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Comparative Study of Maximum Aerobic Capacity by Three Ergometries in Untrained College Women

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Abstract The maximum aerobic capacity ($\dot{V}O_{2\ max}$) of young untrained Bengali girls aged between 22–24 years after maximum workload as determined by bicycle ergometer, standard step test and a treadmill is studied in 22 subjects. It was found that the $\dot{V}O_2$ peak in the treadmill exercise was significantly higher than that obtained by the step test and bicycle ergometer, in that order. On each type of ergometer, $\dot{V}O_{2\ max}$ was found to be positively correlated with body weight, body surface area, maximal pulmonary ventilation and maximal oxygen pulse.

Key words: $\dot{V}O_{2\ max}$, three ergometers, women.

Maximal aerobic capacity ($\dot{V}O_{2\ max}$) when directly determined after exercise involving a sufficient number of muscle groups is considered as a good index of physical fitness of an individual (ÅSTRAND and RODAHL, 1970). $\dot{V}O_{2\ max}$ of untrained young women has been studied in different countries by various workers (ÅSTRAND, 1960; HERMANSEN and ANDERSEN, 1965; COTES *et al.*, 1969; MICHAEL and HORVATH, 1965; PUGH, 1974; PROFANT *et al.*, 1972; DUNCAN and CHAN, 1974; DRINKWATER *et al.*, 1975; and recently on adolescent girls by CHATTERJEE *et al.*, 1979). But such a profile on an Indian adult female population has not been carried out thoroughly; there are also no data available concerning the comparison of three commonly used exercise protocols—bicycle, step test and treadmill—for the determination of maximum aerobic capacity in women. In the present study we have tried to determine the maximal oxygen intake of young untrained Bengali college girls after three types of strenuous exercise, namely bicycle ergometer, step up to standard height and running on a treadmill. Our second objective was to see if the $\dot{V}O_{2\ max}$ determined by these three different modes of exercise showed any significantly different values, as reported by HARRISON *et al.* (1980), in a different ethnic group.

We further wanted to compare the correlations between $\dot{V}O_{2\ max}$ and body

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weight and body surface area obtained in young Bengali women with the values reported by Western workers.

METHODS

Subjects. Twenty-two young, physically fit college girls of comparable socioeconomic backgrounds, aged between 22–24 years, participated in this study as subjects. They were recruited from the Post-Graduate Section of Calcutta University. They had no previous physical training.

Preparation of subjects. Before the actual experiments, the details of procedure were explained to the subjects to allay apprehension. They were asked to refrain from eating or drinking at least for an hour and allowed to take rest lying down for half an hour before the actual experiments, so that the heart rate and pulmonary ventilation could settle to a constant value. During experiments the subjects wore light cotton clothes. Before the exercise tests, the physical parameters of the subjects were measured. The mean and standard deviation of age, height, weight and body surface area were found to be 21.68 yrs $\pm$ 0.95, 156 cm $\pm$ 4.9, 47.8 kg $\pm$ 4.92 and 1.445 sq. m $\pm$ 0.07, respectively.

Exercise test. The maximum aerobic capacity of 22 untrained college girls was determined by three ergometers, the bicycle, step test and treadmill on three different days, respectively.

Bicycle ergometer. The exercise was performed on a magnetic friction-type bicycle ergometer (Model of Prof. E. A. Muller, Max Planck Institute for Work Physiology). A low-resistance high-velocity Collins 'Triple J'-type plastic valve was used for the collection of expired air by the open circuit method.

A preliminary warming up for three min at a rate of 300 kgm $\cdot$ min^{-1} was given to each subject before the application of a set workload which was fixed at 600 kgm $\cdot$ min^{-1}. The workload thereafter was increased by 120 kgm $\cdot$ min^{-1} every three min up to 1020 kgm $\cdot$ min^{-1} till the subjects gave indication of complete exhaustion and their heart rate went above 180 beats $\cdot$ min^{-1}, which was the criterion of maximality (ÅSTRAND and RODHAL, 1970). In this study the workload was considered to be maximum when the heart rate was around 200 beats $\cdot$ min^{-1} and when further increase of workload did not bring about any significant increase in oxygen uptake, or the uptake was less than 100 ml $\cdot$ min^{-1} in response to the next higher load. This was the "levelling off" system for determination of $\dot{V}O_{2\,max}$. Subjects in no case endured more than 10 min in this procedure of a continuously increasing workload.

Step test. The maximal oxygen consumption was determined by the exercise in the modified Harvard step test procedure established by SLOAN (1959) in which a 17 inch (43.18 cm) stool was found to be more suitable for women than the 20 inch (50.8 cm) high stool for men used by BROUHA *et al.* (1943). According to Sloan the best result was obtained by using a 16 inch (40.64 cm) high stool for untrained women. The subjects of the present investigation were thus asked to step up and

down a 16 inch (40.64 cm) high stool for a maximum duration of 3 min at a rate of 30 complete steps per minute keeping time to a metronome. Most of the subjects were unable to complete 3 min and stopped earlier, at about 2 min and 30 s. No warming up was done in the case of the step test.

