AEROBIC CAPACITY AND CARDIOPULMONARY RESPONSE TO EXERCISE IN HEALTHY SOUTH INDIAN CHILDREN

Soumya Swaminathan, V.K. Vijayan, P. Venkatesan and K.V. Kuppurao

From the Cardiopulmonary Medicine Unit, Tuberculosis Research Center, Indian Council of Medical Research, Spurtank Road, Chetput, Madras 600 031.

Reprint requests: Dr. V.K. Vijayan, Deputy Director, Cardiopulmonary Medicine Unit, Tuberculosis Research Center, Spurtank Road, Chetput Madras 600 031.

Manuscript received: May 1, 1996; Initial review completed: June 18,1996;
Revision accepted: September 19,1996

Objective: *To examine the cardiorespiratory response to exercise in healthy South Indian school children.* ***Design:*** *Prospective study.* ***Setting:*** *Cardiopulmonary Medicine Unit, Tuberculosis Research Center, Madras. Subjects: Data was obtained on 47 girls and 48 boys in the age group 7 to 14 years.* ***Intervention:*** *The children performed a graded maximal exercise stress test on a computerized treadmill system.* ***Results:*** *Maximum oxygen consumption (VO_2max) increased significantly at 11 years of age in both sexes but while boys showed a progressive increase beyond 11 years, girls did not. When corrected for weight, only boys at 14 years had a significant increase in VO_2max/kg. Boys had higher values of VO_2max/kg than girls at all ages. Minute ventilation and oxygen pulse values also increased in both sexes at 11 to 12 years. The VO_2max of South Indian children was lower than the predicted values available for North American children when prediction equations based on height were used. However, when regression equations based on weight were used, the predicted values for North American and South Indian boys were similar, though values for the Indian girls were still low.* ***Conclusions:*** *Nutritional and sociocultural factors may play a role in determining VO_2max of children from different populations, rather than ethnic differences alone.*

Key words: *Exercise testing, Cardiopulmonary response, Aerobic capacity.*

EXERCISE stress testing is used in the evaluation of physical fitness and cardiopulmonary status of children(1, 2). It provides objective data regarding cardiac and pulmonary function during exercise and is useful in differentiating between diseases of the two systems. In recent years, it has gained recognition as a valuable tool for evaluating children with a variety of health problems(3,4). A number of parameters including aerobic capacity, cardiac and ventilatory responses to exercise are studied and these could show variation with age, sex, ethnic background and nutritional status of the child. Several investigators have obtained aerobic and anaerobic exercise data on male and female children but most currently available studies have been conducted in Europe and North America(5-8). To our knowledge, there is no data on normal exercise measurements in healthy Indian children.

Before one can apply the exercise test to patients with cardiac or pulmonary diseases, we need an understanding of the normal response to exercise in children of similar ethnicity. Our aim was to study the cardiorespiratory response to exercise and the changes with growth in healthy untrained South Indian school children.

Subjects and Methods

Ninety five children (47 girls and 48 boys) in the age group 7 to 14 years from two local schools were recruited. Six children from each age group for both the sexes were studied. Informed written consent was obtained from the parents. Children with a history of pulmonary, cardiac and other systemic diseases were excluded. On the day of the test, a detailed history was taken and clinical examination done to rule out any obvious disease. Hemoglobin, total and differential cell counts, urine examination for albumin and deposits and a chest X-ray were done on all the children. Children with Hb below 9 g/dl or abnormal chest X-rays were excluded from the study.

