. Men had significantly higher resting diastolic blood pressure ($p < 0.01$) and mean arterial pressure ($p < 0.001$) than women. Men weighed significantly more than women and had significantly greater LBM and lower percent body fat ($p < 0.0001$).

The values in Table II demonstrate that men had significantly greater peak VO_2 (milliliters per kilogram per minute) than the women on all modalities ($p < 0.01$), but there were no significant differences in peak VO_2 (milliliters per kilogram LBM per minute). Both genders had greater peak VO_2 on the treadmill than on any other modality.

There were no significant differences between the genders for either resting norepinephrine or epinephrine excretion (Table III). There were also no significant differences in the ratio of epinephrine to norepinephrine.

Exercise urinary catecholamine excretion was assessed as the difference between postexercise and preexercise samples. There were no significant gen-

Table I. Population description

	Men	*Women*	*p Value*
Age	32 ± 3	27 ± 2	NS
Resting SBP	127 ± 3	120 ± 2	NS
Resting DBP	82 ± 1	76 ± 1	0.01
Resting MAP	98 ± 1	90 ± 1	0.001
Weight (kg)	77.0 ± 2.3	61.1 ± 1.7	0.0001
Percent body fat	14.1 ± 1.4	22.6 ± 0.9	0.0001
LBM (kg)	66.0 ± 1.6	47.2 ± 1.3	0.0001

SBP, Systolic blood pressure; NS, not significant; DBP, diastolic blood pressure; MAP, mean arterial pressure; LBM, lean body mass.

Table II. Peak VO_2 on four exercise modalities

	Men	*Women*	*p Value*
Peak VO_2 (ml/kg/min)			
Walk	54.5 ± 2.9*	46.0 ± 2.1*	0.01
Bike	51.3 ± 2.2	44.6 ± 2.3	0.01
Row	47.4 ± 2.3	42.5 ± 2.4	0.01
Arm	36.2 ± 1.9	28.5 ± 2.3	0.01
Peak VO_2 (ml/kg LBM/min)			
Walk	63.2 ± 3.0	59.3 ± 2.2	NS
Bike	59.7 ± 2.4	57.4 ± 2.6	NS
Row	55.1 ± 2.4	54.7 ± 2.7	NS
Arm	42.2 ± 2.8	36.7 ± 2.8	NS

VO_2, Oxygen consumption; other abbreviations as in Table I.
*Values were significantly greater than all other modalities ($p < 0.01$).

Table III. Resting catecholamine excretion

	Men	*Women*	*p Value*
NE (ng/mg Cr)	35.5 ± 2.7	29.1 ± 3.5	NS
EPI (ng/mg Cr)	9.7 ± 1.4	9.6 ± 1.3	NS

NE, Norepinephrine; C, creatinine; EPI, epinephrine; other abbreviations as in Table I.

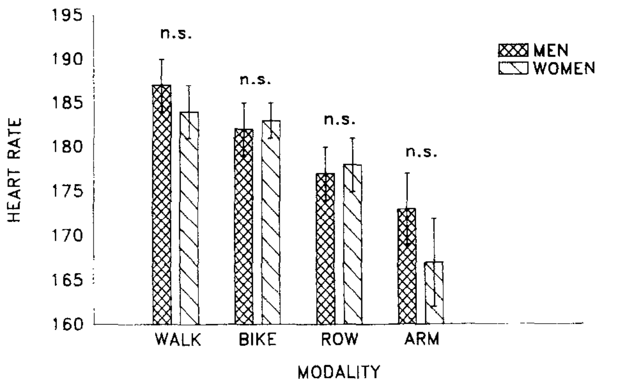

Fig. 1. Peak heart rates on all modalities for men and women. Values are means ± SEM. There were no significant differences between the genders on any of the modalities.