Treadmill. The subjects walked on a treadmill to warm up at a speed of 4 km per hour at a 4.5° inclination for a duration of 5 min (SLONIM *et al.*, 1957). This was followed by running at a constant speed of 7 km per hour for a maximum duration of 5 min. The gradient was increased successively from 4.5° until the subject was unable to continue the task. In no case did it exceed 7.5° inclination. The criteria for maximality was exhaustion and withdrawal from running within the scheduled 5 min period, when the heart rate was about 200 beats $\cdot$ min^{-1} and when a further increase of inclination did not bring about any significant rise in oxygen uptake or the uptake was less than 100 ml $\cdot$ min^{-1}.

Gas analysis. The expired gases were collected in 150 *l*. Douglas bags and analysed with a Scholander microgas analyzer, following the standard procedure described by CONSOLAZIO *et al.* (1963). In all the experiments, irrespective of the mode of exercise, the expired gas was collected in the last minute of the final workload. However sometimes the gas collection was also made earlier if signs of complete exhaustion supervened. In that case the gas was collected in the 2nd minute of the respective workload.

The $\dot{V}O_2$ mas values thus obtained were finally corrected to STPD. Several trials were made in each case and the highest value of $\dot{V}O_{2\ max}$ thus obtained was recorded.

Maximal pulmonary ventilation ($\dot{V}E_{max}$). The $\dot{V}E_{max}$ during each type of exercise was determined by measuring the expired gas volume during the last minute of exhaustive exercise using a wet gasometer and was corrected to BTPS.

Heart rate. The maximal heart rate was recorded manually from the time taken for ten carotid pulsations immediately following the cessation of exhaustive exercise (ÅSTRAND and RODAHL, 1970). The whole series of experiments was performed at a room temperature varying from 27°C to 29°C with the relative humidity varying between 60–80%.

RESULTS

Mean and standard deviations of pre-exercise and maximal values of aerobic capacity and its related parameters and comparison of these parameters between two ergometers at their level of significance in twenty-two sedentary college girls are listed in Table 1.

An individual variation was also noted, i.e., in some cases the $\dot{V}O_{2\ max}$ in the step test was found to be slightly higher than that of treadmill but the mean value was significantly higher than that of the step test. An 11% larger value of $\dot{V}O_{2\ max}$ was found in the treadmill over the step test and a 21% larger value compared to the bicycle. The pre-exercise mean value of aerobic capacity of untrained adult women

Table 1. Mean and standard deviation of pre-exercise and maximal values of aerobic capacity and its related parameters and comparison of these parameters between two ergometers at their level of significance of twenty-two sedentary college girls.

Parameters	Heart rate beats·min^{-1}	$\dot{V}O_2$ $l\cdot min^{-1}$ STPD	$\dot{V}O_2$ ml·kg^{-1}·min^{-1}	$\dot{V}E$ $l\cdot min^{-1}$ BTPS	Oxygen pulse ml·beat^{-1}	Ventilatory equivalent (l)
Pre-exercise values	80 ± 5	0.184 ± 0.01	3.88 ± 0.46	6.399 ± 0.65	2.30 ± 0.20	34.7 ± 2.7
Bicycle (max)	195 ± 6	1.32 ± 0.15	27.69 ± 2.8	49.18 ± 6.4	6.7 ± 0.8	37.4 ± 3.9
Step test (max)	196 ± 8	1.43 ± 0.16	30.16 ± 3.4	55.86 ± 9.59	7.35 ± 1.0	38.8 ± 4.5
Treadmill (max)	201 ± 7	1.59 ± 0.14	33.47 ± 3.1	62.53 ± 8.19	7.9 ± 0.8	39.3 ± 4.07
Bicycle vs. Step test	N.S.	$p<0.05$	$p<0.02$	$p<0.02$	N.S.	N.S.
Step test vs. Treadmill	$p<0.05$	$p<0.01$	$p<0.01$	$p<0.05$	$p<0.05$	N.S.
Bicycle vs. Treadmill	$p<0.01$	$p<0.001$	$p<0.001$	$p<0.001$	$p<0.001$	N.S.

N.S. = Nonsignificant.