Pulmonary function and exercise stress tests were then performed in the Cardiopulmonary Medicine Unit of the Tuberculosis Research Center. The vital capacity and forced expiratory volume in 1 second (FEVj) were measured from a forced exhalation into a dry spirometer (Morgan Transfer Test Model C, Chatham, UK) to ensure that study subjects had normal baseline pulmonary function tests. The child then performed a graded exercise test on a computerized treadmill system (Morgan, Chatham, UK). Children were explained the procedure in detail and given time to get used to the treadmill and all the attachments. The child breathed through a mouth piece and wore nose clips throughout. Expired gas collection was performed with a low resistance, small dead space Rudolph valve. Ventilatory parameters were measured with an intake turbine ventilometer. Expired O_2 content was determined with a Model QA 500 paramagnetic analyzer and carbon dioxide content was measured by a Model 901 infrared CO_2 analyzer (PK Morgan Instrument Inc). Data were supplied to a Magna 88 computer, which provided 15-s averages of oxygen consumption, minute ventilation, tidal volume, respiratory rate, respiratory exchange ratio and ventilatory equivalents for oxygen and carbon dioxide. Analyzers were calibrated with gases of known concentration before each testing session.

Heart rate and arterial oxygen saturation were measured by a pulse oximeter (Ohmeda model IVA) continuously during the exercise stress test. Data were initially obtained for 3 minutes at rest. The child started walking at 2 km/h at 5 degrees grade initially. Treadmill speed was increased by 1 km/h every minute and the grade increased by 2.5 degrees every three minutes until the child could not exercise any further. The protocol for increase in work load was designed to assure that exercise would last between 8 and 12 minutes and maximal oxygen consumption would be attained. Maximal exercise effort was defined by fatigue, facial flushing, dyspnea and unsteady gait in conjunction with respiratory exchange ratio (RER) over 1.00 or achieving maximal heart rate (% predicted ± 5%). Maximum oxygen consumption and ventilatory parameters were taken as the highest achieved during exercise. This study was approved by the Institutional Ethical Committee.

Statistical analysis: All the results are presented as mean ± SD according to age and sex. Comparison of multiple means was done by analysis of variance and multiple comparisons for grouping means was done using Duncan's multiple range test. Linear regression analysis was carried out separately for boys and girls to study the relationship between aerobic capacity and age, height and weight. The regression slopes were compared using two-tailed t test. Appropriate transformation was used to stabilize variance wherever needed. Statistical significance was taken at the $p < 0.05$ level.

Results

All the children studied were of normal nutritional status as judged by their weight for age and body mass index (BMI). Baseline pulmonary function tests were also within normal limits. The hemoglobin levels were similar for boys and girls at different age groups indicating that nutritional status was similar.

Table I shows the baseline cardiac and ventilatory data for boys and girls at rest. The heart rate at rest, varied from a mean of *97* to 115 and was not significantly different at various age groups or between the 2 sexes ($p > 0.1$). The absolute oxygen consumption (ml/min) increased with age in both sexes but boys and girls had similar resting values of VO_2/kg (ml/min/kg) from 7 to 14 years. Resting minute ventilation and oxygen pulse values at rest were similar in boys and girls at all ages tested and tended to increase with age as expected.

Data collected at peak exercise is shown in *Table II.* Peak heart rate ranged from a mean of 193 to 222 indicating that the children exercised maximally. Peak respiratory rate did not vary much with age.

The maximal oxygen consumption (VO_2 max in ml/min) increased with age in both sexes and boys had higher values than girls at all ages ($p < 0.05$). The VO_2max/kg also was significantly higher in the boys compared to the girls ($p < 0.03$). VO_2max increased in boys progressively and continuously from the age of 11 upwards ($p < 0.05$). In girls also, the VO_2max showed a significant increase at the age of 11 years ($p < 0.05$) but in contrast to the boys, there was no further significant increase in