Table IV. Catecholamine excretion on four exercise modalities

	Walk	Bike	Row	Arm
Epinephrine				
Men	18.0 ± 4.0	17.7 ± 4.7	12.2 ± 1.5*	14.9 ± 3.6
Women	11.6 ± 3.1	14.1 ± 4.0	9.6 ± 2.9*	10.4 ± 2.7
Norepinephrine				
Men	56.4 ± 13.8	46.6 ± 8.7	34.0 ± 3.6	28.2 ± 3.8
Women	52.1 ± 8.7	61.0 ± 6.4	49.0 ± 5.4	36.1 ± 4.9

*Significantly less than other modalities, $p < 0.01$.

der differences in norepinephrine or epinephrine excretion during exercise (Table IV). Rowing produced significantly lower epinephrine excretion than the other modalities ($p < 0.01$).

There were significant correlations between SBP at 50%, 75%, and 100% peak heart rate and LBM ($p < 0.02$), BW ($p < 0.01$), and BSA ($p < 0.007$). Pearson's r values ranged from 0.49 to 0.80.

Fig. 1 shows the peak heart rates for men and women on the four different exercise modalities. There were no significant differences between the genders on any of the modalities. Peak heart rate for walking was greater than that for bicycle ergometry ($p < 0.03$), peak heart rate for biking was greater than that for rowing ($p < 0.001$), and peak heart rate for rowing was greater than peak heart rate for arm ergometry ($p < 0.0005$).

The SBP results at the same relative heart rates for the different modalities are shown in Table V and VI.

Absolute SBP. Absolute SBPs at the same relative heart rates for the different modalities are shown in Fig. 2. With the exception of rowing at 50% of peak heart rate, for each modality tested, men had a higher SBP at the same percent peak heart rate than women did.

Weight-adjusted SBP. When SBP is corrected for BW, some of the differences disappear. At 50% and 75% peak heart rate for walking exercise, men had significantly greater SBP per kilogram of BW ($p < 0.05$). For bicycle ergometry, men and women also differed at 50% and 75% peak heart rate ($p < 0.01$). For rowing, men and women differed in SBP per kilogram of BW at 50% peak heart rate only ($p < 0.04$). However, there were no significant gender differences in arm ergometry at either of the submaximal intensities or at peak heart rate on any of the modalities.

LBM-adjusted systolic blood pressure. During exercise at 50%, 75%, and 100% peak heart rate, women had higher SBP/per kilogram of LBM on all four modalities (Fig. 3). Resting SBP/LBM was also higher in women.

BSA-adjusted systolic blood pressure. No significant differences between men and women in BSA-adjusted SBP were found during exercise at 50%, 75%, or 100% peak heart rate on any modality.

DISCUSSION

The results of this study show that gender significantly influences the absolute SBP response to dynamic exercise. Furthermore, this gender difference is seen during exercise on a variety of exercise modalities. This difference is absent when SBP is adjusted for BSA, is reduced when adjusted by BW, and is reversed when SBP is adjusted for LBM.

Indirect assessment of myocardial VO_2 is made by calculation of the rate pressure product of heart rate × SBP.[9] Our data show that women will have a lower rate pressure product than men at a similar percentage of peak heart rate. This may lower the sensitivity of an exercise test for women, particularly if exercise is terminated when a target heart rate is attained. The women in this study, however, were substantially younger than most women with coronary artery disease, and older women may respond differently during exercise.

The gender differences in SBP may be explained by differences in BW, BSA, or LBM. Kumagai et al.[10] found resting SBP, diastolic blood pressure, and mean arterial pressure to be correlated to BW independent of age or percent body fat in young men. Viitisalo et al.[11] found in young men that strength, percent body fat, and LBM all correlated positively with resting blood pressure. Maiorano et al.[12] found a positive correlation between SBP and weight and body index at rest and during isometric exercise.