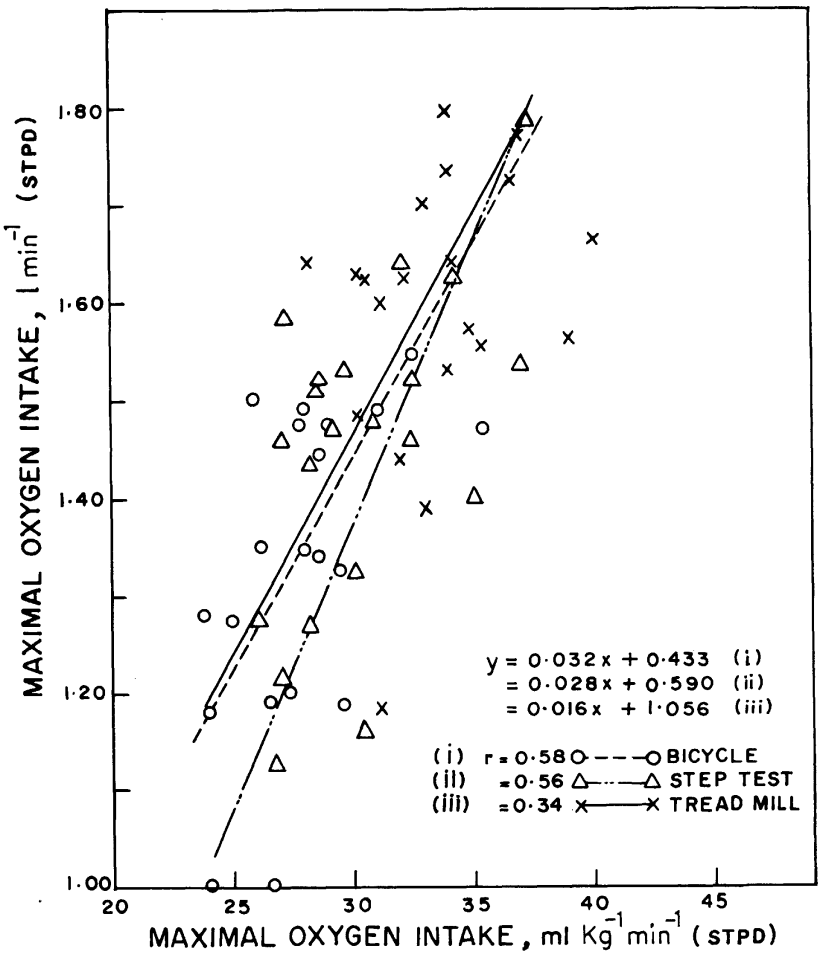

Fig. 1. Maximal oxygen intake lit. per min in relation to maximal oxygen intake ml per kg per min.

was found to be $184\,ml \cdot min^{-1}$. The highest maximum mean $\dot{V}O_2$ was found to be $1.59\,l \cdot min^{-1}$ or $33.47\,ml \cdot kg^{-1} \cdot min^{-1}$ during treadmill running and the lowest mean value was $1.39\,l \cdot min^{-1}$ or $27.69\,ml \cdot kg^{-1} \cdot min^{-1}$ during the bicycle. Between these two was the $\dot{V}O_{2\ max}$ value of the step test at $1.43\,l \cdot min^{-1}$ or $30.16\,ml \cdot kg^{-1} \cdot min^{-1}$. Among ergometers, an individual's maximum value of aerobic capacity was found to be $1.799\,l \cdot min^{-1}$ (treadmill) and lowest individual $\dot{V}O_{2\ max}$ is $1.01\,l \cdot min^{-1}$ (bicycle). A positive correlation between $\dot{V}O_{2max}$ $l \cdot min^{-1}$ and $\dot{V}O_{2\ max}$ $ml \cdot kg^{-1} \cdot min^{-1}$ was noted in the case of bicycle ergometer $r = 0.58$ and step test $r = 0.56$ but poor correlation was found in the treadmill method $r = 0.34$ (Fig. 1). $\dot{V}O_{2\ max}$ $l \cdot min^{-1}$ on each ergometer was correlated well with $\dot{V}E_{\ max}$ $l \cdot min^{-1}$ as $r = 0.68$, 0.72 and 0.58 in the bicycle, step test and treadmill methods,