TABLE I–*Metabolic and Ventilatory Parameters at Rest (Boys and Girls)*

Age (yrs)	HR	RR	VO_2 (ml/min)	VO_2/Kg (ml/min/kg)	VE (Lit)	O_2 Pulse (ml/min/beat)
7 (B)	103 ± 20	29 ± 5	124 ± 19	5.9 ± 1.0	5.9 ± 1.0	1.2 ± 0.2
(G)	108 ± 7	29 ± 3	125 ± 27	6.4 ± 1.2	5.3 ± 1.0	1.1 ± 0.2
8 (B)	101 ± 9	27 ± 3	149 ± 25	6.4 ± 0.3	6.2 ± 0.7	1.4 ± 0.2
(G)	106 ± 10	26 ± 6	120 ± 13	5.2 ± 2.1	5.1 ± 1.3	1.1 ± 0.2
9 (B)	106 ± 7	29 ± 10	163 ± 31	6.6 ± 1.2	7.3 ± 1.6	1.5 ± 0.3
(G)	114 ± 12	26 ± 4	147 ± 11	6.2 ± 1.2	5.9 ± 0.7	1.3 ± 0.1
10 (B)	106 ± 17	25 ± 6	165 ± 44	6.1 ± 2.2	6.0 ± 1.2	1.6 ± 0.6
(G)	115 ± 15	26 ± 7	150 ± 31	6.9 ± 1.4	7.0 ± 1.2	1.4 ± 0.5
11 (B)	108 ± 15	23 ± 8	175 ± 39	5.5 ± 0.9	6.5 ± 1.2	1.7 ± 0.6
(G)	97 ± 4	26 ± 12	161 ± 54	5.3 ± 1.3	6.0 ± 1.4	1.7 ± 0.5
12 (B)	100 ± 11	35 ± 10	169 ± 32	5.2 ± 1.0	9.3 ± 2.7	1.7 ± 0.5
(G)	100 ± 14	25 ± 7	144 ± 37	4.7 ± 1.0	6.0 ± 1.3	1.4 ± 0.2
13 (B)	102 ± 19	32 ± 11	221 ± 74	6.4 ± 3.9	9.5 ± 2.6	2.2 ± 1.0
(G)	107 ± 10	28 ± 6	147 ± 24	4.6 ± 0.9	6.0 ± 1.1	1.4 ± 0.2
14 (B)	97 ± 15	21 ± 2	214 ± 39	5.1 ± 0.7	7.6 ± 1.3	2.2 ± 0.7
(G)	115 ± 4	23 ± 2	179 ± 17	4.7 ± 0.7	6.8 ± 1.0	1.5 ± 0.2

B-Boys; G-Girls; HR-Heart rate; RR-Respiratory rate; VO_2-Oxygen consumption, aerobic capacity; VE-Minute ventilation.

TABLE II–*Metabolic and Ventilatory Parameters at Peak Exercise (Boys and Girls)*

Age (yrs)		HR	RR	VO_2 (ml/min)	VO_2/Kg (ml/min/kg)	VE (Lit)	VE/VO_2	O_2 Pulse (ml/min/beat)
7	(B)	222 ± 18	63 ± 13	824 ± 78	39 ± 3.0	33 ± 6	41 ± 6	4.0 ± 0.3
	(G)	210 ± 21	63 ± 4	667 ± 175	34 ± 6.2	28 ± 7	41 ± 4	3.2 ± 0.8
8	(B)	214 ± 18	65 ± 11	981 ± 328	42 ± 8.0	38 ± 14	39 ± 3	4.0 ± 1.5
	(G)	198 ± 14	58 ± 15	649 ± 47	32 ± 1.5	24 ± 14	34 ± 5	3.3 ± 1.5
9	(B)	211 ± 15	64 ± 6	1079 ± 217	44 ± 8.0	41 ± 10	38 ± 4	5.0 ± 0.8
	(G)	200 ± 16	63 ± 7	839 ± 176	34 ± 4.5	31 ± 4	37 ± 6	4.2 ± 0.8
10	(B)	200 ± 15	64 ± 10	1149 ± 264	41 ± 8.0	42 ± 8	47 ± 4	6.0 ± 1.1
	(G)	205 ± 25	63 ± 13	735 ± 264	34 ± 4.0	30 ± 6	39 ± 5	3.7 ± 0.7
11	(B)	212 ± 8	65 ± 8	1358 ± 320	43 ± 7.0	51 ± 7	37 ± 4	6.0 ± 1.4
	(G)	206 ± 11	63 ± 8	1139 ± 252	36 ± 4.7	44 ± 5	42 ± 8	5.6 ± 1.3
12	(B)	218 ± 13	63 ± 10	1588 ± 297	48 ± 6.0	60 ± 12	37 ± 2	8.0 ± 1.7
	(G)	196 ± 10	60 ± 7	1145 ± 314	37 ± 6.2	45 ± 14	40 ± 2	5.7 ± 1.6
13	(B)	219 ± 12	71 ± 11	1714 ± 384	46 ± 4.0	64 ± 14	37 ± 2	8.0 ± 1.2
	(G)	194 ± 21	61 ± 11	1118 ± 202	33 ± 2.7	44 ± 5	39 ± 5	6.2 ± 1.2
14	(B)	208 ± 7	59 ± 18	2150 ± 122	52 ± 4.0	74 ± 11	34 ± 6	10.0 ± 0.8
	(G)	193 ± 12	51 ± 5	1182 ± 180	31 ± 2.0	45 ± 12	38 ± 6	6.1 ± 1.1