LBM has also been found to correlate with ventricular size,[13] and Devereux et al.[14] found that correction for LBM, as measured by creatinine ex-

Table V. SBP on four modalities by gender

		Arm	Bike	Row	Walk
SBP					
	Men	146.6 ± 4	144.7 ± 3	127.0 ± 7	148.1 ± 3
50%	Women	129.8 ± 5	130.7 ± 5	113.7 ± 4	130.9 ± 3
	p Value	0.014	0.021	NS	0.001
	Men	168.3 ± 4	178.4 ± 5	168.9 ± 8	183.0 ± 5
75%	Women	145.5 ± 4	161.8 ± 4	144.6 ± 3	159.6 ± 4
	p Value	0.001	0.03	0.014	0.001
	Men	190.8 ± 6	213.8 ± 9	212.8 ± 11	216.0 ± 7
100%	Women	160.6 ± 5	161.8 ± 5	174.4 ± 4	186.4 ± 6
	p Value	0.001	0.018	0.006	0.004
SBP/BW					
	Men	1.91 ± 0.05	1.89 ± 0.40	1.65 ± 0.08	1.91 ± 0.04
50%	Women	2.14 ± 0.09	2.15 ± 0.07	1.87 ± 0.06	2.16 ± 0.08
	p Value	0.052	0.007	0.038	0.025
	Men	2.20 ± 0.05	2.33 ± 0.05	2.20 ± 0.10	2.39 ± 0.06
75%	Women	2.38 ± 0.09	2.66 ± 0.07	2.38 ± 0.06	2.63 ± 0.09
	p Value	0.052	0.011	NS	0.048
	Men	2.49 ± 0.06	2.80 ± 0.13	2.78 ± 0.15	2.82 ± 0.10
100%	Women	2.64 ± 0.09	3.10 ± 0.11	2.88 ± 0.12	3.07 ± 0.11
	p Value	NS	0.091	NS	0.12

BW, Body weight; other abbreviations as in Table I.

Table VI. SBP on four modalities by gender

		Arm	Bike	Row	Walk
SBP/LBM					
	Men	2.26 ± 0.05	2.23 ± 0.05	1.92 ± 0.10	2.24 ± 0.03
50%	Women	2.75 ± 0.10	2.71 ± 0.10	2.41 ± 0.07	2.79 ± 0.09
	p Value	0.001	0.001	0.001	0.001
	Men	2.56 ± 0.05	2.71 ± 0.08	2.56 ± 0.11	2.79 ± 0.06
75%	Women	3.09 ± 0.09	3.43 ± 0.10	3.08 ± 0.06	3.39 ± 0.10
	p Value	0.001	0.001	0.001	.001
	Men	2.90 ± 0.09	3.26 ± 0.15	3.23 ± 0.16	3.23 ± 0.16
100%	Women	3.41 ± 0.10	4.01 ± 0.12	3.41 ± 0.13	3.71 ± 0.13
	p Value	0.001	0.001	0.032	0.032
SBP/BSA					
	Men	77.8 ± 1.9	76.7 ± 1.4	67.4 ± 3.7	78.6 ± 1.8
50%	Women	75.9 ± 2.7	76.4 ± 2.3	66.6 ± 2.2	76.7 ± 1.9
	p Value	NS	NS	NS	NS
	Men	89.3 ± 2.7	94.7 ± 2.7	89.5 ± 4.2	97.2 ± 3.0
75%	Women	85.1 ± 2.2	94.6 ± 2.3	84.6 ± 1.7	93.4 ± 2.3
	p Value	NS	NS	NS	NS
	Men	101.2 ± 2.9	113.5 ± 4.8	112.7 ± 5.7	114.7 ± 4.2
100%	Women	94.0 ± 2.5	110.0 ± 2.6	102.2 ± 2.9	109.0 ± 2.9
	p Value	NS	NS	NS	NS

BSA, Body surface area; other abbreviations as in Table I.