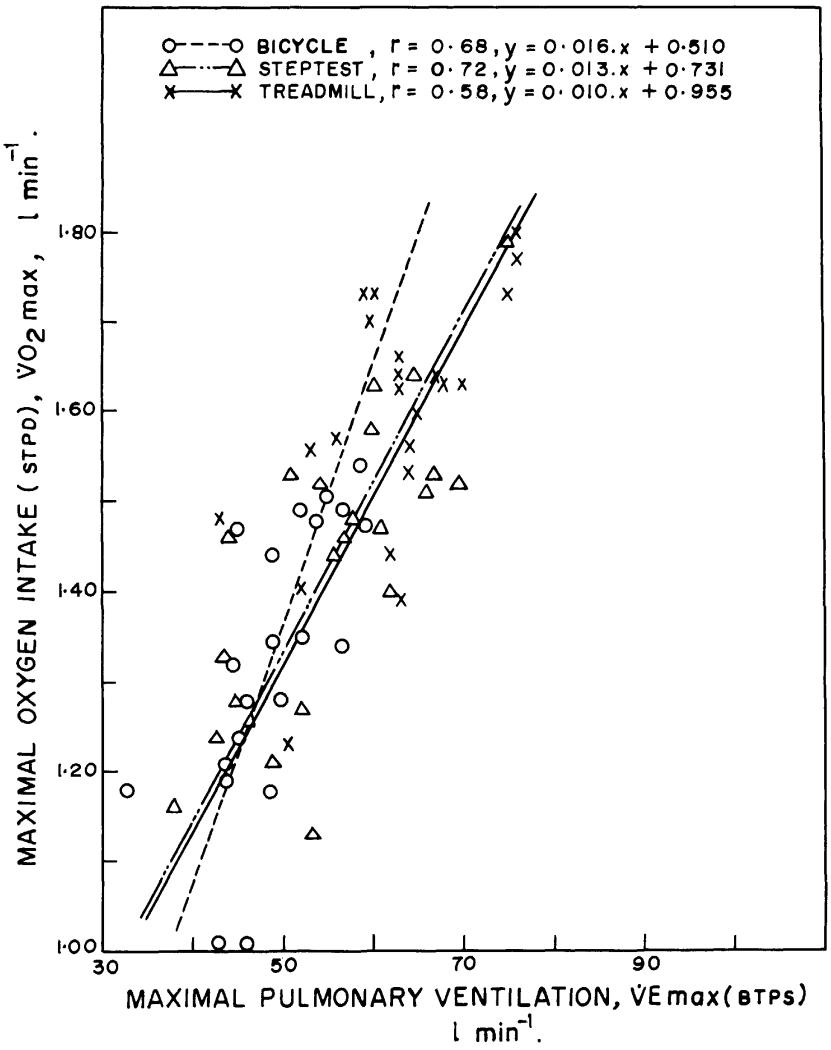

Fig. 2. Maximal oxygen intake in relation to maximal pulmonary ventilation.

respectively (Fig. 2).

A positive correlation was found between body weight and $\dot{V}O_{2\,max}$ $l \cdot min^{-1}$ on bicycle $r=0.61$, step test $r=0.48$, and treadmill $r=0.50$ (Fig. 3). Positive correlation was also noted between body surface area and $\dot{V}O_{2\,max}$ $l \cdot min^{-1}$ on the bicycle $r=0.64$, step test $r=0.46$ and treadmill $r=0.48$ (Fig. 4).

A good positive correlation was found between $\dot{V}O_{2\,max}$ $l \cdot min^{-1}$ and oxygen pulse $ml \cdot beat^{-1}$ e.g., $r=0.97$ bicycle, $r=0.94$ step test, and $r=0.87$ treadmill (Fig. 5).

The correlation coefficient (r) and linear regression equation between $\dot{V}O_{2\,max}$ $l \cdot min^{-1}$ and $\dot{V}O_{2\,max}$ $ml \cdot kg^{-1} \cdot min^{-1}$, $\dot{V}E_{max}$ $l \cdot min^{-1}$, body weight, body sur-