VE/VO_2-Ventilatory equivalent for oxygen consumption. For other abbreviations refer to *Table I* footnote.

VO_2 max beyond 11 years.

Minute ventilation and oxygen pulse at peak exercise increased significantly ($p < 0.05$) at age 12 and continued to increase each year till the age of 14 years in boys. In girls, minute ventilation and oxygen pulse values for ages greater than 11 years were significantly higher ($p < 0.05$) than for ages less than 11 years. Peak minute ventilation in boys was higher than in girls at most ages studied ($p < 0.05$). The ventilatory equivalent for oxygen varied between 34 and 47 but did not change significantly with age, in either sex and was also not different for boys and girls.

Fig. 1 shows graphically the age related trend in maximum O_2 consumption for boys and girls. The graph plots VO_2/kg against age which shows an increase in boys ($p < 0.05$ at age 14 years only) whereas in girls there is an apparent decrease beyond 12 years (not statistically significant). The graph clearly shows the developmental difference in VO_2/kg between boys and girls, around puberty.

Table III shows the aerobic capacity (VO_2max) of North American(6) and Indian children at 3 different arbitrarily chosen heights and weights. These values were calculated from the regression equations of Cooper *at al.(6)* and those derived from our own data (regression equations given at the bottom of *Table III)*.

Discussion

We have measured aerobic capacity and the cardiorespiratory response to exercise in healthy South Indian school children. We have also studied the differences in the patterns of response in boys and girls

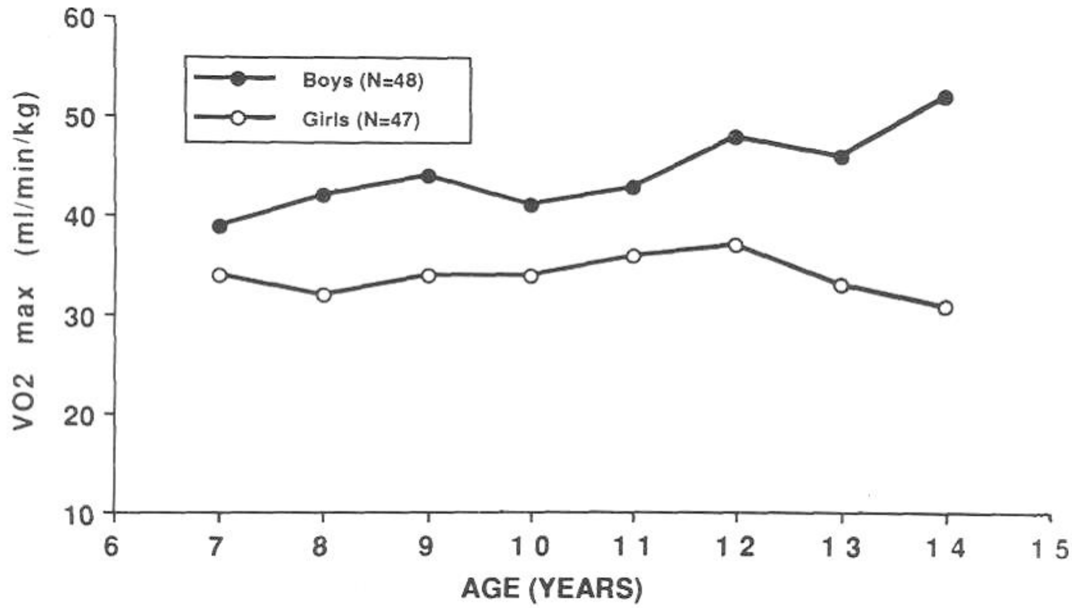

Fig 1. Relationship between age and aerobic capacity corrected for weight, for boys and girls aged 7 to 14 years.