cretion, eliminated the gender difference in left ventricular mass (LVM) index (LVM/BSA). Men and women differed in LBM by 40%, which was much greater than the difference in the present study. Gottdiener et al.[15] found that 14 of 22 patients with maximal exercise SBP ≥210 mm Hg had left ventricular hypertrophy, whereas only one in 17 patients with SBP ≤210 mm Hg had left ventricular hypertrophy. In addition, differences in resting SBP were also noted between patients with or without left ventricular hypertrophy. These studies suggest that SBP during maximal exercise is related to LVM, which in turn is related to LBM. The present study suggests that these relationships may be present during submaximal dynamic exercise because the gender differences in SBP were altered when SBP was corrected for LBM.

Urinary excretion of catecholamines during exer-

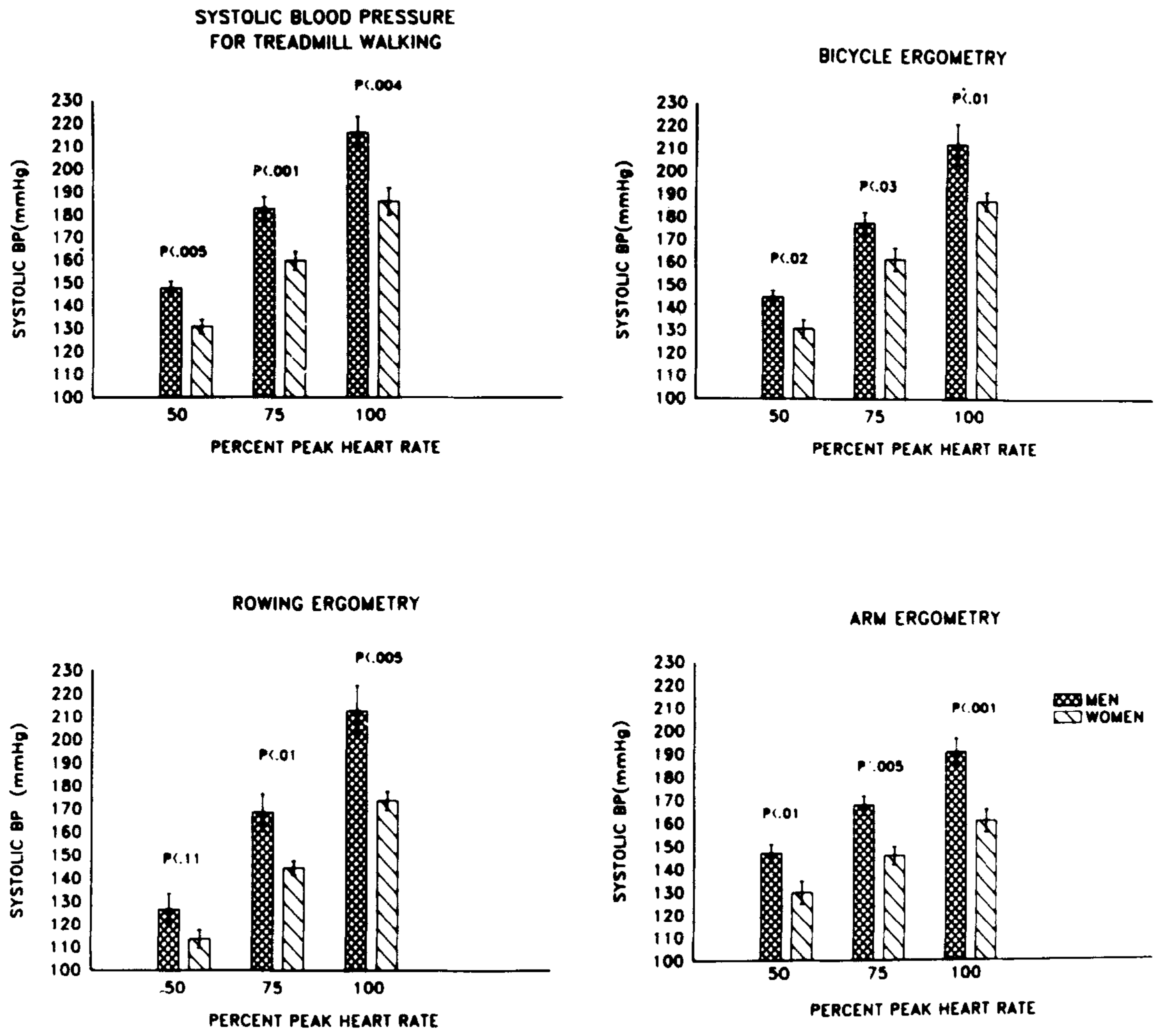

Fig. 2. Means and SEM for systolic blood pressure at 50%, 75%, and 100% peak heart rate for men and women. Men had significantly greater systolic blood pressure at all intensities on all modalities except 50% peak heart rate on the rowing ergometer.

cise reflects the degree of sympathoadrenal activity.[16,17] Previous work has indicated that this measurement of sympathetic nervous system activity correlates equally well with lactate levels, as does plasma norepinephrine.[18] There was no gender difference in the amount of norepinephrine excreted during the exercise trial, a finding that is consistent with previous work.[19, 20] However, to account for differences in glomerular filtration rate and urine volume, creatinine excretion was used to report catecholamine excretion. Creatinine is also an indicator of LBM,[6, 21] so the gender similarity in catecholamine excretion may also be attributed to differences in LBM. In the present study, although the differences were not significant, the men tended to excrete more creatinine than the women over all modalities (11.6 ± 3.8 mg/dl and 9.7 ± 6.2 mg/dl, respectively). The catecholamine excretion measurement in epinephrine or norepinephrine per milligram of creatinine may have already corrected for LBM and could account for the lack of gender differences in catecholamine excretion.

Limitations. An important limitation in the present study, and in clinical exercise testing in general, may be the measurement of blood pressure. Maiorano et al.[12] found positive correlations between arm circumference and SBP during isometric exercise. The gender differences in LBM suggest that there were probably systematic differences in arm circumference between the men and women. Appropriate cuff sizes were used for blood pressure measurement, but the proper size cuff represents a range of acceptable arm circumferences, so some gender differences may be due to systematic measurement error. Unfortu-