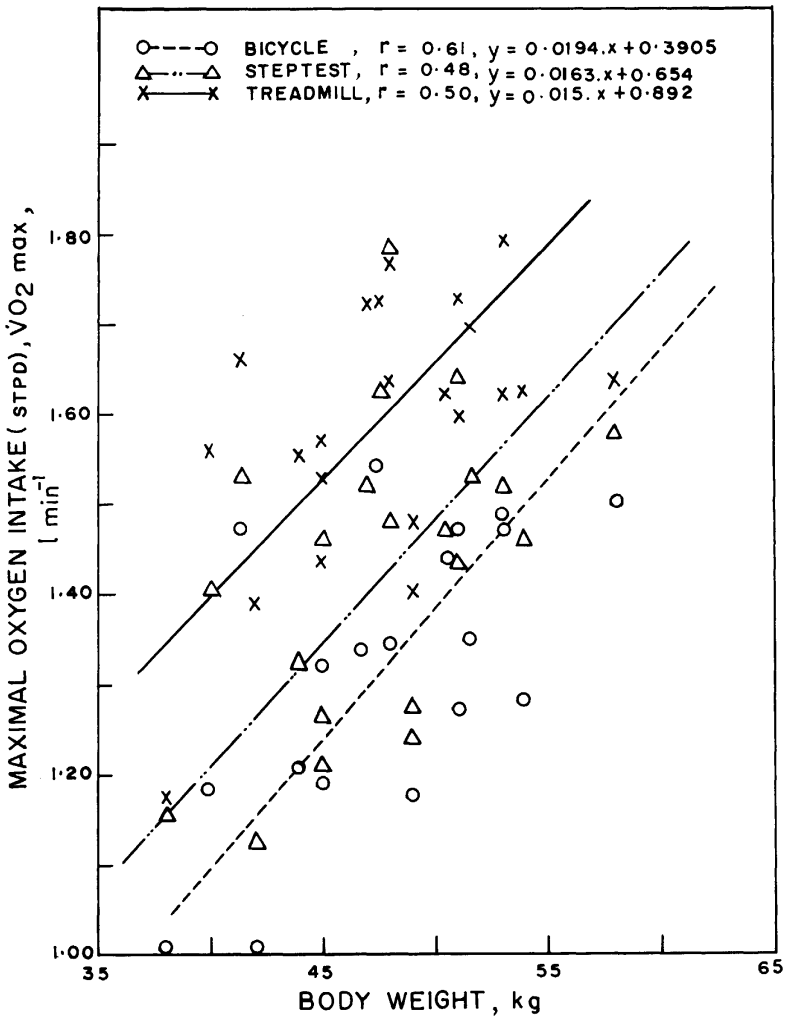

Fig. 3. Maximal oxygen intake in relation to body weight.

face area and O_2 pulse in three ergometers are graphically represented in Figs. 1 to 5.

Heart rate

Table 1 shows almost the same response of cardiac frequency on each ergometer in the case of untrained subjects. A 3% higher value was found in the treadmill compared to the bicycle and the treadmill value was 2.5% higher than in the step test.

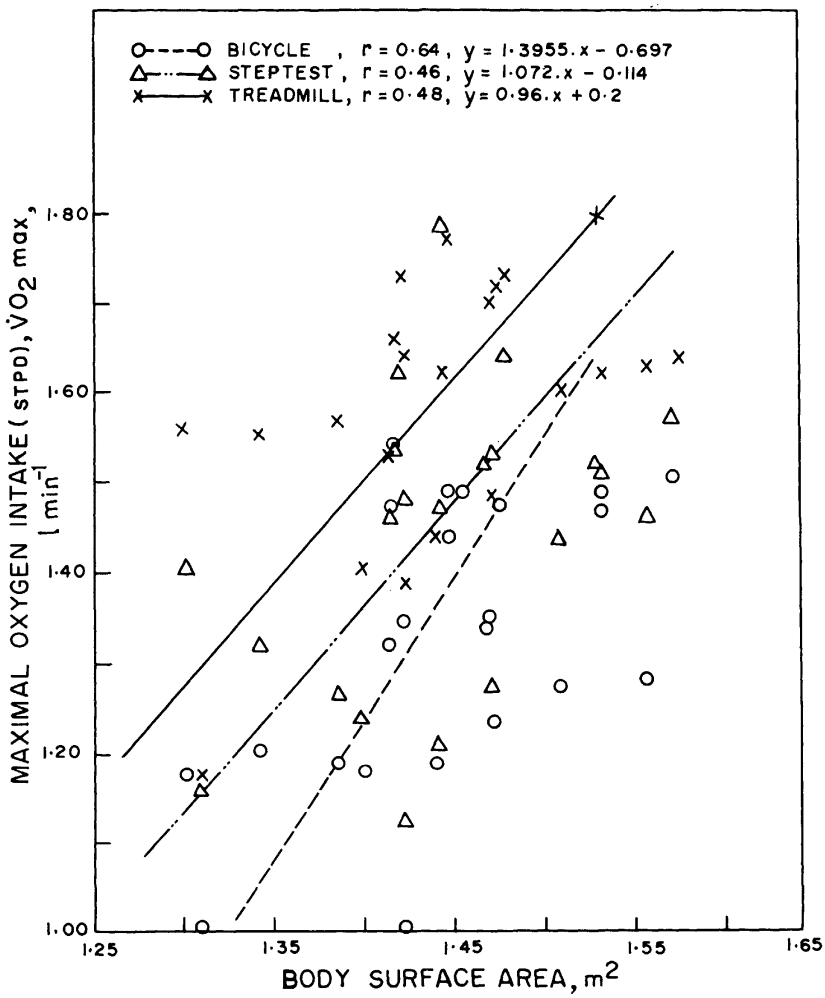

Fig. 4. Maximal oxygen intake in relation to body surface area.

Pulmonary ventilation

Maximal pulmonary ventilation was noted in the treadmill ergometer exercise. The treadmill $\dot{V}E_{max}$ value was 11.9% higher than that in the step test and 27% higher than the bicycle value. Individual maximal value was found to be 76.06 $l \cdot min^{-1}$ on treadmill running and the lowest $\dot{V}E$ value was 32.86 $l \cdot min^{-1}$ on the bicycle ergometer. The ventilatory equivalent values are 37.4, 38.8 and 39.3 l on the treadmill, step test and bicycle ergometer, respectively.