aged 7 to 14 years. It is known that pulmonary function measurements show variation with ethnic background and we were interested in finding out if there are ethnic differences in aerobic capacity and cardiorespiratory response to exercise as well.

TABLE III–*Comparison of VO_2max of North American(6) and South Indian Children Based on Height and Weight*

	Boys		Girls	
	NA	SI*	NA	SI**
Height (cm)				
120	680	710	860	640
149	1550	1370	1310	1040
160	2430	2030	1760	1440
Weight (kg)				
20	760	835	858	587
30	1290	1335	1143	907
40	1820	1835	1428	1227

Regression equations:

* Boys: VO_2max (L/min)=3.33 Height (M)-3.25
VO_2max (L/min)=0.05 Weight (Kg)-0.165

** Girls: VO_2max (L/min)=2.02 Height (M)-1.76
VO_2max (L/min)=0.032 Weight (Kg)-0.053

NA: North American, SI: South Indian

We have demonstrated that oxygen consumption at peak exercise increases at the age of 11 years in Indian children of both sexes but shows a continuous spurt in boys beyond that age while plateauing in girls. The fact that postpubertal girls and adult women actually have lower VO_2max than prepubertal girls has been demonstrated(9,10). This may be due to the change in body composition in girls at puberty with more fat and less lean body mass. Adolescent boys, on the other hand, have an increase in muscle mass which could account for the increase in VO_2max. We have also shown that even during childhood (at most of the ages studied), boys had higher absolute and per kg values of VO_2max than girls. This confirms the earlier(8) findings and disproves the widely accepted concept that maximal oxygen uptake of boys and girls is the same before puberty. Hence, related to biological age, there is a clear sex difference in VO_2max in prepubertal, pubertal and postpubertal years.

The O_2 pulse is the amount of oxygen removed from each stroke volume. It has been suggested that the O_2 pulse in adults is a useful index to evaluate aerobic fitness. In healthy persons, O_2 pulse should continue to increase during exercise and if it levels off early, indicates poor cardiovascular fitness. Data regarding the normal values for O_2 pulse in children are limited. The values obtained by us at peak exercise are slightly lower than those reported by Washington *et al.(7),* especially in girls and this probably reflects the lower VO_2max achieved by South Indian children of the same age. However O_2 pulse increased continuously upto peak exercise and the increase with age was statistically significant in both sexes from the age of 11 upwards. Hence, there appears to be a spurt probably related to puberty at the age of 11 years in both boys and girls, as reflected by an increase in VO_2max, VEmax and O_2 pulse at this age. The pattern of increase in the two sexes however, is different, with values in boys showing a sustained increase beyond 11 years but plateauing in girls.

The ventilatory equivalent for oxygen (VE/VO_2) is a measure of breathing efficiency and is known to be higher in children than in adults. The values obtained in our study were similar for boys and girls and though there was a trend towards decreasing values, with increasing age, this was not significant. At any age, higher than expected values indicate abnormal pulmonary limitation to exercise and therefore knowledge of normal values is important.

Aerobic capacity of children varies with age and sex, as shown here, and also with ethnic background and nutritional status. Several studies have reported a range of VO_2max values in healthy children. Washington *et al.(7)* found that the VO_2max values obtained by them in American children were lower than in some European studies(8,ll) and speculated that this may be due to a more active lifestyle and participation in regular organized sports activities by the European children. Their study was conducted at an altitude of 1600 meters which could be another explanation for the slightly lower VO_2max. Hence, there are several biological and environmental factors which could affect the VO_2max achieved by the study group. The other technical factor that could explain the variation between studies is the use of a cycle ergometer versus treadmill for performance of exercise stress tests. Values obtained on the cycle ergometer are usually about 10% lower than with the treadmill, because more muscle groups are involved with the latter. Running is easier for children as it comes naturally and involves almost all muscle groups in the body, so this was preferred by us.