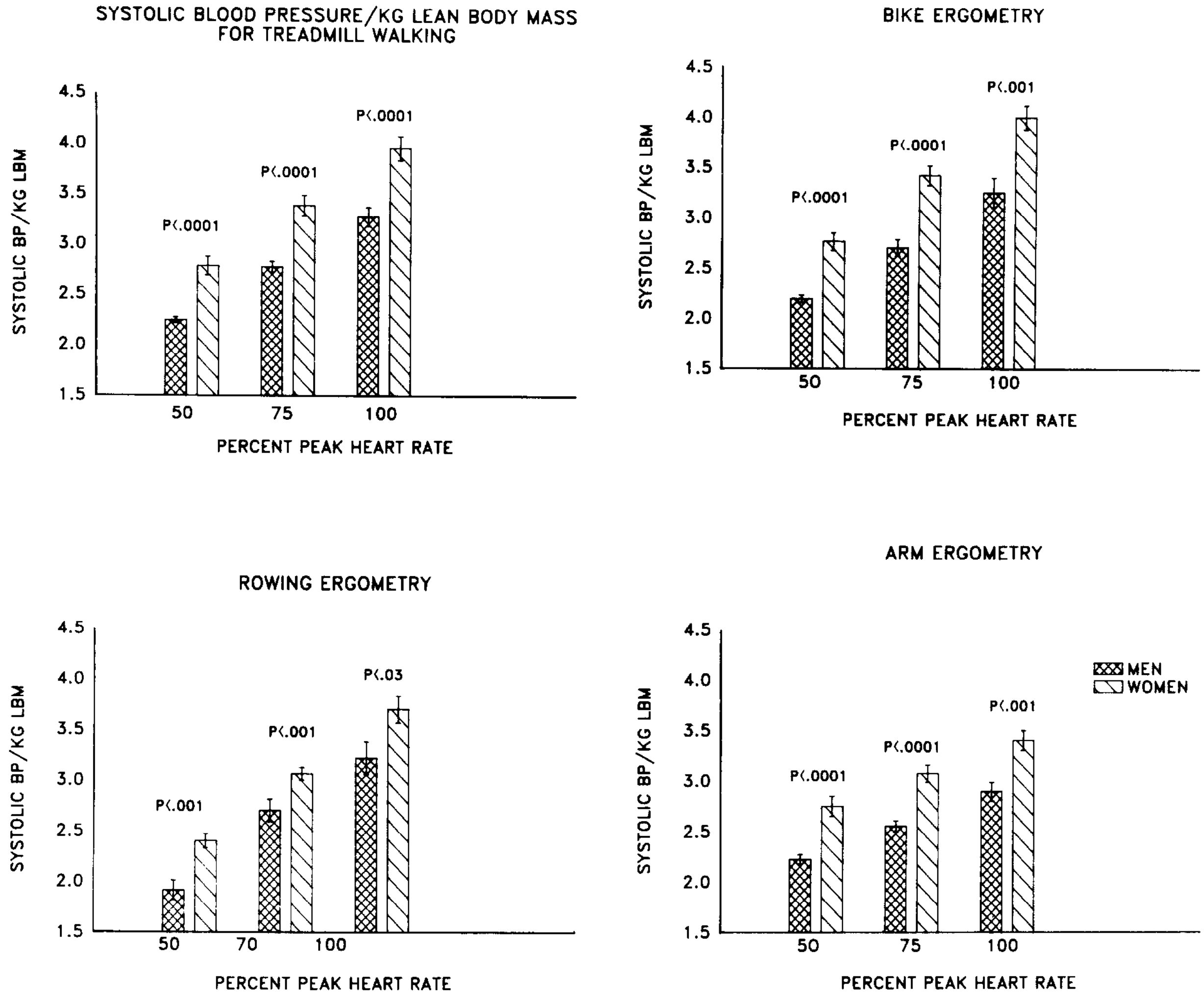

Fig. 3. Means and SEM for systolic blood pressure corrected for LBM at 50%, 75%, and 100% peak heart rate for men and women. Women had significantly greater SBP at all intensities on all modalities.

nately, circumferences were not measured, so the effects of differences are uncertain. It should be noted, however, that the cuff sizes that were used were those recommended for clinical blood pressure measurement. Any errors here may well be duplicated during clinical exercise testing.

It is also possible, because of the differences in muscle mass, that men and women responded differently when they abruptly stopped exercising for the blood pressure measurements. We have no data to support or contradict this possibility. This method was unavoidable to ensure accurate readings, and we minimized the effect by filling the cuff while the subject was still exercising.

No effort was made to control for differences in menstrual status in the women. This may have affected the SBP response to exercise because some hormones that affect cardiovascular function have been shown to be altered during high-intensity exercise at different phases of the menstrual cycle.[22] In addition, it is not known whether any of the women were taking oral contraceptives.

Blood pressure response is a function of cardiac output and total peripheral vascular resistance. No measurement of cardiac output was performed, but results from previous studies show that men have increased stroke volume during mild exercise.[1,4] Peripheral vascular resistance was also not measured in this study, so a conclusive mechanism for the gender differences in exercise-related blood pressure responses is not permitted, although LBM and body size are likely components. Further studies that include assessment of cardiac output, ejection times, plasma catecholamines, and measurement of periph-

eral vascular resistance will provide further insight into the mechanism that underlies the gender differences found in the present study.

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