DISCUSSION

The determination of maximum aerobic capacity by three ergometries re-

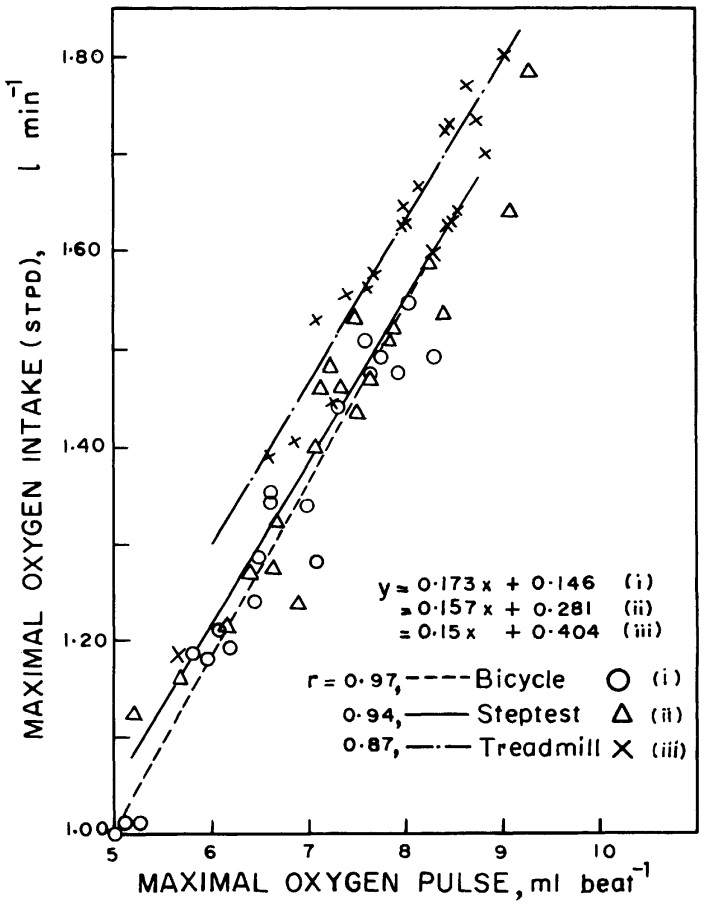

Fig. 5. Maximal oxygen intake in relation to maximal oxygen pulse.

vealed that the treadmill gives a truer account of cardiorespiratory health and is considered superior over the other two ergometers studied. This view is also supported by the findings of SHEPHARD *et al.* (1968). When the $\dot{V}O_{2\ max}$ was compared between two ergometers ('*t*' tested according to Fisher) it was found that aerobic capacity varies according to the ergometer. The step test yielded a 9% larger $\dot{V}O_{2\ max}$ ($l \cdot min^{-1}$) value than that produced during bicycling ($p < 0.05$). When step test scores were compared with treadmill scores, the latter showed an 11% higher value ($p < 0.01$). A highly significant difference was found when bicycle scores was compared with teadmill scores: the latter produced a 21% higher value ($p < 0.001$).

Recently, similar findings have been reported by HARRISON *et al.* (1980). They found almost the same difference of percentage of $\dot{V}O_{2\ max}$ between bicycle and treadmill procedures, i.e., the aerobic capacity was 20% lower in the bicycle than on the treadmill. Some other investigators such as KEREN *et al.* (1980), MILES *et al.*

(1980), GLASSFORD *et al.* (1965) and NAGLE *et al.* (1965), also observed a significant difference in oxygen uptake among these three ergometers.

A positive correlation is found between $\dot{V}O_{2\,max}$ $l \cdot min^{-1}$ and $\dot{V}O_{2\,max}$ $ml \cdot kg^{-1} \cdot min^{-1}$ in the case of the bicycle ergometer ($r=0.58$) and step test ($r=0.56$) but poor correlation is obtained in the case of treadmill ergometer exercise ($r=0.34$) (Fig. 1). There is a close resemblance to the study of MICHAEL and HORVATH (1965), who observed a 0.32 correlation between $\dot{V}O_{2\,max}$ $l \cdot min^{-1}$ and $ml \cdot kg^{-1} \cdot min^{-1}$ in the case of untrained young American college girls. They also observed a 0.56 correlation between body weight and $\dot{V}O_{2\,max}$ among untrained female subjects. KNUTTGEN (1967) noted a better relationship between $\dot{V}O_{2\,max}$ and body height (0.25) among young North American girls. Such findings indicate the common dependence of maximal aerobic capacity and body dimensions. Attempts have been made to explain this poor correlation on the basis of higher adipose tissue and muscle mass ratio in women. Since maximum aerobic capacity is dependent in part on the number of muscle units working at a given time, higher adipose tissue will lower the muscle mass per kilogram of body weight, leading to lower $\dot{V}O_{2\,max}$. CHATTERJEE *et al.* (1979) studied $\dot{V}O_{2\,max}$ on 10–18-year-old girls using the treadmill running method and observed that $\dot{V}O_{2\,max}$ kg^{-1} body weight was reduced from an average value of $40\,ml \cdot min^{-1}$ in pre-pubertal age groups to around $36\,ml \cdot min^{-1}$ in post-pubertal girls, whereas in the present study on adult sedentary female students it was further reduced to around $33.5\,ml \cdot kg^{-1} \cdot min^{-1}$ (treadmill method). This requires further study in which quantitative measurements of muscle mass and the adipose tissue content of body is correlated with maximal oxygen consumption.