We have compared our data on aerobic capacity with data from North American (86% Caucasian) children(6). Cooper *et al.(6)* performed exercise stress tests on a bicycle ergometer in 109 healthy children aged 6-17 years. The VO_2max of South Indian boys and girls at different heights (derived from our regression equations) was lower than the North American values except for boys at 120 cm. The difference was more pronounced for the girls and the taller boys (160 cm). However, when the VO_2max was expressed as a function of body weight, the South Indian boys had similar values as the North American boys. South Indian girls of the same weight still had lower values of VO_2max than North American girls. This implies that for any given body weight the aerobic capacity of

Caucasian and South Indian boys is the same. The lower aerobic capacity of South Indian children of similar height may be a function of the lower body weight/muscle mass in these children.

South Indian girls had lower aerobic capacities as compared to their North American counterparts both when expressed as a function of height and weight. Since even girls of the same weight could not perform as well as their Caucasian counterparts (in contrast to the boys), other factors must be playing a role in addition to the nutritional factor. In this study, the boys and girls had similar BMI and hemoglobin values and the sex differences cannot, therefore be related to nutritional factors or anemia. In the sociocultural context, Indian girls live more protected lives, are kept indoors and may be less physically active than the boys. It is known that regular physical exercise improves the aerobic capacity and that a sedentary lifestyle tends to decrease it. It is difficult to postulate an ethnic difference for the girls alone, hence environmental and sociocultural factors probably play a more important role here.

We have studied the developmental differences in response to exercise in healthy South Indian school children. Further studies are required taking children from different sociocultural and nutritional groups to understand the reasons for differences in aerobic capacity.

REFERENCES

1. Nixon PA, Orenstein DM. Exercise testing in children. Pediatr Pulmonol 1988, 5: 107-122.
2. Swaminathan S. Exercise testing in children: Indications and Technique. Indian J Pediatr 1991, 58: 305-310.
3. Platzker ACG, Keens TG. Pulmonary function testing in pediatric patients. *In:* Pulmonary Function Testing: Indications and Interpretation. Ed Wilson AF. Florida, Grune and Stratton Inc 1985, pp 275-292.
4. Bar-Or O. Pediatric Sports Medicine for the Practitioner. New York, Springer-Verlag, 1983, pp 1-65.
5. Godfrey S, Davies CTM, Wozniak E, Barnes CA, Cardiorespiratory response to exercise in normal children. Clin Sci 1971, 40: 419-431.
6. Cooper DM, Weiler-Ravell D, Whipp BJ, Wasserman K. Aerobic parameters of exercise as a function of body size during growth in children. J Appl Physiol: Respirat Environ Exercise Physiol 1984, 56: 628-634.
7. Washington RL, van Gundy JC, Cohen C Sondheimer HM, Wolfe RR. Normal aerobic and anaerobic exercise data for North American school age children. I Pediatr 1988,112: 223-233.
8. Rutenfranz J, Lange Anderson K, Seliger V, Ilmarinen J, Klimmer F, Kylian H, *et al.* Maximal aerobic power affected by maturation and body growth during childhood and adolescence. Eur J Pediatr 1982, 139: 106-112.
9. Rowland TW, Green GM. Physiological responses to treadmill exercise in females: Adult-child differences. Med Sci Sports Exercl988, 20: 474-478.
10. Astrand PO. Experimental Studies of Physical working capacity in Relation to Age and Sex. Copenhagen, Ejnar Munksgaard, 1952, pp 21-37.
11. Lange Anderson K, Seliger V, Rutenfranz J, Mocellin R. Physical performance capacity of children in Norway Part 1: Population parameters in a rural inland community with regard to maximal aerobic power. Eur J Appl Physiol 1974, 33: 177-195.