The relationship between the aerobic capacity and pulmonary ventilation is highly significant at maximal work level. A positive correlation is established between O_2 uptake $l \cdot min^{-1}$ and maximal pulmonary ventilation $l \cdot min^{-1}$ on each ergometer. The corresponding values on bicycle, step test and treadmill ergometers are 0.68, 0.72, and 0.68, and all are significant at the $p<0.001$ level (Fig. 2). This is well corroborated by the study of DUNCAN and CHAN (1974) on untrained Malayasian women. This positive correlation indicates that the subjects are engaged in high rates of pulmonary ventilation in response to the high metabolic demands.

In the present study, the subjects' age and height were within a narrow range and no correlation was established with $\dot{V}O_{2\,max}$ and age and height factors, whereas a better correlation was found between body weight and maximal aerobic capacity on each ergometer. The respective values are $r=0.61$ (bicycle), 0.48 (step test) and 0.5 (treadmill) (Fig. 3). Consequently a positive correlation was also found between $\dot{V}O_{2\,max}$ and body surface area on each ergometer, as shown in Fig. 4.

A negative correlation between $\dot{V}O_{2\,max}$ and heart rate was found in the present investigation. The correlations are -0.67 (step test) and -0.4 (bicycle) but a very poor relationship is noted in the case of the treadmill ergometer. Such a pattern of heart rate response to $\dot{V}O_{2\,max}$ has also been noted by many other investigators, which emphasizes that it is a general occurrence among untrained

subjects. A negative correlation between $\dot{V}O_{2\ max}$ and cardiac frequency was observed by COTES *et al.* (1969). According to HERMANSEN and ANDERSEN (1965) the linear relationship between heart rate and oxygen consumption became curved in the least fit subjects towards the maximal level of work. According to WYNDHAM *et al.* (1959) the most interesting features concerning the heart rate response to maximal exercise in its asymptotic nature. From this $\dot{V}O_{2\ max}$/heart rate relationship it can be stated that the oxygen consumption did not increase accordingly as the heart rate reached its maximal level in response to strenuous physical exertion in the case of untrained subjects, whereas oxygen uptake was found to be much greater in response to increasing heart rate in the case of trained subjects. A highly positive correlation is found between $\dot{V}O_{2\ max}$ and oxygen pulse on each ergometry, $r=0.97$ (bicycle ergometer), $r=0.94$ (step test) and $r=0.87$ (treadmill), graphically represented in Fig. 5 and comparable with the study of DUNCAN and CHAN (1974). Swedish subjects of course exhibited much higher values in all aspects of cardiorespiratory parameters (HERMANSEN and ANDERSEN, 1965).

CONCLUSION

Physical fitness in terms of maximal aerobic capacity of untrained Bengali women was studied by three commonly used ergometers in the present investigation. The results of the present study showed that the physical fitness of untrained Indian women is poor compared with their Western and especially Scandinavian contemporaries (ÅSTRAND, 1960; HERMANSEN and ANDERSEN, 1965; COTES *et al.*, 1969; PUGH, 1974). Comparatively low levels of $\dot{V}O_{2\ max}$ reported from sedentary American females (PROFANT *et al.*, 1972; MICHAEL and HORVATH, 1965; DRINKWATER *et al.*, 1975) corroborate the present data. From the present investigation it was found that the maximum oxygen consumption elicited by the treadmill ergometer exercise in Bengali women is 84% that of American women (MCARDLE *et al.*, 1971) and only 68% that of Swedish females studied on bicycle ergometer (KILBOM, 1971).

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REFERENCES

ÅSTRAND, I. (1960) Aerobic work capacity in men and women with special reference to age. *Acta Physiol. Scand.*, **49** (Suppl.): 169.

ÅSTRAND, P. O. and RODAHL, K. (1970) Text Book of Work Physiology. McGraw Hill Book Company, New York.

BROUHA, L., HEATH, C. W., and GRAYBIEL, A. (1943) The step test, a simple method of measuring physical fitness for hard muscular work in adult men. *Rev. Can. Biol.*, **2**: 86–91.

CHATTERJEE, S., BANERJEE, P. K., CHATTERJEE, P., and MAITRA, S. R. (1979) Aerobic

capacity of young girls. *Indian J. Med. Res.*, **69**: 327–333.

CONSOLAZIO, C. F., JOHNSON, R. E., and PECORA, L. J. (1963) Physiological Measurements of Metabolic Functions in Man. McGraw Hill Book Company, New York.

COTES, J. E., DAVIES, C. T. M., EDHOLM, O. G., HEALY, M. J. R., and TANNER, J. M. (1969) Factors relating to the aerobic capacity of 46 healthy British males and females aged 18–28 years. *Proc. R. Soc. Lond. (Biol.)*, **174**: 91–114.

DRINKWATER, B. L., HORVATH, S. M., and WOLLS, C. L. (1975) Aerobic power of females, ages 10 to 68. *J. Gerontol.*, **30**: 385–394.

DUNCAN, M. T. and CHAN, K. Y. (1974) Aerobic work capacity in young untrained Asian women. *Q. J. Exp. Physiol.*, **59**: 181–190.

GLASSFORD, R. C., BATCROFT, G. H. Y., SEDGWICK, A. W., and MACNAB, R. B. J. (1965) Comparison of maximal oxygen uptake values determined by predicted and actual methods. *J. Appl. Physiol.*, **20**: 509–513.

HARRISON, M. H., BROWN, G. A., and COCHRANE, L. A. (1980) Maximal oxygen uptake: its measurements, application and limitation. *Aviat. Space Environ. Med.*, **51**: 1123–1127.

HERMANSEN, L. and ANDERSEN, K. L. (1965) Aerobic work capacity in young Norwegian men and women. *J. Appl. Physiol.*, **20**: 425–431.

KEREN, G. A., MAYAZANIK, and EPSTEIN, Y. (1980) A comparison of various methods for the determination of maximal oxygen uptake. *Eur. J. Appl. Physiol.*, **45**: 117–124.

KILBOM, A. (1971) Submaximal intensities in women. *Scand. J. Clin. Lab. Invest.*, **28**: 141–161.

KNUTTGEN, H. G. (1967) Aerobic capacity of adolescent. *J. Appl. Physiol.*, **22**: 655–658.

MCARDLE, W. D., MAGEL, J. R., and KYVALLOS, L. C. (1971) Aerobic capacity, heart rate and estimated energy cost during women's competitive basketball. *Res. Q.*, **42**: 178–186.

MICHAEL, E. D. JR. and HORVATH, S. M. (1965) Physical work capacity of college women. *J. Appl. Physiol.*, **20**: 263–266.

MILES, D. S., CRITZ, J. B., and KNOWLTON, R. G. (1980) Cardiovascular, metabolic and ventilatory responses of women to equivalent cycle ergometer and treadmill exercies. *Med. Sci. Sports Exercise*, **12**: 14–19.

NAGLE, F. J., BALKE, B., and NAUGHTON, J. P. (1965) Graditional step tests for assessing work capacity. *J. Appl. Physiol.*, **20**: 745–748.

PROFANT, G. R., EARLY, R. G., NILSON, K. L., KUSUMI, F., HOFER, V., and BRUCE, R. A. (1972) Response to maximal exercise in healthy middle aged women. *J. Appl. Physiol.*, **33**: 595–599.

PUGH, L. G. C. E. (1974) The aerobic capacity of forty British women aged 17–27 years. *Ergonomics*, **17**: 185–192.

SHEPHARD, R. J., ALLEN, C., BENADE, A. J. S., DAVIES, C. T. M., DIPRAMPERO, P. E., HEDMAN, R., MERRIMAN, J. E., and SIMMONS, R. (1968) The maximal oxygen intake, an international reference standard of cardiorespiratory fitness. *Bull. WHO.*, **38**: 757–764.

SLOAN, A. W. (1959) A modified harvard step test for women. *J. Appl. Physiol.*, **14**: 985–986.

SLONIM, N. B., GILLESPIE, D. G., and HAROLD, W. H. (1957) Peak oxygen uptake of healthy youngmen as determined by a treadmill method. *J. Appl. Physiol.*, **10**: 401–404.

WYNDHAM, C. H., STERYDOM, N. B., MARITZ, J. S., MORRISON, J. F., PETER, J., and POLGIETER, Z. U. (1959) Maximum oxygen intake and maximum heart rate during strenous work. *J. Appl. Physiol.*, **14**: 927–936.